Annual Report
2014-2015

ESSO
Earth System Science Organization
Ministry of Earth Sciences
Government of India

Contents

OVERVIEW

1.1   INTRODUCTION

Earth System Science comprises the understanding of complex interactions among various components of the Earth, viz. atmosphere, oceans, cryosphere, geosphere and biosphere. The knowledge about the earth system helps to improve prediction of climate, weather and natural hazards. The exploration of polar regions and seabed for discovery of new resources or phenomena has been undertaken. The national agenda includes promotion of discovery to provide new perspective on earth systems, better understanding of earth processes and apply this knowledge for sustainability of the Earth and develop services for the societal benefits.

An Earth System Science Organization (ESSO) was established with the objective to provide the nation with the best possible services for monsoons, weather, climate, oceans and natural hazards. The policies and programmes of the ESSO are largely being pursued through mission mode projects through its centres, viz. India Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF), Indian Institute of Tropical Meteorology (IITM), National Centre for Antarctica and Ocean Research (NCAOR), National Institute of Ocean Technology (NIOT), Indian National Centre for Ocean Information Services (INCOIS), National Centre for Earth Science Studies (NCESS), Centre for Marine Living Resources and Ecology (CMLRE) and Integrated Coastal and Marine Area Management (ICMAM).

The details of various programs are elucidated below.

1.2   ATMOSPHERIC SCIENCE AND SERVICES

Some of the salient accomplishments in the atmospheric sector during the year include, extending five days tourist forecast for 109 destinations and public weather forecast for 318 cities and nowcast for 130 cities with SMS alerts; accurate prediction of Hudhud, Nilofer and other cyclonic storms; establishment of 'SMS based Cyclone Alert/Warning System'; establishment of 'RAPID' (Real-time Analysis of Products and Information Dissemination: A web based system for INSAT Data Products); establishment of 'CRIS' (Customized Rainfall Information System: A GIS based system for processing Real-time rainfall data to generate rainfall products); SMS based Fog Dissemination Service to Airlines; Dissemination of Agromet advisories to 70.6 lakh farmers through SMS; Environmental Impact Assessment of 1771 Development Projects; and augmentation of Doppler Weather Radars (1 installed, 6 under process).

South West Monsoon 2014: The long range forecast revised in August 2014 for the season (June-September) rainfall for the country as a whole was 87% against actual rainfall of 88% of LPA for the year 2014. The seasonal rainfall was 79% of its LPA over Northwest India, 90% of its LPA over Central India, 93% of its LPA over South Peninsula and 88% of its LPA over Northeast (NE) India. Out of 36 meteorological subdivisions, 23 subdivisions constituting 67% of the total area of the country received normal season rainfall and 12 subdivisions (30% of the total area of the country) received deficient season rainfall. One subdivision (South Interior

Karnataka) constituting 3% of the total area of the country received excess rainfall. The monthly rainfall over the country as a whole was 57% of LPA in June, 90% of LPA each in July and August, and 108% of LPA in September. The onset of Monsoon over Kerala as well as All India Monthly Forecast for July and August were predicted accurately. The Quantitative Precipitation Forecast (QPF) is being provided for flood forecasting for different river basins. About 23,000 QPFs were issued by different FMOs. Customized forecasts for expeditions, adventure sports, pilgrimage, etc. are being generated. Aviation services are being provided for Delhi, Mumbai, Kolkata and Chennai as well as 70 other airports of the country.

Weather Forecasting: A paradigm shift in numerical modeling activity for operational weather forecast has been achieved. The atmospheric model of GFS with a spatial resolution of 18 km was set up. The data assimilation scheme of GFS has been upgraded to include a new version of the Community Radiative Transfer Model (CRTM). The data assimilation capacity has been increased from 2 GB to 20 GB during the year.

Agro Advisory Services: The district level quantitative five-day weather forecasts - rainfall, maximum and minimum temperature, cloud amount, maximum and minimum relative humidity, wind speed and wind direction - based on Multi Model Ensemble (MME) system have been generated to support Agro-Meteorological Advisory Service (AAS) of India. The AAS has been extended to 608 districts of the country. Currently, over eight million farmers are receiving crop-specific advisories under the AAS in vernacular languages. Block level forecast has been initiated in a pilot mode. Communication of Agro-advisory to farmers has resulted in cost effectiveness and increase of productivity.

Air Quality Monitoring: A location specific information on air quality (ozone, oxides of nitrogen, carbon monoxide, benzene and other hydrocarbons as well as particulate matters (PM) PM-10 and PM-2.5) has been provided for Delhi and Pune in near real-time and its forecast 24 hours in advance. The concentration of PM-10 and PM-2.5 over Delhi has been found to be much higher than permissible limits especially during winters.

Cyclone Prediction: There has been a remarkable improvement in the prediction of track and landfall of cyclone. The cyclone track and landfall 24-hour prediction has been improved to 140 and 80 km, respectively. The prediction of associated rainfall, waves and storm surge is provided to assess the area likely to be inundated. This has been accomplished by virtue of augmentation of observation system networks and enhanced computing capability. Hourly updates on the movement and intensity of the cyclone were made available to the National and State level disaster managers and media persons on the day of landfall. On the occasion of Good Governance Day, Dr. Harsh Vardhan, Hon'ble Minister of Ministry of Science and Technology and Earth Sciences dedicated the SMS Alert Service for Disaster Alert System to the Nation.

Fog Forecasting: The fog forecast is being issued to airlines every six hours. This enables them to plan their flights accordingly and reduces inconvenience to travelers. The diversions from Delhi's Indira Gandhi International Airport (IGIA) has been minimal during the current season. Though the skill of forecasting at 6-18 hours in advance, increased over 90%, the actual timing of onset and lifting of fog 24-hour to 36-hour in advance, still remain a challenge. Performance of NWP models (GFS, WRF) 24, 48-hour rainfall forecast to predict extremely heavy rainfall event of J&K during 06th September 2014 was satisfactory.

Monsoon Mission: The monsoon mission, a multi-institutional and inter-agency research programme was initiated with the ultimate aim to improve the monsoon prediction over the country on all time scales by developing a state-of-the-art coupled ocean-atmospheric climate model. The comparison of dynamical forecasts of Monsoon-2014 with Monsoon-2013 showed

BOX-1

> While addressing a gathering at the Indian Science Congress, Mumbai, on 3rd January 2015 the Hon'ble Prime Minster mentioned that "I must congratulate the Indian Scientific Team for accurate prediction of Cyclone Hudhud saved thousands of lives ".
>
> Hon'ble Prime Minister appreciated the forecast of Cyclone Hudhud in his speech:
>
> इस Cyclone में Technology का बहुत ही Perfect उपयोग हुआ, पहले दिन से ही। इस Cyclone में मौसम विभाग ने Technology का बखूबी उपयोग किया और 6 तारीख से ही ये संकेत दे दिए गए थे। जो अनुमान थे, उतनी ही Velocity रही। जो दिशा थी अनुमानित, वही दिशा रही। जो अनुमानित Time था, वही Time रहा। और एक प्रकार से इस संकट से बचने में ये Technology का उपयोग भी, काफी काम आया।
>
> "From the beginning, technology was used perfectly to forecast the cyclone. In this cyclone, IMD used this technology tactfully and indicated its possibility of arrival on 6th of the month. Velocity, direction and time were as per the expectations. And thus, this technology performed a very good role in facing the hazard."
>
> **Narendra Modi**
>
> **Hon'ble Prime Minister**

a significant reduction of error in rainfall forecast. There is also a significant improvement in monsoon rainfall special correlation coefficient (CC). This improvement is mainly with the assimilation of more observations from various new Indian satellites. For the first time in India, an indigenous climate model has been developed for studying variability and predictability of monsoon on seasonal, inter-annual and decadal time scale.

1.3   CLIMATE CHANGE RESEARCH

An Earth System Model (ESM), together with comprehensive assessment of various interactions among different earth system components has been developed. The first version of the ESM consists of T126L69 atmospheric model coming from the NCEP GFS coupled to the MOM4P1 ocean model. It also contains an active sea-ice model. The model has shown a good representation of the present global climate and short-term variability. Using this model, the high-resolution climate change scenarios have been developed for the 21st century.

The High-Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar has completed one year of observations of cloud physics and aerosol. X-Band and Ka-Band Radars have been deployed at Mandhardev in co-location with each other for spatial/ temporal distributions of precipitation and clouds respectively. This would contribute to study microphysical characteristics of aerosols and clouds and associated environmental conditions. A campaign for aircraft and ground based measurements of cloud-aerosol interactions for the Ganga basin has been completed.

1.4   OCEAN OBSERVATIONS

The state-of-the art technology ocean platforms being operational in the Indian Ocean include the moored and drifting buoys, Argo floats, HF radars, current meter moorings, automatic weather stations on ships, autonomous vehicles, tide-gauges, RAMA Observation Acoustic Doppler Current Profilers, etc. Physical and bio-geo-chemical time-series measurements

at the existing stations (Goa, Mangalore, Kochi, Parangipettai, Vishakhapatnam and Gopalpur) were continued and three more stations (Veraval, Chennai and Sundarban) were added to the network. The total number of active Argo floats in the Indian Ocean has gone up to 700. Over 30,000 temperature and salinity profiles pertaining to the Indian Ocean were archived in the past one year. All the data related to ocean has been assimilated and can be accessed through web.

1.5   OCEAN SCIENCE

The Air Sea Interaction Research Initiative (ASIRI) and Ocean Mixing and Monsoon (OMM) were launched in July 2014 to improve the knowledge of air-sea exchange and horizontal and vertical mixing in the upper ocean at different spatio-temporal scales in the Bay of Bengal. As a part of the OMM-ASIRI program, for the first time, three research cruises were conducted in the Bay of Bengal (15th June – 28th June 2014 using the R.V. Revelle, 22nd August – 9th September 2014 using the ORV Sagar Nidhi, 24th November – 13th December 2014 using the ORV Sagar Nidhi) to study lateral and vertical gradients of temperature, salinity and density in the upper ocean of the Bay of Bengal.

1.6   OCEAN SERVICES

The PFZ advisories are improved by integrating the surface current vectors along with sea surface temperature and chlorophyll. The Tuna fishery advisories based on satellite derived sea surface temperature, Chlorophyll and Kd490 (Water Clarity) data have been continued. An improved version of Tuna advisory maps containing surface current (as quiver), mixed layer depth (as background raster) and depth of 20°C isotherm (as contour) are also made available since March, 2014.

The tsunami warning system was set up in October 2007 has been operational 24x7 which is now capable of providing advisories about travel time and run up height at 1800 coastal forecast points within 10 minutes to all concerned within India and the Indian Ocean Rim countries. Three earthquakes occurred in the Indian Ocean region, however none has generated tsunami. A mock tsunami drill IOWave14, which simulates tsunamis originating from two earthquake sources, one in the Eastern Indian Ocean and the other in the North-western Indian Ocean were conducted.

Coral Bleaching Alert System – One hundred and ten coral bleach advisories were generated and disseminated in 2014. There were 12, 4, 4, 4 and 2 warning signals recorded for Lakshadweep Islands, Andaman Islands, Nicobar Islands, Gulf of Mannar and Gulf of Kachchh, respectively during this period.

Ocean models (ROMS and HYCOM) with varying horizontal resolution from approximately 25 km x 25 km outside the Indian Ocean to 2.25 km x 2.25 km near the coast have been setup. Data assimilation based on Ensemble Kalman Filter method is being developed to assimilate available ocean observations to the ROMS model.

Ocean State Forecast is provided for next five days for every six hours. In order to meet the operational requirements of various ports and harbours along the Indian coast, forecasts of waves, currents, winds and tides upto a distance of 50 km from the shoreline are being provided.

Coastal and Marine Environment – The multi-hazard vulnerability assessment has been completed for the Indian mainland based on the availability of the high-resolution topographic data.

1.7   OCEAN TECHNOLOGY

The technology for autonomous vehicles, remotely operable vehicles, mining equipments, drilling equipments, testing equipment for harnessing mineral resources is under development. Remotely Operable Vehicle and Soil Tester has been deployed and successfully tested to assess environment and seabed properties at 6000 m in the central

Indian Ocean. The seabed images and sensor data were recorded and transmitted in real-time using the web cast facility installed on-board Oceanographic Research Vessel (ORV) Sagar Nidhi. The first Autonomous Underwater Profiling Drifter (AUPD) was deployed off Kochi in the Arabian Sea and three deep profiles up to 1600 m were obtained. AUPD is programmed to dive to sea depths of 2000 m where it drifts with the current and after a defined time period, it rises to the sea surface, measuring temperature and salinity with respect to depth. At the surface, it relays this information via satellite and sinks again to begin the next cycle.

The demonstration of shore protection measures has been successfully carried out and the solution of artificial beach nourishment is being implemented by the Puducherry Government and a beach width 30 m was formed. The bathymetry survey and field observations of the Kalpasar project were completed. The development of Buried Object Scanning Sonar (BOSS), fabrication of the new stream lined tow body has been completed and has been successfully tested.

The autonomous ambient noise system has been successfully deployed and made operational with GPRS communication off Chennai. A state-of-the-art low frequency calibration set up has been implemented and the existing ATF has been enhanced for the frequency range from 3 kHz to 500 kHz.

1.8   OCEAN RESOURCES

The basic survey of the Exclusive Economic Zone (EEZ) for mineral resources, exploration for polymetalic nodules, gas hydrates, hydrothermal sulphides, etc, have been undertaken.

1.9   POLAR SCIENCE

The 34th Expedition to Maitri and Bharati, Antarctica and 8th expedition to the Himadri, Svalbard, Norway, Artic were launched for glaciological and atmospheric investigations.

The President of India interacted through video-conferencing to the Indian Scientists based at Himadri and inquired about studies being coming out. First ocean moored observatory for time series measurement of ocean parameters in the Kongsforden system, Svalbard, Norway has been commissioned. India has been accorded "Observer" status in the Arctic Council in recognition of India's scientific contribution and endeavor in Polar research. India successfully commenced operations at 3rd Indian Permanent Station Bharati, in the Larsemann Hills, East Antarctica which would give a major thrust to study the fields of glaciology, atmosphere, paleoclimate and Polar biology.

1.10   SEISMOLOGY

Earthquake is one of the hazards, which is still not understood. A national seismological network of seismometers, accelerometers, and GPS has been built for monitoring earthquakes, studying crustal dynamics, seismological research, active fault monitoring, etc. on 24x7 basis. The location, magnitude and depth of an earthquake are provided within 10 minutes. A database has also been created for operational as well as research purposes. The relationship between earthquake pre-cursors and earth generation processes is explored through long-term, multi-parametric observations. Equipments related to multi parametric geophysical investigation have been installed in Imphal. Preparatory activities have been initiated to undertake suite of observations in a borehole in the Koyna region to study the stress regime, pore fluid pressure and its variations, heat flow and its variations, orientation of faults, study of physical properties, etc. As a preparatory study for Scientific Deep Drilling Investigation in the Koyna region, eight shallow boreholes have been drilled, respectively. The cores recovered from the boreholes were exposed to the geo-scientific community and scientific proposals have been evolved around these core samples. Also, air-borne gravity and MT surveys have

been completed. A report on Seismic Hazard Microzonation of NCT Delhi 1:10000 scale has been prepared. A pilot study for Earthquake Early Warning (EEW) in the central Himalayan region has been initiated. Under this study, 100 P-alert systems are being deployed in the identified spatial window.

1.11 HIGH PERFORMANCE COMPUTING SYSTEM

The High Performance Computer (HPC) System of 1.20 Petaflop with 9 Petabytes of storage has been acquired. The present HPC System will boost research in weather and climate forecasting and will help the research initiatives undertaken under the monsoon mission.

1.12 RESEARCH, EDUCATION, TRAINING AND OUTREACH

International Interface – During the last six months, MOUs and LOIs have been signed with UNESCO, Paris; University Corporation for Atmospheric Research, USA; Kuwait and Japan for cooperation in the area of the earth system sciences.

Training – An International Training Centre for Operational Oceanography (ITCOocean) at ESSO-INCOIS in collaboration with IOC/UNESCO has been established. ITCOocean conducted another four workshops/training courses, covering different aspects of operational oceanography, for the trainees from Africa and Indian Ocean Rim countries.

Capacity Building – Two regional workshops were conducted in the field of atmospheric science and services for BIMSTEC countries. World Meteorological Organization (WMO), in collaboration with the WMO Regional Training Centre of the ESSO-IMD, organized a group training program on "Maintenance and Calibration of Instruments", during 3rd – 28th November 2014 at Meteorological Training Institute, Pune.

1.12 SCIENTIFIC PUBLICATIONS

There has been an exponential growth in the SCI publications of the Ministry during the past few years. In 2014-15, the number of publications and its impact factor during are 316 and 715 respectively. The quality of the publications has improved considerably over this period (Fig 1.1).
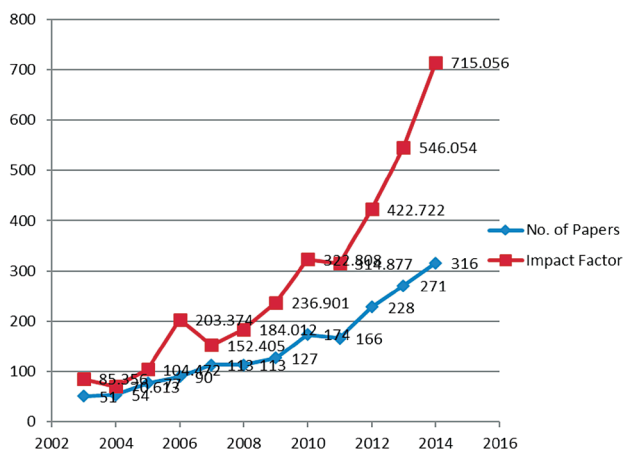

Fig 1.1 - A snapshot of publications of the Ministry

1.13 RESULTS FRAMEWORK DOCUMENT

The performance was evaluated as a part of Results Framework Document (RFD) and it consistently rated well. A score of 86% was achieved during the year.

1.14 BUDGET AND EXPENDITURE

The outlays of the Ministry for current year 2014-15 were Rs. 1281 crores and Rs. 409.00 crores, respectively, for plan and non-plan. The major scheme-wise allocation for the current financial year (2014-15) (Rs. in crores) is shown (Fig 1.2 and 1.3).
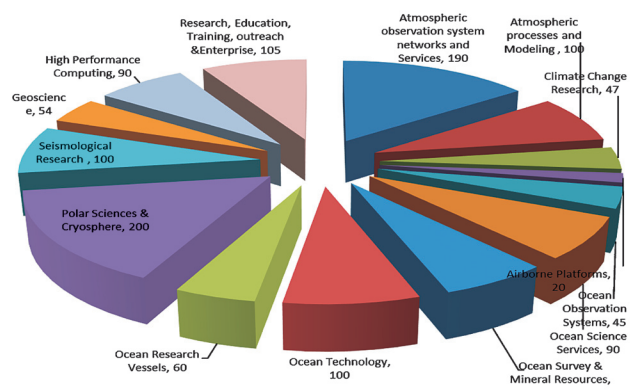
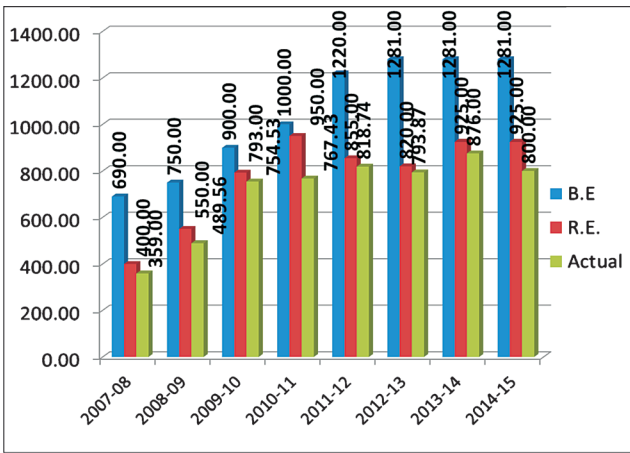Fig 1.2 - Budget Allocation of Ministry for 2014-15

Fig 1.3 - Comparison of budget of Ministry for different
financial years

ATMOSPHERIC OBSERVATIONS AND SERVICES

Atmospheric observations are vital for quality of weather and climate services. In order to provide weather services the atmospheric observational network has been significantly enhanced. Installation of automatic weather stations (AWS), automatic rain gauge (ARG) systems, Doppler Weather Radars (DWR), GPS RS/RW and a network of radiation instruments in various parts of the country have contributed towards augmentation of the observational network. AWS located at remote places collects data from meteorological sensors, validates, processes and disseminates it automatically. Meteorological observations from space are received through meteorological satellites. DWRs and satellite observations have made a significant contribution in nowcasting. Details of major accomplishments are presented below.

2.1 ATMOSPHERIC OBSERVATIONS AND NETWORKING

The weather predictions start from the best possible knowledge of the initial state of the Earth's atmosphere, which is built using frequent, global observations of the upper air atmosphere and the underlying surfaces. The observations from satellites are one of the prominent sources and today have become indispensable for forecasting of the weather.

2.1.1 Satellite Observations and Networking:

The meteorological data from satellites namely Kalpana-1, INSAT-3A and INSAT-3D are being received and processed through INSAT-3D Meteorological Data Processing System. The qualitative products generated after processing the satellite data are transmitted to users for their use in weather forecasting.

INSAT-3D water vapor radiance data and Atmospheric Motion Vector (AMV) and Sounder Radiances are being assimilated in Numerical Weather Prediction (NWP) models. The AMV, Outgoing Long Wave Radiation (OLR), Sea Surface Temperature (SST) of INSAT-3D data for the period of six months (July - December 2014) has been validated.

Three ground receiving and processing systems for NOAA/METOP and MODIS Polar orbiting satellites were installed at Delhi, Chennai and Guwahati. 30 products are derived from MODIS/ NOAA/METOP satellites. They are disseminated through website for the use of forecaster on real-time basis. Advanced Tiros Operational Vertical Sounder (ATOVS) data of NOAA Polar Orbiting Satellites received at New Delhi and Chennai is being sent to Regional ATOVS retransmission service (RARS) group of WMO. NOAA/METOP ground receiving system has been upgraded to receive and process the data from recently launched SUOMI-NPP polar orbit satellite. The processed imagery and derived quantitative products from a number of operational satellites are archived.

The existing analog and digital Cyclone Warning Dissemination System (CWDS) has been replaced by DTH based system. Till date 178 numbers of DTH based CWDS have been installed successfully. DTH based CWDS helps in disseminating cyclone warnings to the affected coastal areas. The generation of specially enhanced cyclone images based on

NHC curves and BD curves from INSAT-3D satellite has been started which leads to the improvement in determining the center and intensity of cyclone.

2.1.2 Radar Observational Network:

The DWR network has been expanded to 15 systems. All the DWRs have been networked with a central server based at HQ to generate DWR secondary products. Storage servers have been installed at two places and functionality initiated for storing DWR data.

2.1.3 Augmentation of Observational Services:

Fig 2.1 - Pyrheliometer on Solar Tracker V-SOL-2A2P at Goa

The observational services comprise Automatic Weather Station (AWS) - 675, Automatic Rain Gauge (ARG) - 1224, GPS Sonde - 16, Ozone Instruments - 15 and 37 UVB Radiometers. During the year, a Solar Tracker V-SOL-2A2P has been installed at MC Panaji, Goa and 98 surface observatories (RMC Mumbai - 29, RMC Nagpur - 16, RMC Chennai - 53) automated by providing Hand Held Data Loggers. Four Digital Distant Indicating Wind Equipment were installed each at Mysore, Tuticorin, Salem and Guwahati airports. Five Digital Current Weather Instrument System (DCWIS) were installed at different places.

2.2 OPERATIONAL WEATHER SERVICES

2.2.1 Operational Numerical Weather Forecasting Services:

The operational numerical weather forecasting services have improved due to advances in modeling of the atmosphere. The National Centre for Environmental Prediction (NCEP) based Global Forecast System (GFS T574/L64) has been made operational, incorporating Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to seven days. In addition to this, the meso-scale forecast system WRF (ARW) with 3D-VAR data assimilation is being operated daily twice, at 27 km, 9 km and 3 km horizontal resolutions for the forecast up to three days using initial and boundary conditions from the GFS-574/L64 (horizontal resolution over the tropics ~23 km).

Hurricane Weather Research Forecast (HWRF) model for tropical cyclone track and intensity forecast for north Indian Ocean (NIO) region has been adopted. The basic version of the model HWRF (ver. 3.2+) with nested domain of 27 km and 9 km horizontal resolutions and 42 vertical levels with outer domain covering the area of 80 80 and inner domain 6 6 with center of the system adjusted to the center of the observed cyclonic storm has been made operational.

The Ensemble and deterministic forecast products from UKMO (50+1 members), NCEP (20+1 members), UKMO (23+1 members) and MSC (20+1 members) are available near real-time for NIO region for named Tropical Cyclones (TCs). These products include Deterministic and Ensemble TC track forecasts, Strike Probability Maps and Strike Probability of cities within the range of 120 km 4 days in advance.

The comparison of GFS model forecast during monsoon 2014 with monsoon 2013 show a significant reduction of Root Mean Square Error (RMSE) in rainfall during 2014 as compared to the same during 2013 over all the subdivisions of India in all day-1 to day-7 forecast. More improvement is noticed over Central India in all day-1 to day-7 forecast

during monsoon 2014 (Fig 2.2). There is also a significant improvement in monsoon rainfall special correlation coefficient (CC), around 17% to 28% in day-4 to day-7 forecast. District level quantitative five days weather forecasts based on Multi-Model Ensemble (MME) system are being generated to support Agro-Meteorological Advisory Service of India. All these NWP products are routinely made available on the web site www.imd.gov.in.
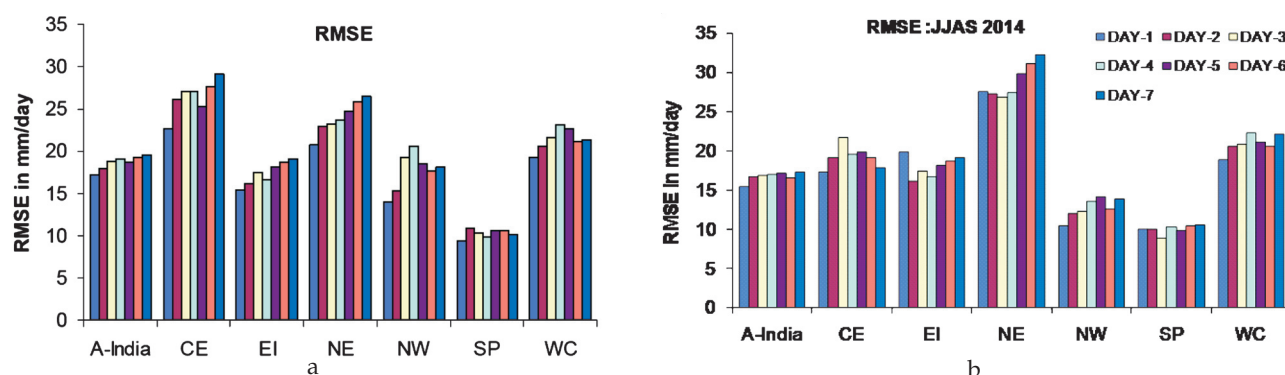

Fig 2.2 - Seasonal (1st June – 30th September) mean RMSE of GFS T574 day-1 to day-7 forecast over Indian monsoon region for 2013 (a) and 2014 (b)

With the improvement of NWP models (GFS and HWRF) and statistical-dynamical models, significant improvement was seen in five days advance prediction of tropical cyclone track and intensity of 'HudHud' (7th – 14th October 2014) over the Bay of Bengal and 'Nilofar' (25th –31st October 2014) over the Arabian Sea. MME track forecast error reduction during 2014 is illustrated (Fig 2.3).
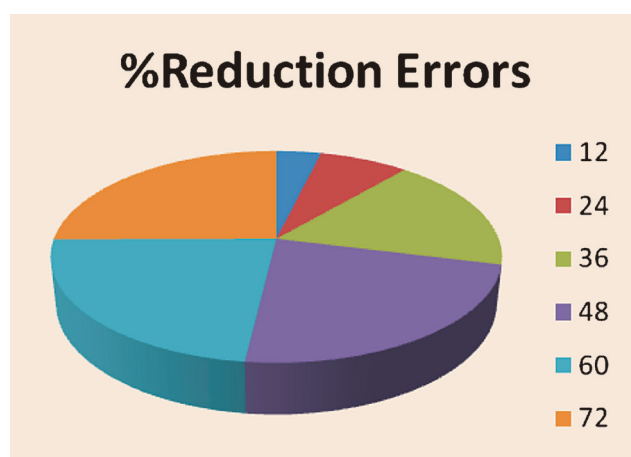

Fig 2.3 - MME track forecast error reduction (km) track for cyclone HudHud during 2014

2.2.2 Agro Advisories Services:

District level agro advisories are prepared for 608 districts using five-day weather forecast and issued on every Tuesday and Friday, which are disseminated to the farming community. Above eight million farmers are provided this information through SMS. The State Composite Bulletins (23 numbers) and National Agromet Advisory Services (AAS) Bulletins are also issued simultaneously.

Block level weather forecast for the parameters like rainfall, maximum and minimum temperature, cloud amount, maximum and minimum relative humidity, wind speed and wind direction is being issued for all the blocks in the country.

National Agromet Advisory Services (AAS) Bulletins based on Extended Range Weather Forecast for southwest monsoon 2014 were issued for the next fortnight with updated on every Friday to fulfill the needs of farmers and other users. The crop yield forecasts are being provided at different stages of the growth period, viz. mid-season (F2) and pre-harvest (F3), stages using agromet models.

2.2.3 Aviation Meteorological Services:

A crucial service to the national and international civil aviation sector in fulfillment of the requirements prescribed by the International Civil Aviation Organization (ICAO) and the Director General of Civil Aviation of India (DGCA) is provided. The aviation meteorological services are provided through 18 Aerodrome Meteorological Offices (AMO) and 54 Aeronautical Meteorological Stations (AMS) located at various national and international airports of the country. An agreement between CSIR-NAL and ESSO-IMD was signed for fabrication, installation and commissioning of Drishti transmissometer. IGI Airport in Delhi is equipped with Drishti transmissometer.

2.2.4 Hydro Meteorological Services:

Inputs to the Central Water Commission (CWC) through their 10 Flood Meteorological Offices (FMOs) established in different parts of India are provided for operation flood forecasting. During the southwest monsoon 2014 about 23,000 Quantified Precipitation Forecasts (QPFs) were issued. The operational run of sub-basin-wise WRF (00 UTC and 12 UTC) and MME (00 UTC) models output (1-day, 2-day and 3-day) for rainfall are generated for 122 sub-basins under FMOs, which is an additional guidance for issuing QPF. The sample of NWP models output for rainfall maps is shown in Fig 2.4.

The rainfall statistics using rainfall data of about 3300 stations for India as a whole and subdivision-wise rainfall statistics were prepared for the southwest monsoon 2014. Design Storm Studies are being carried out to evaluate design storm estimates (rainfall magnitude and time distribution) for various river catchments/projects in the country for designing hydraulic structures. During 2014, design storm studies of 37 projects were completed.
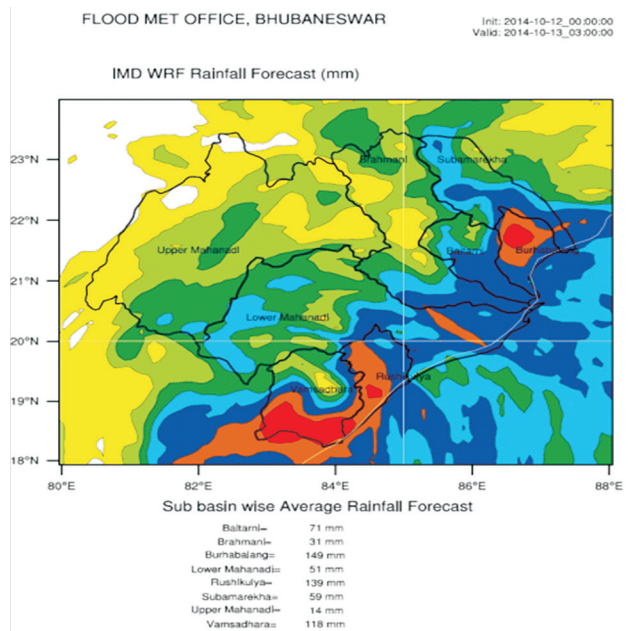

Fig 2.4 - Sample of NWP models output for rainfall maps

2.2.5 Cyclone Forecasting Services:

During the year 2014, eight cyclonic disturbances developed over the NIO region including one Very Severe Cyclonic Storm (VSCS) and one Cyclonic Storm (CS) over the Arabian Sea, one land depression (D) and five cyclonic disturbances over the Bay of Bengal. Considering season-wise distribution, out of eight disturbances, one developed during winter season, one in pre-monsoon, three during monsoon and three during post-monsoon season.

CS 'Nanauk' originated on 9th June 2014 from a low-pressure area over east central Arabian Sea, intensified into a Cyclonic Storm (CS) in the early morning of 11th June 2014. The VSCS 'HudHud' developed from a low-pressure area, which lay over Tenasserim coast and adjoining the north Andaman Sea in the morning of 6th October 2014 and intensified into a Severe Cyclonic Storm (SCS) in the morning of 9th October 2014 over southeast Bay of Bengal and further into a VSCS on 10th

October 2014. The VSCS, 'Nilofar' developed from a low-pressure area on 21st October 2014 and intensified into a VSCS on 27th October 2014.

During VSCS 'HudHud', HWRF model was run with 27/9/3 km resolution based on 0000 and 1200 UTC observations. Hourly updates on the movement and intensity of the cyclone were made available to the National and State level disaster managers and media persons on the day of landfall from 0530 IST of 12th October 2014 till landfall. In view of the improvements in operational track forecast during last five years, the cone of uncertainty has been reduced by about 20-32 % for 24-120 h forecast period. The new radii of cone of uncertainty are 120, 200, 270, 320 and 360 km for 24-, 48-, 72-, 96- and 120-h respectively (Fig 2.5).

Fig 2.5 - Forecast track of Hudhud with cone of uncertainty on 9th October 2014 showing forecast track in red and observed track in black colors

2.2.6 AVERAGE TRACK FORECAST:

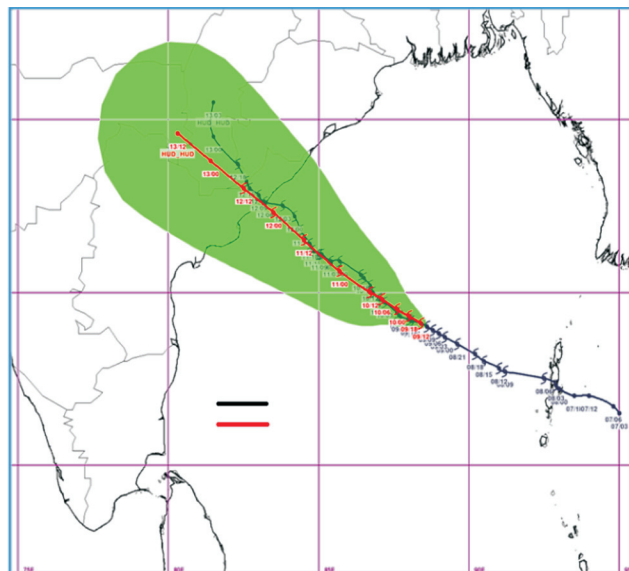The prediction capability for genesis, skill of forecast for cyclone track, landfall, intensity and associated disaster weather have improved tremendously during the year. The details of landfall, track and intensity forecast is given in Table 2.1.

Table 2.1 - Details of landfall, track and intensity forecast of VSCS 'HUDHUD'

Lead Hours	Landfall forecast		Track Forecast Error (km) and skill (%)		Intensity forecast errors (knots) and skill (%) with ref. to persistence			
	Point Error (km)	Time Error (h)	Forecast error	Skill ref. to climatology	Absolute Error	RMS Error	Absolute Error	RMS Error
12	10	0	50.8 (21)	43.8	8.8	12.5	22.8	30.9
24	20	0	63.4 (19)	63.8	8.9	11.3	55.5	65.5
36	17	4 early	67.2 (17)	74.9	9.2	12.3	64.5	69.6
48	04	4 early	78.0 (15)	79.6	10.7	14.7	58.8	59.9
60	08	3 early	88.1 (12)	82.2	13.3	16.4	49.2	53.1
72	24	1 early	84.9 (11)	86.8	15.3	18.0	40.0	42.5
84	40	3 early	90.7 (9)		15.7	19.1	58.5	61.6
96			98.0 (7)		19.7	22.0	54.8	53.2
108			90.8 (5)		18.8	21.1	50.0	66.8
120			203.0 (3)		16.9	17.4	15.5	32.6

2.2.7 Nowcasting Services for Severe Weather:

Doppler Weather Radar (DWR) based information for nowcast of thunderstorm and associated weather for 148 cities were selected. and 39 Nowcast Bulletins were issued every three hourly intervals utilizing Synoptic data, Model outputs, Satellite products and finally various Radar outputs.

2.2.8 Information System and Services:

Global Information System Centre (GISC), New Delhi within the framework of WIS (WMO

Information Systems) of WMO has been set up. The WIS portal www.wis.imd.gov.in has been launched meeting all WIS specifications like metadata creation/upload and metadata synchronization with other GISCs. It has the provision for 24-hour cache data, authentication of other users etc.

The WIS is designed for regional and global connectivity to collect and distribute the information meant for routine global dissemination, while serving as a collection and distribution center in its areas of responsibilities and providing entry points, through unified portals and comprehensive metadata catalogues, for any request for data available within the WIS. WIS consists of two parallel parts: GTS and DAR (Discovery, Access and Retrieval). WMO continues its efforts to enhance and improve GTS, while new DAR functionality is integrated into all WMO and related international programmes.

The WIS consists of three types of centers such as National Centers (NCs), Global Information System Centers (GISCs) and Data Collection or Production Centers (DCPCs). NCs are responsible for collecting national observation data and submitting them to the WIS network. NCs are also responsible for domestic data distribution networks and in-country authorization of WIS users. GISCs are responsible for Management of the Area Meteorological Data Communication Network (AMDCN) services relating to data intended for global distribution (known as a GISC cache) and cataloguing of the entire WIS. DCPCs are designated for each WMO programme activity. They typically engage in production of specialized information, collection and archiving of information in a domain and telecommunication hub activities.

2.3   RAINFALL MONITORING

The southwest monsoon seasonal rainfall over the country as a whole was below normal. The area-weighted rainfall for the season of this year was 87.7% of its LPA value. Out of

36 meteorological sub-divisions, only one subdivision (South Interior Karnataka) received excess rainfall, 23 received normal rainfall and the remaining 12 sub-divisions received deficient rainfall. The rainfall for the season was below normal over northwest India (78.6% of LPA) and east/north-east India (88.2% of LPA) while it was normal over central India (90.4% of LPA) and south peninsula (93% of LPA).
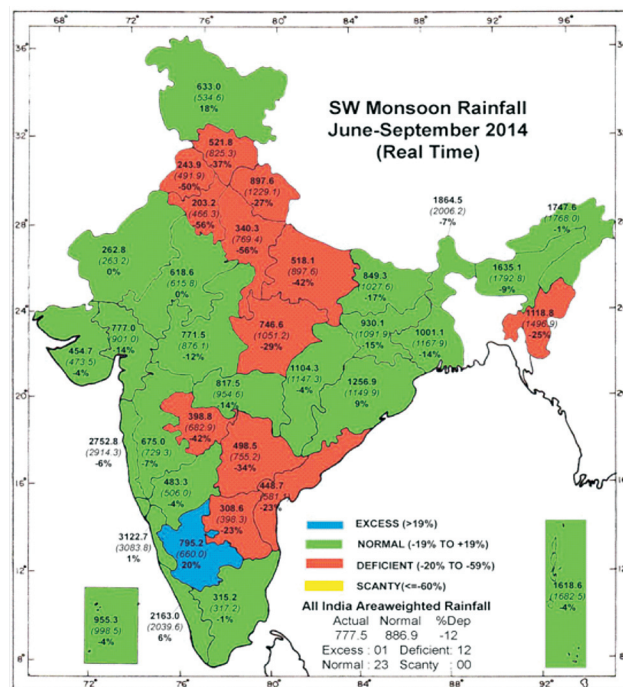
Fig 2.6 - Sub divisional rainfall during June – September

The northeast monsoon rains commenced over the south peninsula on 18th October, simultaneously after the withdrawal of southwest monsoon from the country. Rainfall feature over the south peninsula during the season as a whole was subdued and it was 88% of Long Period Average (LPA). Rainfall was 110%, 57% and 78% of LPA during October, November and December months, respectively.

2.4   MONSOON FORECASTING

This year, the long range forecast for the southwest monsoon rainfall was issued on 24th April, 9th June and 12th August in three stages. Based on an indigenously developed statistical

model, it was predicted on 15th May 2014 that monsoon will set in over Kerala on 5th June 2014 with a model error of ±4 days. The actual monsoon onset over Kerala took place on 6th June, 1 day later than the forecasted date. This is the tenth consecutive correct operational forecast for the date of monsoon onset over Kerala.

The actual season rainfall for the country as a whole is 87.7% of LPA, which is less than the first stage forecast issued in April by 7% of LPA. It is less than the first update by 5% of LPA and more than the second update by 1% of LPA. Considering the four broad geographical regions of India, the forecast update issued in June (August) for the season rainfall over northwest India, central India, northeast India and over south peninsula was 85% (76%), 94% (89%), 99% (93%) and was 93% (87%) of LPA, respectively, all with a model error of ± 8%. The actual season rainfalls over northwest India, central India and south peninsula are within the limits.

The forecasts for the monthly rainfall over the country as a whole for the months of July and August issued in June were 93% and 96% respectively with a model error of ± 9%. The actual monthly rainfall during July and August is 90% of LPA each.

The forecast for the second half of the monsoon season (August – September) for the country as a whole was 95% with a model error of 8% of LPA against the actual rainfall of 97% of LPA. The country received near normal rainfall 94% of LPA during the July to September period. But due to the large rainfall deficiency in June, the 2014 season rainfall over the country as a whole (88% of LPA) ended as deficient (<90% of LPA).

2.5 HEAVY RAINFALL FORECASTING

There has been consistent improvement in the accuracy and skill of operational forecasts and heavy rainfall warnings issued in the recent past as shown (Fig 2.7).
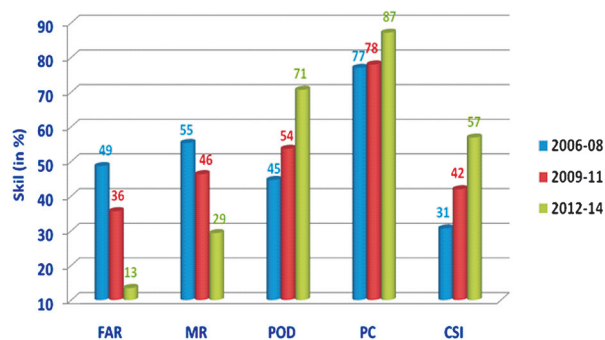
Fig 2.7 - Accuracy and skill of operational forecasts

Percentage Correct (PC) for Heavy Rainfall Warnings during monsoon 2014 was 88%. Probability of Detection (PoD) and Critical Success Index (CSI) during monsoon 2014 was 73% and 58%, respectively. False Alarm Rate (FAR) was only 8% and Missing Rate (MR) was 27%, which is the best performance so far. PoD and CSI has improved by 40% and 52% in 2014 as against mean of 2002 to 2014. FAR and MR has improved by 80% and 44 % in 2014 as against mean of 2002 to 2014.

ATMOSPHERIC AND CLIMATE PROCESSES AND MODELING

The meteorological and climate services have significant impact on society. Public, private and government sectors demand accurate weather and climate forecasts at various spatial and temporal scales. Improved and reliable forecast of weather and climate requires high-resolution dynamical models and dense observational networks. Thus, a combined approach involving land, ocean and atmospheric processes hold the key to improve forecasts at various temporal and spatial ranges. On the other hand, intensive monitoring of various weather systems through various observing systems including satellites provide necessary information about current weather systems. Their effective assimilation in numerical models provide accurate forecasts.

3.1 PHYSICS AND DYNAMICS OF TROPICAL CLOUDS

3.1.1 Aircraft Observations:

The third phase of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) was conducted near Varanasi to investigate the cloud processes under high pollution conditions. The observational campaign included aircraft based observations for 49 hours during September 2014. A ground-based observational campaign was conducted at the South Campus of the Banaras Hindu University (BHU), Varanasi on aerosol and cloud chemistry.

The vertical variation of ice nuclei (IN) over the Indian region was examined. Spatial variation in IN concentration was observed in the range 0 to 5 L 1 with an average of 1.12 L 1 at the highest ice super saturation (20-25%) interval. These concentrations are much less compared to the ones prescribed in numerical models. The instantaneous vertical heating rate induced by Black Carbon (BC) in cloud layers is found to be as high as 2.65 K/day and is found to be inducing a reduction in the cloud liquid water content (LWC). Aircraft observations over the Western Ghats revealed that forced updrafts foster rapid condensational growth of cloud droplets, triggering coalescence process within few hundred meters of cloud depth. It was found that on an average, MODIS retrieved mean Cloud Optical Depth (COD) and cloud Liquid Water Path (LWP) are underestimated, while mean Re (effective droplet radius) is overestimated as compared to the ground retrievals.

Fig 3.1: Instrumented Research Aircraft during CAIPEEX Phase-III, 2014

3.1.2 High Altitude Cloud Physics Laboratory (HACPL) Observations:

Over Mahabaleshwar, bi and mono-modal rain Drop Size Distribution (DSD) are observed during light and heavy rainfall events, respectively. The DSDs are parameterized and their radar reflectivity factor-rainfall intensity relationships are evaluated which suggested the dominance of collision-coalescence processes. Canister sampling and analysis by the Proton Transfer Reaction Mass Spectrometer (PTRMS) shows that possible contribution from biogenic VOCs contributing to the high concentration of aerosols and CCN during the morning hours.

3.1.3 Thunderstorm Dynamics:

The electrical characteristics of thunderstorms observed during the pre-monsoon season in the eastern part of India illustrate that some thunderstorms were having strong and dominant positive charge region in the lower portion of cloud. The spatial distribution of convective available potential energy (CAPE) and lightning activity in different seasons have been studied over the Indian region to find out the dependence of lightning activity on CAPE.

3.2 CLIMATE PROCESSES

3.2.1 Pollution Hazards at the Lumbini Heritage Site of Lord Buddha:

Lumbini has been inscribed on UNESCO's list of World Heritage for its Outstanding Universal Value, as it is the birthplace of Gautama Buddha, the founder of Buddhism. To determine the status of air quality in various environments in and around Lumbini, atmospheric measurements of PM10, PM2.5, and Ozone along with weather parameters were conducted at four strategically selected locations.

3.2.2 Air Pollution Studies:

The role of aerosols in modulating the dangerous ultra-violet (UV) radiation has been investigated over four metro cities in India. Average aerosol forcing efficiency ranged from -0.85 ± 0.33 to -3.83 ± 0.35 KJm-2 AOD-1 observed during different seasons. This enhanced aerosol radiative forcing efficiency is found to reduce the dangerous incoming UV radiation by 30-60% in different seasons. Estimation of nitrogen oxides lifetime over India has been carried out using Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) observations. Lifetime of NOx has been estimated as 11.9 h (approx) based on model simulation and is comparable as per the calculations using satellite observations.

3.2.3 Development of Emission Inventory for Mumbai-SAFAR:

One of the most crucial parts of SAFAR is to generate primary data and to validate the secondary data for the development of micro-level emission inventory for Mumbai. The generation of primary and activity data related to industrial, transport, residential and other sectors is going on. Emission inventories are being prepared for NOx, CO, PM2.5, PM10, VOCs, SO2, BC and OC in a region of 50x50 km centered around Mumbai with 1km x 1km resolution using GIS based statistical model.

3.2.4 Greenhouse Gases Monitoring and Modeling:

The land-based observations of atmospheric CO_2 from Sinhagad captures both the oceanic and continental sources of CO_2. This data has been used for evaluating the seasonal cycle of CO_2 over peninsular India and also used to identify the CO_2 transport mechanisms over India. In addition to this, in-situ CO_2, CH_4, H_2O concentration available since June 2014 are important for estimating CO_2 fluxes (i.e. sources and sinks) across the earth surface by inverse modeling. This provides a unique opportunity to utilize new generated data of atmospheric CO_2 over Sinhagad in the inversion models.

3.3 NUMERICAL MODELING

3.3.1 The ESSO-NCMRWF Unified Model (NCUM):

NCUM has been tested with a new dynamical core, which allows switching to different options like hydrostatic formulation, coordinate system, transport and time integration schemes to produce realistic simulations. This core can handle different space-time scales simultaneously in a seamless manner.

A Nested UM suite (1.5 km resolution) was recently implemented and was tested for various domains namely, Jammu and Kashmir, Madhya Pradesh and Gujarat using orography generated from 90 m SRTM topography. Fig 3.2 displays the day-1, day-2 and day-3 rainfall forecasts valid for 3rd – 5th September 2014 during the period of J&K floods by UM global and 1.5 km regional models against gridded rainfall analysis at 50 km resolution. The 1.5 km resolution regional model predictions shows better match with the observations in terms of distribution, more details and closer location of rainfall patterns.

The climatological Land Use Land Cover (LuLc) data in NCUM over South Asia and adjoining region have been replaced by the NRSC/ISRO data derived from IRS-P6 satellite during 2012-13. Initial experiments using the NRSC/ISRO LuLc data have shown improvements in the short-range rainfall forecasts.
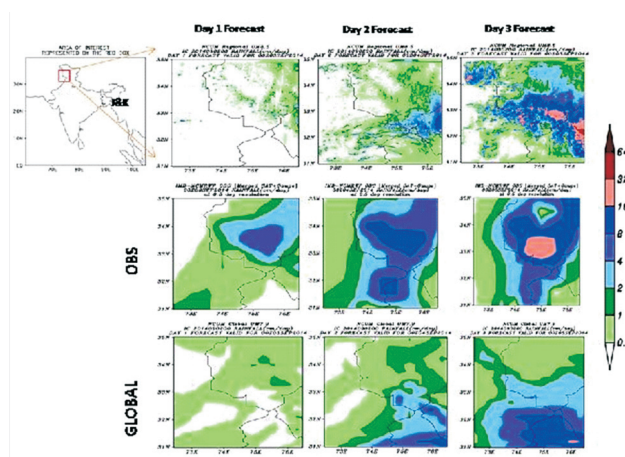
3.3.2 The Global Ensemble Forecast System (GEFS):

The 20-member NGEFS system (T190L28) has been further improved to provide more real-time forecast products using bias correction methods. The calibrated forecasts show improvement in the forecast in terms of reduced tropical cyclone track errors. On an average, the 24-h forecast track errors improves by about 50% after the bias correction. Two new ensemble based products were introduced: (i) The probabilistic rainfall forecasts over the meteorological sub-divisions of India (Fig 3.3); and (ii) Forecasts of snow probability over the western Himalayas. The former is a very useful product during the monsoon seasons while latter product is of particular relevance during winter and for the western disturbance events affecting the weather in north India.
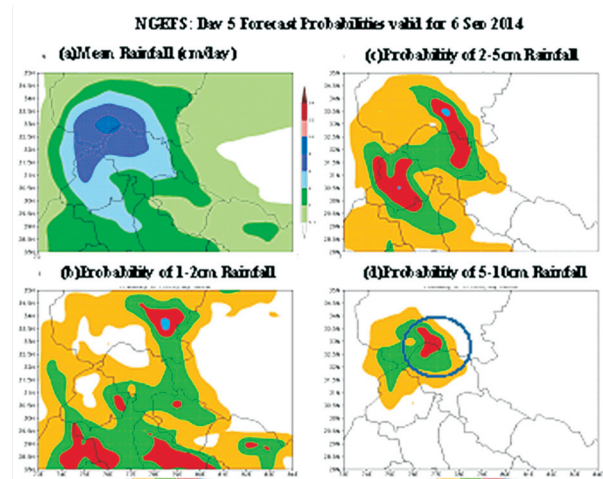
Fig 3.3 - NGEFS ensemble mean rainfall and the forecast probabilities for different rainfall amounts

Panels in Fig 3.3 show the ensemble mean rainfall over J&K on 6th September 2014 (a) and the PQPF plots for three rainfall thresholds 1-2cm/day (b), 2-5cm/day (c) and 5-10cm/day (d). The high probability (65-95%) of 5-10 cm/day rainfall 5 days ahead was predicted in the NGEFS system. These forecasts are also made available to the Bhakra and Beas Management Board (BBMB) for hydrological assessment for potential flood hazard.

Fig 3.2 - Rainfall forecasts from global UM and 1.5-km regional UM for J&K region (3-5 September, 2014)

3.3.3 Data Assimilation:

The volume of data received both through GTS and Internet Data Service (IDS) has increased manifold in the recent years (Fig 3.4). This growth is mainly due to reception of Asia-Pacific RARS data, half-hourly reception of INSAT-3D Atmospheric Motion Vector (AMV) wind vectors, INSAT-3D sounder and imager radiance data and NOAA NPP (CrIS and ATMS radiance etc.). Apart from this, 14 GB radar observations from 17 Indian radar stations have been received resulting in total volume of data received ands assimilated around ~35GB/day.
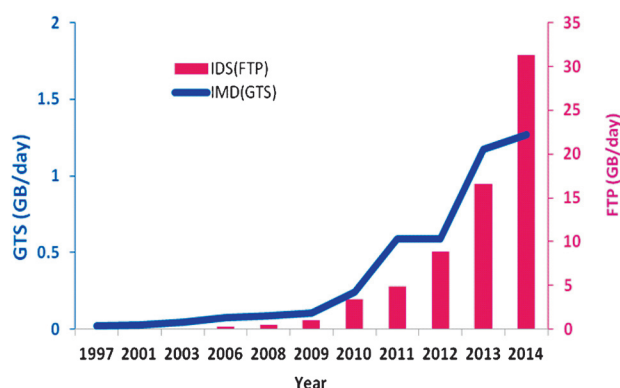

Fig 3.4 - Volume of data received at ESSO-NCMRWF over the year

The quality of INSAT-3D satellite-derived winds have improved considerably (Fig 3.5) and are now being assimilated in NGFS and NCUM. The quality of IR-AMVs of INSAT-3D are now comparable to that of other satellites. Development work towards assimilation of sounder radiances data was carried out and started using the new CSBT radiance product. With the new changes the agreement between model simulated and satellite observed radiances is increased and assimilation system started accepting the sounder radiance data. An observation monitoring system for various satellite sensors health based on various products from its Global Data Assimilation forecasting system has been operationalised.
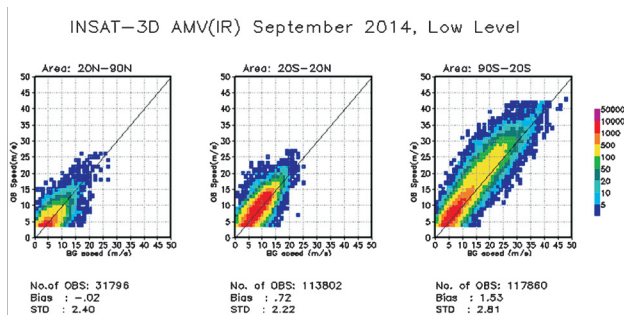

Fig 3.5 - Speed bias density plot of low-level IR AMVs for September 2014 for INSAT-3D

The operational usage of MT-SAPHIR radiance data in the operational system has shown an increase in the quality of humidity forecasts by about 3 to 4%. Soil moisture is a key variable, which describes the exchange of moisture and heat between the land surface and the atmosphere. A soil moisture assimilation scheme based "nudging" technique is used for the preparation of soil moisture analysis. The screen level observations of humidity and temperature as well as the ASCAT (Advanced SCATterometer instrument in METOP Satellite) surface soil wetness observations are used for the preparation of soil moisture analysis, which is used to initialize the Unified Model. Six hourly soil moisture analyses are being prepared routinely.

3.3.4 Evaluation of Model Forecasts:

Verification of the model forecasts is a continuous process for development of next generation numerical weather prediction systems with increased reliability through research and development. A set of diagnostics, which include forecast systematic errors and standard verification scores suggested by WMO/CBS are generated every month. The Root Mean Square Error (RMSE) of the magnitude of the wind vector (RMSEV) for the GFS T574L64 operational model day-3 forecasts at 850-hPa level against the radiosonde observations over India since January 2005 has decreased (Fig 3.6). The overall decrease in the RMSEV can be attributed to the increase in the resolution of the model, increase in the amount of data being assimilated and improvements in data assimilation techniques and model physics.
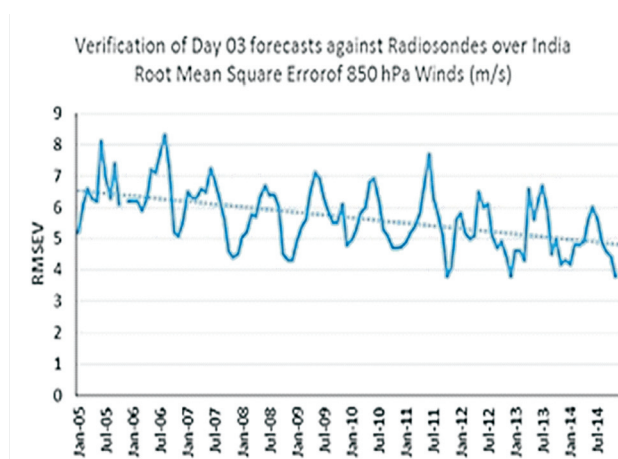
Fig 3.6 - RMSE in the day-3 forecast vector winds at 850-hPa in the NGFS
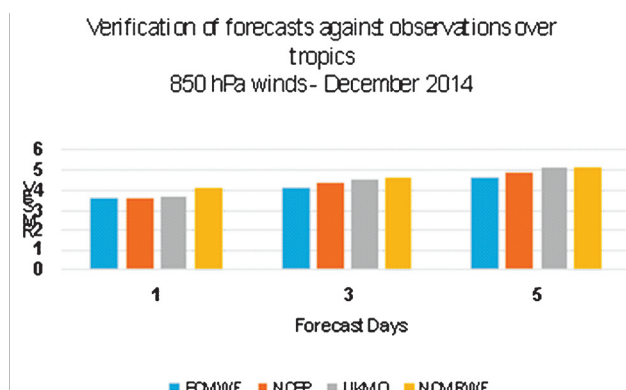

Fig 3.7 - Comparison of RMSEV of wind forecasts at 850-hPa level over tropics

Fig 3.7 shows the RMSE of the magnitude of the wind vector (RMSEV) for day 01, 03 and 05 forecasts at 850-hPa level against the radiosonde observations over the tropics from the major operational NWP centres (ECMWF, NCEP, Met Office, U.K., and ESSO-NCMRWF). The forecast skill of ESSO-NCMRWF is comparable with that of the other centres.

3.3.5 Visibility and Dust Forecasts:

Forecast of fog and visibility over most parts of the Indo-Gangetic plain is becoming increasingly important in the winter season. In the NCUM, determination of atmospheric visibility mainly depends on two crucial factors; one is the relative humidity and second is the aerosol concentration. The model visibility is being verified against surface visibility observations from meteorological airport reports (METAR).

Fog products are also being verified against visible and IR based fog products from INSAT-3D also.

Since forecast of airborne dust is very important especially over the northwestern part of the country, it is required to have the numerical prediction capability of dust. Dust forecast by NCUM is verified against various space and surface based observations for all seasons over the Indian region. Forecast of dust Aerosol Optical Depth (AOD) is mainly compared against the observations, since AOD is the commonly measured parameter from both satellites (from CALIPSO, MODIS, MISR, OMI etc.) and ground based (AERONET) measurements. The comparison results show that the model dust forecast has good skill over the western part of the country in the pre-monsoon season (Table 3.1).

Table 3.1 - NCUM day-2 forecast and CALIPSO satellite observations of dust AOD over western part of the country (and nearby regions) during April-May, 2014

Time period	Mean Bias Error (BE)	Root Mean Square Error (RMSE)	Willmott's index of agreement (d)	Correlation Coefficient (CC)	Data points (N)
April 2014	0.1417	0.1734	0.6561	0.7033	5115
May 2014	0.0434	0.1780	0.6676	0.7071	5494

3.3.6 Application of NWP Forecasts for Various Sectors:

A high-resolution (3 km grid) WRF forecasts of several variables are provided over eight nuclear sites of the Nuclear Power Corporation of India (NPCIL). The high-resolution forecasts are provided at hourly intervals covering about 1.5 x 1.5 grid box for each site. This data is used by NPCIL for driving dispersion models for emergency warning system.

Rainfall and temperature forecasts are provided over the north Indian domain covering 29 -34 N and 74 -83 E to the Bhakra and Beas Management Board (BBMB). The high-resolution (9 km) forecasts are based on the WRF model runs based on 1200 UTC initial conditions extending up to 72 hours. In addition, 10 day probabilistic rainfall forecasts based on the NGEFS are also being provided to BBMB.

Customized weather forecast products were developed for the southern Indian Ocean region for use by ESSO-NCAOR. These forecast products which include winds at 10m, 925, 850 and 500 hPa levels, rainfall and cloud cover and their interpretation are being provided every day in real-time. SASE's regional atmospheric modeling efforts are being supported by providing forecast outputs from global model in real-time. The regional model products are further used for snow and avalanche prediction.

A large number of wind energy farms are operational in India and at present the total installed capacity is about 19000 MW and it is expected that an additional capacity of 2000 MW will be added every year. It has become mandatory for all wind power generators to provide generation schedules in advance. It necessitates accurate high-resolution gridded data of observed and short-term forecasts of wind speed and direction at surface and lower levels (up to 100 m) for wind power forecasting and scheduling.

Seven days forecasts of wind and geopotential height to were provided during the launch of PSLV-C24 on 4th April 2014, PSLV-C23 on 30th July 2014 and PSLV-C26 on 15th October 2014.

3.3.7 Forecast Generation for Neighboring Regions:

RIMES: The Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) is an international and intergovernmental institution, owned and managed by its Member States, for the generation and application of early warning information. Customized weather forecasts for each country is generated daily and provided through RIMES website/e-mail.

India-Africa Center: An India-Africa Center for Medium Range Weather Forecasting (IAC-MRF) has been planned to fulfill India's commitments made at the second Africa-India Forum Summit in the area of capacity building in Africa. Geographical plots of predicted winds, rainfall, maximum/minimum temperature, near surface dust concentration over African region along with meteograms for 52 capital cities of African Union countries showing 7-days prediction of surface temperature, humidity, pressure, wind and rainfall are being generated regularly and posted in ESSO-NCMRWF web site.

3.4   CLIMATE PREDICTION MODELING

3.4.1   Earth System Model (ESM) Development:

An important achievement in ESM development was achieved during this year. The ESSO-IITM ESM has been implemented by transforming the CFS seasonal prediction model to a long-term climate model. This transformation is performed by incorporating a new ocean component (MOM4p1) in the CFS coupled model. The MOM4p1 is a comprehensive ocean general circulation model with interactive ecosystem and biogeochemical processes. The ESM development during the last six months has resulted in improved simulation of sea-ice distribution (Fig 3.8). This improvement has been possible through correct representation of flux exchange across the atmosphere, ocean and sea-ice components.
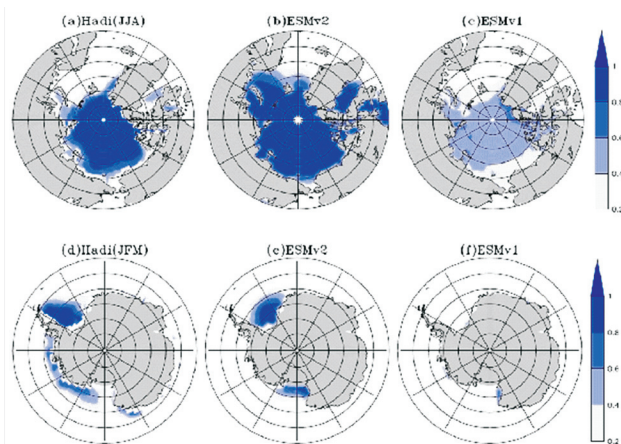
Fig 3.8 - Mean Sea Ice Fraction in summer hemisphere from Observations (Hadley Centre), ESMv1 simulation and ESMv2 simulation. Top panel is for the JJA season in the NH. Bottom panel is for the JFM season in the SH. Note the improvement in the simulated sea ice distribution in ESMv2 as compared to ESMv1.

3.5   REGIONAL CLIMATE DOWNSCALING

CORDEX South Asia - In CORDEX South Asia, regional climate scenarios are developed using multiple high-resolution regional climate models (RCMs) for the historical period and the future. High-resolution simulations of 20th century climatic variations and future climate projections developed at ESSO-IITM are presently made available for download. The climate projections are based on a global climate model with telescopic zooming (~ 35 km in longitude x 35 km in latitude) over the South Asian region. To improve the management and distribution of CORDEX South Asia datasets, the ESSO-IITM climate data portal is being upgraded as an ESGF data node.

3.6   MONSOON MISSION

Using the Monsoon Mission Model (CFS V2.0), ESSO-IITM has produced coupled dynamical seasonal and extended range predictions of the monsoon for the year 2014 on real-time basis and shared with the India

Meteorological Department (ESSO-IMD) for operational use. The predictions have been verified for all-India rainfall and rainfall over different homogeneous regions of India, viz. Central India (CEI), North-East India (NEI), North-West India (NWI), South peninsula (SPI) and the monsoon core zone of India (MZI).

The latest high-resolution (T382 spectral resolution) research version of the coupled model (CFS Version 2) has been used to generate the experimental forecast for the 2014 southwest monsoon season rainfall (over Indian region) using the February initial condition with 56 ensembles. The forecast suggested that the monsoon rainfall during the 2014 monsoon season (June-September) averaged over the country as a whole is likely to be 96% (+/- 5%) of long period model average (LPMA). The actual rainfall during the 2014 southwest monsoon season (JJAS) averaged over the country as a whole has been 88% of its long period average (LPA) value. Thus, the CFS model slightly overestimated the 2014 seasonal monsoon rainfall (Fig 3.9).

The real-time forecast for the active/ break spells of 2014 monsoon season was disseminated with the newly developed Multi-Model Ensemble (MME) system using the CFS based Grand Ensemble Prediction System (CGEPS). The CGEPS includes three sub-ensembles, from CFSv2 run at T126 (~100km; hereafter termed as CFS126) and T382 (~38 km; termed as CFS382) horizontal resolutions, plus the GFS forced with bias corrected SST from CFS126 (termed as GFSbc). CGEPS has 21 ensemble members of GFSbc and 11 members each of CFS126 and CFS382. Each of these ensembles is run for 45 days lead-time every 5 days, starting from 16th May to 28th September.
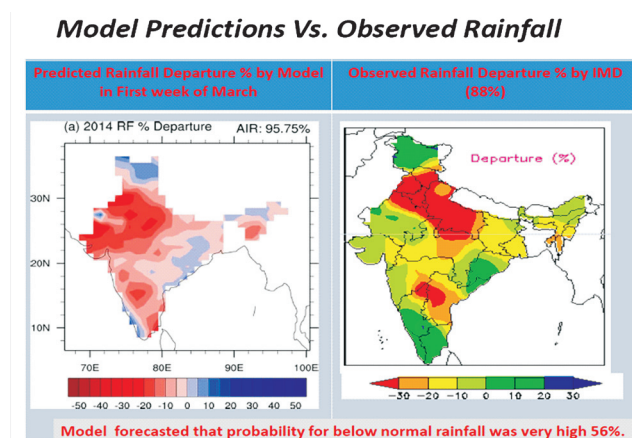
Fig 3.9 - Seasonal prediction of Indian summer monsoon rainfall issued in March 2014 (left) and Observed rainfall (right)

The MME has successfully predicted the delayed onset, delayed progression and the revival of monsoon during the first half of July at 3-4 pentad lead time (Fig 3.10). This is significant considering the prediction at lead-time of 15 days is quite efficient and useful for the user community (farmers, reservoir managers etc.).
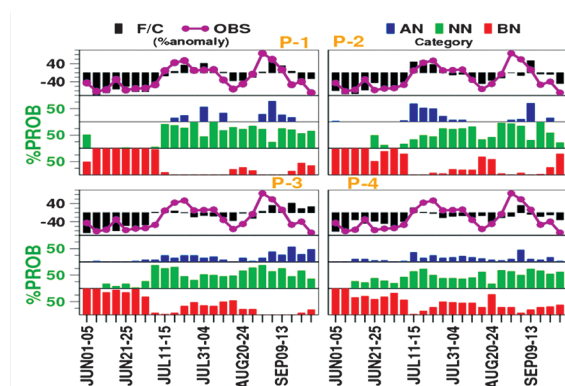

Fig 3.10 - Performance of the extended range forecasts during the 2014 monsoon season

CFS Hindcast Experiments - with and without assimilation: Two coupled model experiments are carried out to understand the impact of ocean data assimilation on the Indian summer monsoon evolution. First experiment used GODAS-IITM generated initial state using ARGO profiles of the upper 2000 m of ocean. The second experiment is similar to the first but without any ocean data assimilation. In both the model experiments, atmospheric initial conditions were the same. The hindcast experiments are carried out for the period 2005 to 2009 with ensemble of three (May initial conditions). The experiment with ocean data assimilation showed improvement in the seasonal rainfall features.

3.7 COUPLED MODELLING FOR SEAMLESS PREDICTION

ESSO-NCMRWF in collaboration with UK Met Office has implemented the HadGEM3AO (N96L85O1L75) based coupled model and is being further developed for Indian/monsoon conditions. The atmosphere component UM has a horizontal resolution of 1.875o x 1.25o and has 85 layers in the vertical going up to 85 km. The Ocean component NEMO is configured at 1o x 1o resolution, but near equator its resolution is 0.33o. It has 75 layers in vertical, with 35 layers in upper 300 m (1 m near surface). For Sea-Ice, the CICE model of Los Almos Lab, USA is integrated to the coupled system. The coupled system will be upgraded to N216L85O25L75 higher resolution on the new computer. This coupled model has been adopted as part of the 'Monsoon Mission' to enhance the skill of monsoon prediction from days to seasons in a seamless context. Fig 3.11 shows the mean rainfall from the hindcast runs. The GA3.0 having better physical parameterisation processes has reduced rainfall biases compared to older GA2.0 version in UM.
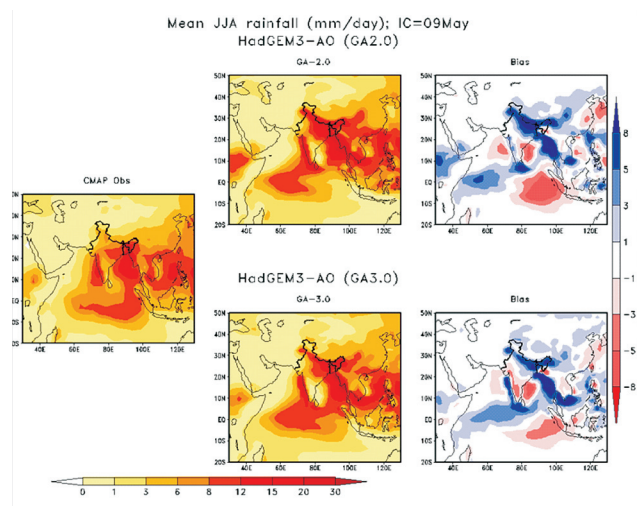
Fig 3.11 - Mean Monsoon JJA rainfall and biases from coupled model

3.8 INDIAN OCEAN WARMING

Recent studies have pointed out an increased warming over the Indian Ocean warm pool (the central-eastern Indian Ocean characterized by sea surface temperatures greater than 28.0 C) during the past half-century, although the reasons behind this monotonous warming are still debated. The results reveal a larger picture - namely, that the western tropical Indian Ocean has been warming for more than a century, at a rate faster than any other region of the tropical oceans, and turns out to be the largest contributor to the overall trend in the global mean sea surface temperature (SST). During 1901–2012, while the Indian Ocean warm pool went through an increase of 0.7 C, the western Indian Ocean experienced anomalous warming of 1.2 C in summer SSTs.

3.9 MODELING OF CHANGING WATER CYCLE AND CLIMATE

Snow Accumulation and Ablation Variability over western Himalayas has been studied using remote sensing data of snow water equivalent (SWE) and snow cover area (SCA). The snowmelt factor has been estimated and it is found that this parameter varies from month to month and it also varies with topography. A non-linear relationship between SCA and SWE has been found over the western Himalayas.

COASTAL AND OCEAN OBSERVATION SYSTEMS, SCIENCE AND SERVICES

India has a long coast line of over 7500 km with an exclusive economic zone (EEZ) of two million sq. km. Twenty percent of India's population inhabits coastal areas and it is growing rapidly due to coastal developmental activities.

The coastal environment of India is vulnerable to both natural and manmade pressures and under multiple stresses arising from local to global scale drivers, viz., influx of nutrients/sediments and coastal pollution, ecosystem degradation, river flooding, shoreline erosion, storms, tsunamis, sea level rise and mineral and sand mining.

The coastal and oceanographic processes particularly those occur in the seas around India, viz., Bay of Bengal and Arabian Sea are unique in many ways. These are primarily driven by a wide range of large-scale oceanic and atmospheric processes. Besides, the oceanic margin of eastern Indian Ocean, tectonically active subduction zones are prone to generate large earthquakes and occasionally generate tsunamis.

Towards building resilience and improved quality of life of coastal population of India, a comprehensive Ocean Science and Services (OSS) program is being implemented. The OSS encompasses,

i. providing a suite of ocean information and advisory services (IAS) for the coastal population,

ii. promoting research for sustainable utilization of marine living resources,

iii. assessment of health of coastal waters of India,

iv. conducting multi-disciplinary surveys for coastal protection measures to mitigate from natural and man-made disasters,

v. establishment and sustaining coastal and oceanic observation networks, and

vi. forge cooperation with the countries of South Asian region and the Indian Ocean Rim countries for capacity development and addressing of the common coastal issues.

4.1 COASTAL AND OCEAN OBSERVATIONS

A comprehensive ocean observation system to acquire real-time data on surface meteorological and upper oceanographic parameters from the Indian Ocean region has been continuing. The primary purpose of acquiring a suite of accurate measurements of ocean parameters is to cater to needs of research and a wide range of operational services including issue of early warning to tsunami and storm surges. These measurements are also useful

Fig 4.1 - Location of Moored Buoys

for ocean-atmospheric modelling purposes and for validation of satellite data.

4.1.1 Moored Platforms:

The moored platforms encompass a wide range of state-of-the-art systems viz., moored data buoys, current meter arrays, Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) moorings, Acoustic Doppler Current Profiler (ADCP) and tide gauges which are deployed at selected locations for continuous reception of time series data on ocean parameters. 264 ship days covering 21,715 nautical miles are required to manage these buoys.

The Moored Buoy Network is performing satisfactorily and providing valuable data close to 90% of the time despite many challenges being faced. The state-of-the-art buoy systems installed at 12 locations are collecting and transmitting hourly meteorological, ocean and subsurface parameters (66) in real-time to shore. In addition 4 coastal buoys with INSAT and GPRS telemetry and CALVAL, a buoy system to validate satellite data are being maintained successfully. The OMNI buoys captured the ocean data during the three cyclonic disturbances formed during the northeast monsoon and one during the summer transition period. These data helped in issuing cyclone advisories.

An Integrated Marine Surveillance System (IMSS) for buoy (R-Dharsh) was developed indigenously and deployed successfully off Goa on 24th May 2014. This system has been transmitting the video data from buoy location, in real-time, via 3G telemetry. This system was selected for Department of Science and Technology award under the title "Societal Innovation-2013".

HF Radars:

A network of ten HF Radar systems has been established at various regions along the Indian coast. All stations are operational. The response in ocean circulation and coastal waves associated with passage of various cyclones are captured by HF Radar stations.

Tsunami Buoys:

The Indian Tsunami Early Warning System (ITEWS) comprises a network of 7 Tsunami Buoys (Fig 4.1) deployed close to the tsunamigenic source regions in the Bay of Bengal and Arabian Sea to detect the propagation of tsunami wave in the open ocean. The surface buoy STB02 (Arabian Sea) was replaced in May 2014. ITB03 buoy detected a tsunami event on 21st March 2014 at the Nicobar Islands.

Tide Gauge Network:

A network of 21 state-of-the-art tide gauge stations has been established at strategic locations along the Indian coastline and islands to measure tidal waves as well as monitor progress of tsunami waves for validation of the model results. The installation and maintenance of these tide gauges are done in collaboration with the Survey of India (SoI), Dehradun.

Wave Rider Buoys:

A wave rider buoy was deployed off the coast of Tuticorin on 3rd July 2014 to measure the wave parameters. With this deployment, a network of 10 wave rider buoys is being maintained around the Indian coastline.

RAMA Observation Network:

With the deployment of 1 Atlas and 1 ADCP at 0 and 67 E, respectively, 34 out of the proposed 46 RAMA buoys (74%) site were occupied. In addition, the first CO_2 flux and ocean acidification mooring in the northern Indian Ocean is deployed at 15 N, 90 E. It measures pCO_2, pH, chlorophyll, dissolved oxygen and backscatter parameters at the ocean surface and marine boundary layer air pCO_2.
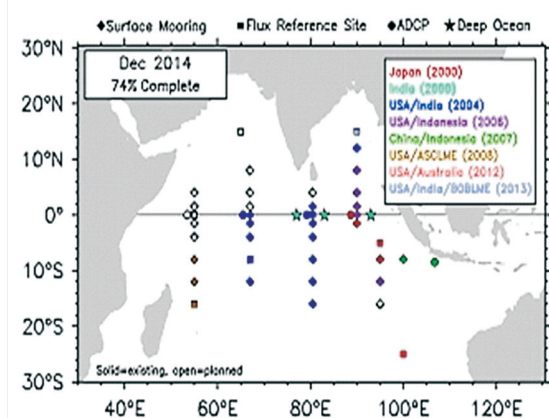
Fig 4.2 - Current Status of Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) Observation Network

Equatorial Current Meter Mooring:

For the first time, four year old deep-sea moorings at 10N-930E, 10N-930E, 00-930E and 10S-930E were successfully recovered. Utilizing these instruments, an additional deep-sea mooring was deployed at 10N-830E. The four deep-sea moorings at 10N-770E, 00-770E, 10S-770E and 00-830E were continued with redeployed instruments. With this, at present there are five active deep-sea current meter moorings in the equatorial Indian Ocean. A wealth of information from the equatorial Indian Ocean region has been retrieved.

Coastal ADCP Mooring:

At present, 17 moorings are active (presumably, since as they are all at subsurface), which includes 2 pairs and 2 individual ADCPs on the west coast of India and 4 pairs and 3 individual ADCPs in the east coast of India. Over 15 operations were carried out at different sites during last one year, which included 9 recovery and 6 deployments on the west coast of India.

Automatic Weather Stations (AWS):

With the deployment of two AWS in 2014 (on the vessels MV Nicobar operated by the Shipping Corporation of India and MV Blue Marlin operated by the Fisheries Survey of India), the network has expanded to twenty. The AWS provide marine meteorological data.

4.1.2 Profiling Floats:

The profiling floats are primarily drifters, Argo floats, gliders, etc. meant for collection of limited parameters covering a large area.

Argo Profiling Floats:

India continued to contribute to global efforts by deploying 45 Argo floats (16 ARVOR-I/L model type and 12 Bio-Argo type) during 2014 in the Indian Ocean. Bio-Argo floats are equipped with sensors for measuring dissolved oxygen, chlorophyll fluorescence and backscattering sensors. 117 Indian floats are currently active and providing data on temperature and salinity upto 2000 m in real-time.

Drifting Buoys and XBT Profiles:

During last one year, 53 drifters were deployed in the Bay of Bengal, the Arabian Sea and equatorial Indian Ocean. Besides, about 166, 1286 and 134 XBT/XCTD data were collected, respectively from the Arabian Sea, the Bay of Bengal and southern Indian Ocean during the year 2014. All the XBT/XCTD data are processed, quality controlled following international standards and archived.
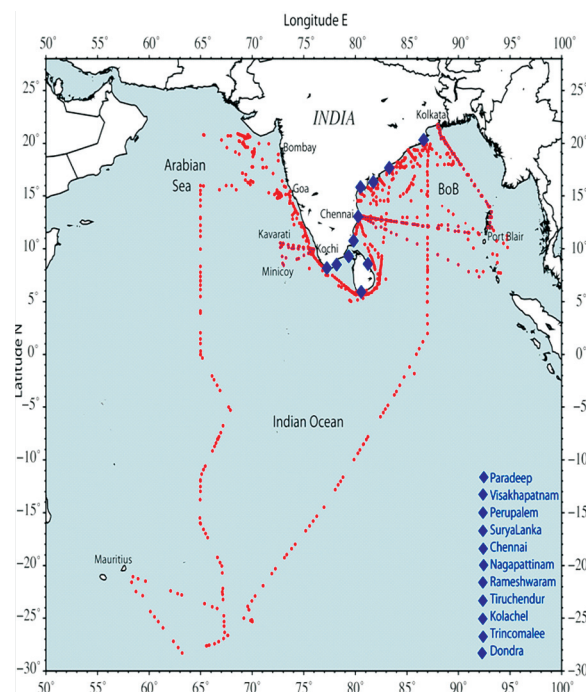

Fig 4.3 - Temperature/Salinity data density during 2014 in the Indian Ocean (red dots indicate point of data collection)

4.1.3 Special Ship-Based Observations:

The Air Sea Interaction Research Initiative (ASIRI) and Ocean Mixing and Monsoon (OMM) is a collaborative program between ESSO, India and Office of Naval Research, US launched in July 2014 to improve the knowledge of air-sea exchange and horizontal and vertical mixing in the upper ocean at different spatio-temporal scales in the Bay of Bengal. Three research cruises were conducted in the Bay of Bengal (15th June – 28th June 2014 using RV Revelle, 22nd August – 9th September 2014 using the ORV Sagar Nidhi, 24th November – 13th December 2014 ORV Sagar Nidhi) to study lateral and vertical gradients of temperature, salinity and density in the upper ocean of the Bay of Bengal. During this field campaign, very fine scale near surface thermohaline observation was collected. An air sea flux mooring was successfully deployed in December 2014. Further, more than 10000 underway CTD profilers and 500 line km of upper ocean ADCP current profiler data were collected.

4.1.4 SIBER Program:

The SIBER-India programme involves 11 different institutes and universities from India and has 14 projects under two main clusters (Open Ocean and Estuaries and Coasts). One of the main objectives of this programme was to establish long-term open ocean time series stations one each in the Arabian Sea (Arabian Sea Time Series; ASTS at 17 N 68 E) and the Bay of Bengal (Bay of Bengal Time Series; BoBTS at 18 N 89 E) with a view to assess the exchange of important elements between ocean and atmosphere of the northern Indian Ocean. Since the inception of the programme, the ASTS station was visited 10 times and the BoBTS station was visited 9 times. In addition to open ocean observations, monthly and seasonal measurements have also been carried out in various estuaries and coastal sites in their vicinity, both on the east and west coast of India. These include the CaTS stations (off

Goa), Mandovi, Zuari and Cochin estuaries on the west coast, and the Vellar-Coleroon Estuary, Parangipettai coastal waters, Hooghly, Saptamukhi, Thakuran and Matla estuaries on the east coast. In the last year (2013-14), the ASTS was visited twice, whereas the BoBTS was visited 3 times.

From the measurements carried out at ASTS station, it was observed that in general, the seawater temperature varied between 30.20 C at the surface and 1.81 C at 3000 m. The maximum surface temperature was observed during summer (May 2012) leading to stratification of the surface waters, whereas the minimum surface temperature was observed during the northeast monsoon (February 2013) with the mixed layer as deep as 50 m. The thermocline generally varied between 25 m and 200 m. On the other hand at the BoBTS station, the seawater temperature varied between 30.58 C at the surface and 2.25 C at 2160 m. In addition, the Arabian Sea showed a characteristic seasonal development of deep chlorophyll maximum in the upper water column, in winter period. This feature was observed in the dim light conditions (roughly 2.5% of the surface irradiance) between 60 and 80 m coinciding with the oxycline. Prochlorococcus spp. formed an important part of total autotrophic community in this zone. On an average 60% of autotrophic biomass (Chl-a) and 20% of primary production of upper 100 m was found at this depth. This highlights the importance of this feature in the northern Indian Ocean (Arabian Sea). This work is now extended to understand the physicochemical environment of this biological characteristic zone and the associated heterotrophic community. In addition we have also carried out various experiments to get a better insight in the cycling of nitrogen in the oxygen minimum zones of both these basins.

4.2 DATA SERVICES

The data centre at ESSO-INCOIS archived the real-time in-situ data from the various ocean observing systems. The data centre also

received data on XBT/XCTD, Met observations (NODPAC), OSCAT data (SAC), data under CTCZ programme from various agencies in delayed mode. A major accomplishment was establishment of improved process chains for INSAT data reception and data obtained from ESSO-NIOT, which has tremendously improved efficiency of management of heterogeneous data. The remote sensing data from various sensors flown on board Oceansat-2, NOAA series of satellites, METOP,

Terra and Aqua satellites are received in real-time and processed at the ground stations. Notable additions are the bio-geo-chemical and physical data obtained from various cruises conducted by ESSO-CMLRE (FORV Sagar Sampada) and equatorial current meter mooring data from the north Indian Ocean (NIO) region. Processing of the Physical, Chemical and Biological Oceanographic data received from ESSO-ICMAM for the period 2002-2007 is also under progress.

Table 4.1 – Data Collection and Archival

Institute / Programme	Parameters	Period of Observation	No. of Platforms / Stations Reported	Status
NIO (XBT, XCTD)	T Profiles	Jan - Nov 2014	152 profiles	Updated in the database
	T & S Profiles	Jan - Nov 2014	74 profiles	
NODPAC (Met Observations along Ship track)	Surface met parameters	Jan - Nov 2014	2011 records	Archived
ESSO-NIOT - NDBP (Moored buoys)	Met-Ocean parameters	Jan - Nov 2014	19 buoys	Updated in the database
NIO (Drifting buoys)	Met-Ocean parameters	Jan - Nov 2014	51 buoys	Updated in the database
PMEL (RAMA buoys)	Met-Ocean parameters	Jan - Nov 2014	20 buoys	Updated in the database
ESSO-INCOIS (Ship-mounted AWS)	Met parameters	Jan - Nov 2014	17 stations	Updated in the database
ESSO-INCOIS (Wave rider buoys)	Wave parameters	Jan - Nov 2014	10 stations	Updated in the database
ESSO-NIOT (HF RADAR)	Currents	Jan - Nov 2014	05 pairs of stations	Updated in the database
ESSO-INCOIS (onboard ORV SN – Wave Height Meter)	Wave Parameters	Jan - Nov 2014	1 station	Updated in the database
Argo CTD	Temperature and Salinity	Jan - Nov 2014	27271 profiles	Updated in the database
NIO (Equatorial Current Meter Mooring)	Currents	2000-2013	Archived	
ESSO-CMLRE (FORV Sagar Sampada)	Bio-geo-chemical	Cr. No. 201 to Cr. No. 320	Archived	
CTCZ	Met-Ocean	Monsoon 2013	Archived	

4.3 OCEAN INFORMATION ADVISORY SERVICES (O-IAS)

A number of ocean information and advisory services are being provided to cater to needs of various stakeholders in India and countries of the Indian Ocean region. These include,

(i)   Tsunami Advisories,

(ii)   Ocean State Forecast,

(iii)   Potential Fishing Zone Information.

These services of immense economic benefit are catered to needs of over 12 sectors of both private and public enterprises, which have been contributing substantially to the Gross Domestic Product (GDP) of the nation. The details of major accomplishments under various areas are as follows:

4.3.1 Tsunami Advisories:

The Indian Tsunami Early Warning Centre (ITEWC) had monitored 51 earthquakes of magnitude   6.5 during the period 1st January – 24th December 2014. Out of these 51 earthquakes, 3 earthquakes occurred in the Indian Ocean region. ITEWC assessed the tsunamigenic potential of these earthquakes and had declared that there would not be any tsunami threat for India. Being the Regional Tsunami Service Provider, the earthquake bulletins were also sent to the Indian Ocean Rim countries through e-mail, GTS, FAX and SMS. ITEWC participated in the mock tsunami drill IOWave14. The mock drill simulated tsunamis originating from two earthquake sources, one in the eastern Indian Ocean and the other in the northwestern Indian Ocean. ITEWC, ESSO-INCOIS along with ICG/IOTWS had organized a Regional Workshop on "Standard Operating Procedures for Tsunami Warning and Emergency Response for Northern and Western Indian Ocean Countries" during 23rd – 27th June 2014.

Table 4.2 – Performance Indicators of ITEWC

S. No.	Parameter	Targets	Performance
1	Elapse Time from EQ to Initial EQ info issuance (Local/Distant)	10/15 min	10.6 Minutes
2	Probability of Detection of IO EQ with Mw >= 6.5	100 %	Achieved
3	Accuracy of Hypocenter Location	within 30 km	~12 km
4	Accuracy of Hypocenter Depth	within 25 km	~18 km
5	Accuracy of Earthquake Mw Magnitude	0.3	~0.2
6	Reliability of RTWP Operations (Power, Computer, Communications)	99.5%	Achieved
7	Contact Information updated and Quarterly Communication tests		COMMs Test held on 11 June and 10 December, 2014

The ITEWC had organized a one day national workshop on "Indian Tsunami Early Warning System: Progress, Challenges and Future Road Map: A review of the developments during last decade" in commemoration of the Indian Ocean Tsunami on 26th December 2014 at ESSO-INCOIS, Hyderabad. Hon'ble Union Minister for Science and Technology and Earth Sciences, Dr. Harsh Vardhan had inaugurated the workshop.

(b)

Fig 4.4 - Inauguration of the national workshop on "Indian Tsunami Early Warning System: Progress, Challenges and Future Road Map: A review of the developments during last decade"

(c)

4.3.2 Ocean State Forecast:

Ocean State Forecast is provided for next five days for every six hours. In order to meet the operational requirements of various ports and harbours along the Indian coast, forecasts of waves, currents, winds and tides upto a distance of 50 km from the shoreline are being provided. The advisory bulletins on ocean state forecasts were issued to all the concerned locations along Andhra Pradesh, Odisha, West Bengal, Tamil Nadu and Andaman & Nicobar coasts during the cyclone Hudhud that occurred during 6th – 14th October 2014. The significant wave height off Vishakhapatnam recorded by the wave rider buoy reached a peak value of 8.1 m, which was in close agreement with the predicted wave height of 8.4 m. Predictions of the height of the storm surge and its inundation limits are also disseminated.

(a)
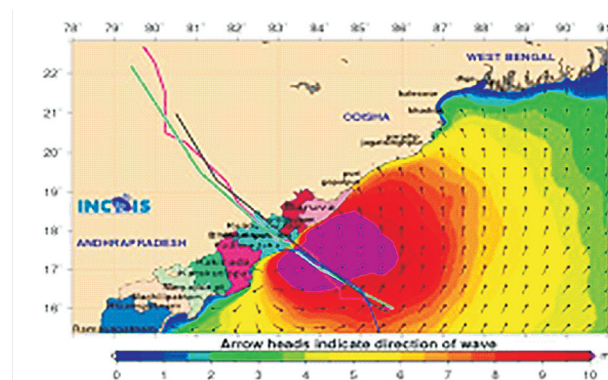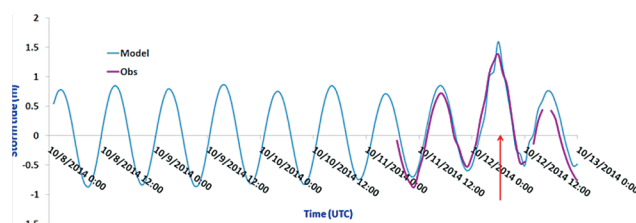
Fig 4.5 - The observed and forecasted Significant Wave Height (a); forecasted spatial variation of Significant Wave Height (b); predicted surge height is compared with tide-gauge observation (c); during the passage of cyclone Hudhud

The following new ocean forecast services have been launched in 2014 – Ocean state forecast specific to the Lakshadweep Islands and Okha, Jakhau and Veraval of the Gujarat coast are now disseminated in local languages (Malayalam and Gujarati) through SMS and e-mail.

4.3.3 Oil Spill Advisory:

The experimental set up of Online Oil Spill Advisory system has been launched on 12th May 2014 for the Indian Coast Guard, port authorities, maritime boards and other agencies involved in managing oil spills. The system is based on the oil spill trajectory model GNOME, which is forced by the predictions of ocean currents and surface wind.

4.3.4 Potential Fishing Zone Information:

About seven million people living along the Indian coastline depend on fishing for their

livelihood. A reliable and timely advisory on the potential zones of fish aggregation benefits the fishing community to reduce the time and effort spent in searching for the shoals of fish, thus improving their profitability and their socio-economic status. The PFZ advisories based on sea surface temperature and chlorophyll have been improved by integrating the surface current vectors. From 1st January 2014 onwards, advisories are being provided on a daily basis.

Tuna Fishery Advisories:

Multi-lingual Tuna fishery advisories based on satellite derived Sea Surface Temperature, Chlorophyll and Kd490 (Water Clarity) data are being continued (Fig 4.6). Tuna advisory maps now contain surface current (as quiver), mixed layer depth (as background raster) and depth of 20oC isotherm (as contour) since March, 2014. Like PFZ advisories, Tuna advisories are not being disseminated during adverse sea-state conditions.
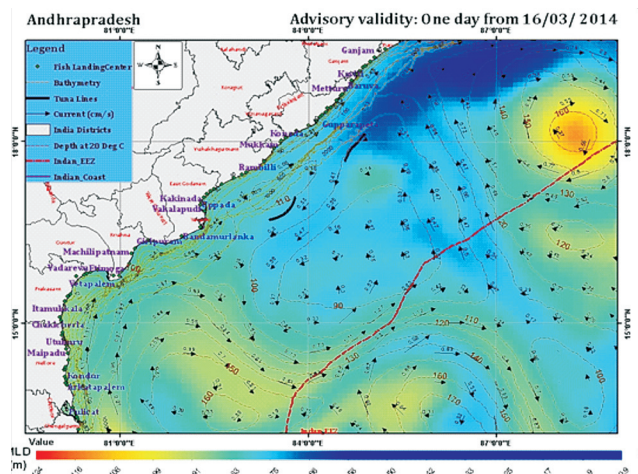
Fig 4.6 - A Tuna advisory map with newly introduced template

Satellite Telemetry of Tuna in the Indian seas (SATTUNA):

Under the multi-institutional SATTUNA project collaborated with CMFRI and FSI, 7 Yellowfin (Thunnus albacares) Tuna were tagged during the fishing season of 2014. Underwater migration routes of four Tuna were processed with Track-and-Loc program at CLS, France. It is found that the average distance between tagging and pop-off locations is about 200 km and with average daily movement up to 45 km.

4.3.5 Coral Bleach Alert System:

Coral reefs are ecologically sensitive and possess a wealth of information about the past climate. The health of coral reefs is important for fisheries as well. In order to monitor the health of the coral system, particularly to study the effect of temperature, a unique Coral Reef Bleach Alert System has been developed. One hundred and ten coral bleach advisories were generated and disseminated during 1st January 2014 to 26th December 2014. There were 12, 4, 4, 4 and 2 warning signals recorded for Lakshadweep, Andaman Islands, Nicobar Islands, Gulf of Mannar and Gulf of Kachchh respectively, during this period.

4.3.6 Dissemination of marine advisory services:

Potential Fishing Zone (PFZ) advisories and Ocean State Forecast (OSF) to the users are disseminated by M/s Tata Consultancy Services (TCS) Ltd., IFFCO (Indian Farmers Fertiliser Cooperative Limited), Kisan Sanchar Limited (IKSL) and Reliance Foundation.

• Android version of Fisher Friend Mobile Application (FFMA) was launched in Andhra Pradesh. This intuitive-GUI based app not only helps fishermen fetch data services such as PFZ and OSF (high-wave alerts) but also offers additional utilities such as real-time location and warning while approaching to International Boundary Line.

• A new website and ocean data portal, which was developed and launched on 1st September 2014. The new website has better presentation of the services and major improvements in the existing features. The responsive layout of the website is also accessible through a wider range of web browsers and devices, including mobiles and tablets.

4.4 OCEAN MODELLING

Towards accurate forecasting of various oceanic parameters, a high-resolution Operational Ocean Forecast and Reanalysis System, comprising a hierarchy of ocean models has been set up. Ocean models (ROMS and HYCOM) with varying horizontal resolution from approximately 25 km x 25 km outside the Indian Ocean to 2.25 km x 2.25 km near the coast have been set up. Data assimilation based on Ensemble Kalman Filter method is being developed to assimilate available ocean observations to the ROMS model. Bio-geochemical module is also being incorporated to the basin-scale ROMS setup. Wave model setup based on SWAN model has been operationalized for coastal waters of Puducherry at a spatial resolution of 250 m. The model takes boundary conditions from the multi-grid setup of Wavewatch III model predictions. Three-hourly outputs from the model include wave height and direction, swell height and direction apart from a new deliverable 'wave steepness'. The forecast is for a lead-time up to three days.

4.5 SATELLITE OCEANOGRAPHY ENHANCED PRODUCTIVITY FOLLOWING PASSAGE OF CYCLONE PHAILIN:

Analysis of Chlorophyll-a (Chl-a) and Sea Surface Temperature (SST) data from MODISA satellite showed during the Phailin cyclone elevated concentration of Chl-a and decrease in SST along the cyclone track. Even though, the changes were more significant in the near-shore waters, there were significant increase in Chl-a (710%) and decrease in SST (2.30C) in near-shore waters during the passage of the cyclone (Fig 4.7).
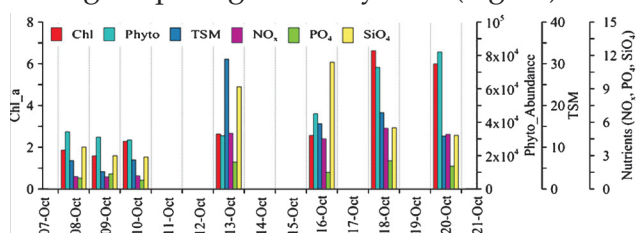
Fig 4.7 - Average distribution of Chl-a (mg/m3), phytoplankton abundance (cells/l), TSM (mg/l), NOx (µmol/l), PO4 (µmol/l) and SiO4 (µmol/l) during pre and post phases of Phailin

Consequence of Noctiluca Scintillans Red Tide Event on Physico-Chemical Properties:

A bloom of Noctiluca Scintillans (NS) was observed in a coastal region of the northwestern Bay of Bengal during April 2014, resulting brown to dull-red discoloration of surface waters. The peak cell density observed was 3.3×10^5 cells/l with low species diversity and low abundance of other phytoplankton during the study period. Nutrient depletion in these waters may have preconditioned the water column for proliferation of NS. Increased concentrations of ammonia during the latter phase of the NS bloom were indicative of active grazing and nutrient regeneration. Dissolved oxygen concentrations in sub-surface waters decreased to near hypoxia. Picoplankton contributed 66% of the total phytoplankton (chlorophyll) biomass during the early stage of the NS bloom but declined sharply in the waning phase due to grazing of NS.

4.6 COASTAL WATER QUALITY

4.6.1 Coastal Water Quality Monitoring:

Coastal water quality data of about 25 parameters including physical, chemical, biological and microbiological characteristics of water and sediment at select transects from 0 to 5 km offshore sector/ the entire coastal zone are collected. The salient findings/ observations pertaining to water quality monitoring during 2014-15 are as below:

Gujarat: Water quality of Vadinar was observed to be good with high levels of DO (6 – 7 mg/l) and low levels of nutrients and pathogenic bacteria. Water quality of Veraval harbour continued to be degraded with low DO, high nutrients and high BOD due to sewerage discharge and dumping of waste from fish processing industries including poor flushing. However, coastal waters off Veraval were observed to be normal. Water quality of the Tapi estuary shows high nutrients load, low DO and high levels of pathogenic bacteria (SFLO: 10 – 10,000 CFU/ml) in upper estuary, while DO

and nutrients were normal in middle and lower estuaries. This indicates that upper estuary is in stressed condition, due to domestic waste and sewerage discharges. However, in monsoon, though nutrients were high in estuary, DO was normal (6-7 mg/l), indicating adequate flushing due to rainfall. DO was normal and nutrients were high off Hazira indicating contamination due to industrial effluents and domestic wastes received through estuary.

Maharashtra: Water quality of Thane, Worli was observed to be moderate with high levels of nutrients (NO3: 0.7 - 124 μmol/l) and normal DO (2 - 7.9 mg/l). Water quality of the Thane creek was observed with lowest DO and high level of nutrients, indicating high organic discharges. Water quality in the lower Thane creek and off Mumbai showed normal DO and moderate levels of nutrients. Water quality of Ratnagiri and Malvan transect was observed to be good with normal values of DO (2 – 7 mg/l) and nitrate (0.1 - 7 μmol/l).

Goa: At Mandovi, water quality was observed to be good with normal level of DO (4 - 7mg/l), nutrients and pathogenic bacteria (SFLO: ND - 68 CFU/ml).

Karnataka: At Mangalore, water quality was observed to be good with normal levels of DO (2 – 7.4 mg/l) and nutrients (nitrate: 2 - 29.8 μmol/l). However, high levels of pathogenic bacteria (SFLO: NG-14600 CFU/ml) indicate contamination due to domestic sewerage discharge.

Kerala: At Kochi, water quality was observed to be moderately good with DO concentration ranging from 3.6 to 8 mg/l and nutrients (nitrate levels varying between 1.4 and 25.4 μmol/l). High levels of pathogenic bacteria (SFLO: NG-24500 CFU/ml) indicate contamination due to domestic wastes.

Odisha: At Dhamra, water quality was observed to be good with normal range of DO (7.3–8.2 mg/l) and nutrients. Levels of pathogenic bacteria (SFLO: 35-350 CFU/ml) indicate less contamination. At Paradip, water quality was observed to be good with high DO values (6.8 – 8.1 mg/l) and normal range of nutrients. Levels of phosphate at Paradip were high indicating contamination, possibly from industrial sources. High levels of pathogenic bacteria (SFLO: 50-3900 CFU/ml) indicate contamination due to domestic sewage.

Andhra Pradesh: At Kakinada, water quality was observed to be good with normal levels of DO (5.7-7.0 mg/l). Moderate levels of nutrients (NO3: 5.50 umol/l) indicate terrestrial organic load.

Tamil Nadu and Puducherry: Water quality of Ennore, Puducherry and Tuticorin were observed to be good with normal range of DO (4–6.8 mg/L) and nutrients (NO3: 3-12 umol/l). However, significantly high levels of pathogenic bacteria (SFLO: NG-4300 CFU/ml) were observed at many shore locations, indicating contamination due to domestic sewerage.

Andaman and Nicobar Islands: Water quality along Port Blair was observed to be good with normal levels of DO (5–7.7mg/L) and nutrients. However moderate level of pathogenic bacteria was observed at Phoenix Bay (SFLO: 177 CFU/ml).

4.6.2 Prediction of Water Quality along the Chennai Coast:

Water quality and sediment parameters for 36 locations along 30 km of Chennai coastline were monitored since, January 2013. Phytoplankton blooms of toxin producing Phaeocystis sp. was commonly reported due to discharge of untreated sewerage through Adyar and Coovum rivers. The bacterial analysis of 360 samples indicates that the E. Coli is predominant and the total coliforms are exceptionally higher (~ x107 CFU / ml) than the permissible limit of 100 CFU /100 ml. A model domain of 180 km2 (30 km 6 km) is set up for coastal waters taking account of the Adyar, Cooum and Ennore rivers and coastal structures of the Chennai port. Simulations and sensitivity analyses with different scenarios of pollutant loading at the coast were carried out

to develop an optimal model. Validation of the observed drifter tracks are carried out through Particle Tracking Modelling indicating that pollutants discharge through the Cooum river move southerly, reaching and affecting Marina beach.

Water quality model simulated for the northeast monsoon seasons representing 15th December 2013 to 2nd January 2014 calibrated with nine variables viz. (i)Dissolved Oxygen (DO); (ii)Biological Oxygen Demand (BOD); (iii)Chlorophyll-a (Chl-a); (iv)Ammonia (NH_3); (v)Nitrite (NO_2); (vi)Nitrate (NO_3); (vii) Phosphate (PO_4); (viii)Faecal coliforms (CF); and (ix)Total coliforms (CT). The observed DO (mg/l) concentration off Marina beach was 5.97 mg/l, while the mean simulated DO was 4.49 ranged between 3.58 ~ 6.87 mg/l during the time series observations (Fig 4.8).
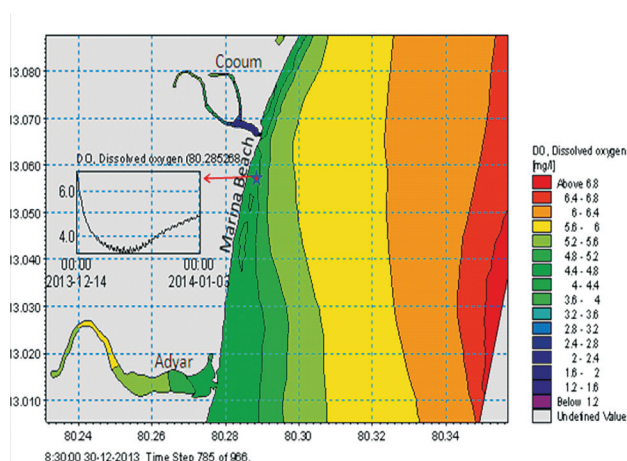
Fig 4.8 - Simulated values of Dissolved Oxygen (DO) in mg/l off Marina Beach

4.6.3 Marine Eco-toxicology to Develop Seawater Quality Criteria:

Bioassay experiments to develop Seawater Quality Criteria (SWQC) for Chennai (Ennore) coast were initiated for heavy metals like 'Nickel', 'Cobalt', 'Selenium' and Organophosphorus pesticide 'Chlorpyrifos'. Based on the bioassay test results, seawater quality criterion for Nickel was derived as 8.6 µg/l and experiments for Selenium and Chlorpyrifos are under progress. A few experiments were completed to study

the toxicity of Cobalt on (i)diatoms (Fig 4.9a), Odontella mobiliensis; (ii)copepods (Fig 4.9b), Acartia danae and Oithona similes; and (iii) striped mullet, Mugil cephalus.
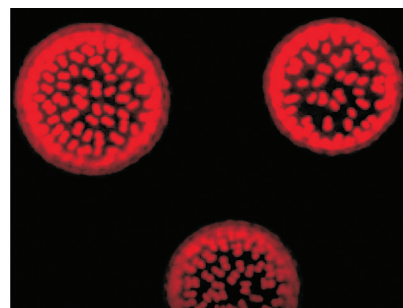
(a)

(b)

Fig 4.9 - Fluorescence microscopic photograph showing the chloroplast pigments of diatom Cosinodiscus centralis (a); Mass culture of copepod Acartia danae (b)

Ecotoxicological experiments were completed for Nickel on selected marine organisms viz., (i) Penaeus monodon, (ii) Therapon jarbua and (iii) Perna viridis and analysed histopathology. Further, biomarker enzyme assay for anti-oxidant enzymes viz., Esterase, Superoxide Dismutase (SOD) and Malate Dehydrogenase (MDH) for Nickel exposed to these test organisms was completed.

4.7 MARINE ECOSYSTEM MODELLING FOR SOUTHWESTERN COAST OF INDIA

The main objective is to understand the biogeochemical processes so as to quantify and predict the primary productivity along the coastal waters (within 50 m depth contour)

from Goa to Kanyakumari, covering an area of 30,000 sq. km (approx.). The data include field measurements, historical data sets, global data sets and satellite data. The ROMS model output data (3D flow field and sea levels, temperature, salinity) is being utilized for ecosystem model simulations.

The physical data collected at select inlets (Zuari, Mandovi, Honavar, Netravathi, Tejaswini, Azhikkal, Beypore, Valiazhikkal, Neendakara and Perumathura) along the southwest coast of India during the different seasons revealed that the cross-sectional depth profiles of the various inlets are mostly U-shaped except at Tejaswini and Neendakara. The highest and lowest residual discharge over a tidal cycle was observed as 117 m3/s at Tejaswini and 8 m3/s at Perumathura in November 2014. The surface water column of low density extended up to a subsurface depth of 20m especially in the offshore region of the Cochin backwaters, which suggests the extensive influence by the land run off in the 90 km coastal stretch between Paravoor and Alleppey.

The enrichment of coastal waters through river runoff may be influencing the biological production in the inshore waters. Blooms of Trichodesmium sp. were noticed in the northern sector of the Kerala coast during April/May 2014. High solar radiation, warm and stable waters, and low nutrient levels are the favourable conditions for the growth of Trichodesmium sp. In the Cochin backwaters, all the biogeochemical parameters (except Chl-a) showed significant ($p<0.05$) spatio-temporal variations.

4.8 COASTAL PROCESS AND SEDIMENT TRANSPORT STUDIES

4.8.1 Erosion Study at a Pilot Location:

The focus of the project is to understand the coastal processes responsible for erosion at a pilot location i.e. Vangurla-Ratnagiri. Towards understanding of nearshore hydrodynamics and sediment regime to investigate the causes of coastal erosion and shoreline changes, measurements are being carried out along South Maharashtra coast. Two wave rider buoys have been deployed at 15 m water depth (15 50' N; 73 34.14' E) and at 5 m water depth (15 50.6' N; 73 37.5' E) at off Vengurla (Sindhudurg District) to assess the wave transformation. The comparison of wave parameters measured at 5 and 15 m shows that the variation is large during the monsoon period and is marginal during the post-monsoon period.

Seasonal measurements at nine select stations of Suspended Sediment Concentration (SSC), sea bottom sediment, surface current, water levels etc., were carried out during September-October, 2014 to estimate the sediment transport. The SSCs are high at Vengurla waters during pre-monsoon when compared to the Ratnagiri waters (Fig 4.10). During monsoon period (September-October, 2014) reverse is the case where SSC is showing higher value at the Ratnagiri waters than the Vengurla coastal waters. During pre-monsoon months, deposition was occurred and beach width increased. But during monsoon period, beach width was drastically reduced due to erosion all along the beach due to high waves and currents.
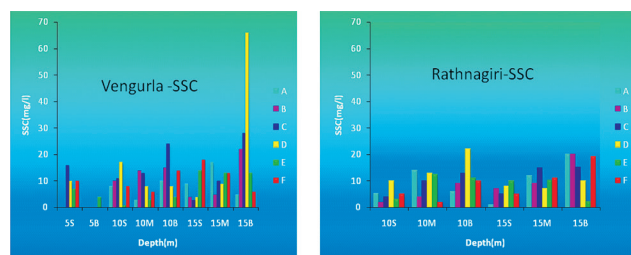

Fig 4.10 - SSC distribution during pre-monsoon at Vengurla and Ratnagiri coastal waters

4.8.2 Integrated Study of Estuary-Beach-Innershelf Dynamics:

The physical processes of the estuary, beach, nearshore and inner-shelf area are monitored on the southwest coast of India between Quilandy and Puthiyapa in northern Kerala.

4.8.3 Establishment and Maintenance of Wave Gauge Stations in the Coastal Waters of the South-est Coast of India:

Wave rider buoys were functional off Kollam (70 km north of Trivandrum) and off Kozhikode coast in north Kerala at distances of 9 and 12 km, respectively, from the shore in a water depth of 22 m. The total energy level at both the locations was found to be more or less of the same magnitude. The study provides some preliminary evidence of influence of the Shamal waves along the north Kerala coast. During the Shamal event (3rd June 2014) mixed sea condition was observed and detailed analysis of the data revealed the co-existence of locally generated wind waves from the northwest direction as well as southerly swells.

4.8.4 Integrated Island Management Plan (IIMP) for the Lakshadweep islands:

The Integrated Island Management Plans (IIMP) for all the inhabited islands of Lakshadweep viz. Agatti, Amini, Androth, Bitra, Chetlet, Kavaratti, Kadamat, Kalpeni, Kiltan and Minicoy have been completed following the guidelines provided in the Island Protection Zone Notification of MoEF, 2011.

4.9 SHORELINE VULNERABILITY MAPPING

Shoreline is constantly influenced by sea level variations, climate and ecosystems that occur over a wide range of time-scales, from geological time to short-lived extreme events such as storms. Shoreline change rates along Tamil Nadu, Andhra Pradesh and Kerala coast are computed using LANDSAT 5 (1990), LANDSAT 7 (2000), CARTOSAT-1 (2006, 2008), RESOURCESAT-1 LISS-III (2008) and RESOURCESAT-2 LISS-IV (2012/13) data. The maps are indexed in 1:25000 scale as per Survey of India (SoI) standard, considering their compatibility and portability to other Government of India (GoI) products (Fig 4.11). The district-wise shoreline information of the state of Andhra Pradesh is as given below:

Table 4.3 – Shoreline information for the state of Andhra Pradesh

S. No.	Name of District	Coastal Length (km)	Erosion (km)	Accretion (km)	Stable (km)
1	Nellore	167.1	53.6	83.0	30.5
2	Prakasam	92.3	16.0	62.7	13.7
3	Guntur	32.6	0.0	32.6	0.0
4	Krishna	83.5	30.5	47.5	5.6
5	West Godavari	14.8	7.3	7.3	0.2
6	East Godavari	139.7	74.3	57.2	8.2
7	Vishakhapatnam	125.6	73.1	16.5	36.0
8	Vizianagaram	26.9	9.9	6.9	10.2
9	Srikakulam	162.9	10.0	103.8	49.1
	Total	845.5*	274.7*	417.4*	153.4*

*excluding river mouth, deltaic region and coastal structures
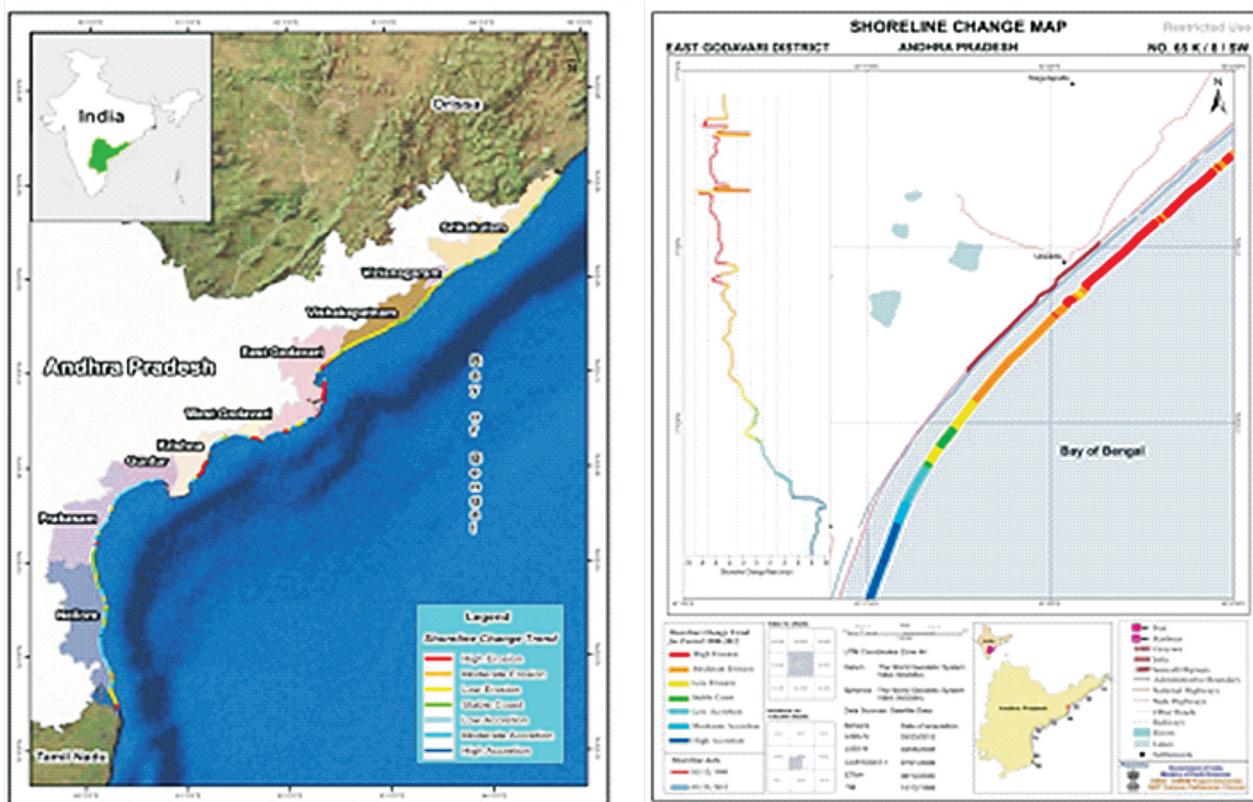
Fig 4.11 - Shoreline Change

4.10 MARINE LINING RESOURCES (MLR)

4.10.1 Monitoring and Modelling of Marine Ecosystems (MMME):

Benthic Biodiversity: From the continental shelf of the Andaman and Nicobar Islands, 324 species of macrobenthicpolychaetes have been identified so far. A majority of these species are first records for the region and three are new to the science. Among epifaunal echinoderms, a total of 132 species have been recorded in recent surveys along the Indian EEZ. Among the meiofaunal nematodes of the southeastern Arabian Sea, two new species were identified from recent surveys; Paramicrolaimusdamodarani (Chromadorida: Paramicrolaimidae) and Scaptrellafilicaudata (Monhysterida: Xyalidae). These two species represent the first report of their respective genera in the Indian Ocean (Fig 4.12).
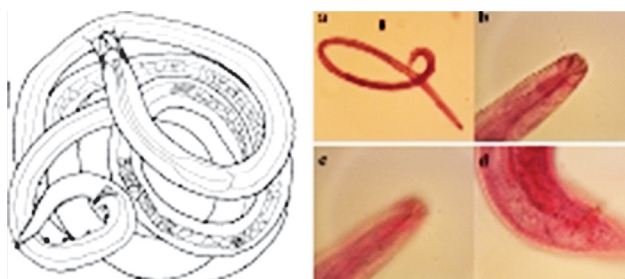
Fig 4.12 - Paramicrolaimusdamodarani sp. nov. holotype – Entire organism imaged using Camera Lucida (left); Scaptrellafilicaudata sp. nov. holotype – Entire organism, Head and Caudal region showing spicule (right)

Harmful Algal Blooms: A software package for the species identification of mixed algal bloom in the northern Arabian Sea using Remote Sensing techniques has been developed. Similar attempts were made for characterisation of red Noctiluca scintillans (without endosymbiont Pedinomonasnoctilucae) bloom observed along the coastal waters of the southeastern Arabian Sea (Mangalore, 50m) during late summer monsoon 2014 (September 2014).
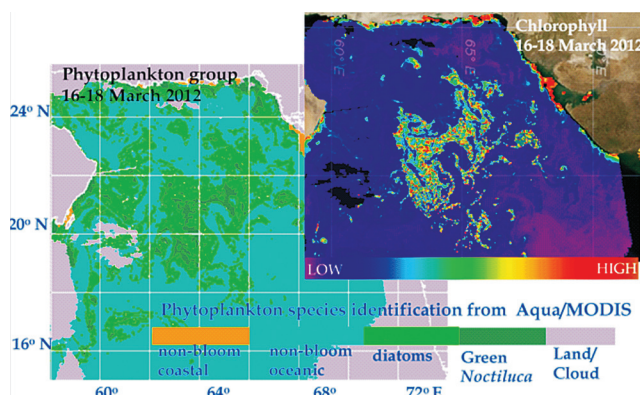
Fig 4.13 - Chlorophyll image (left) and phytoplankton species identification (below) using MODIS/ Aqua data

Studies on Physical Processes: The role of mesoscale cold core eddies (CCE) coexisting with the convective mixing processes in regulating the observed high biological production during Winter Inter Monsoon - Summer Inter Monsoon (October - March) is studied based on Satellite derived long-term data sets (2002-2013) on Chl-a, SSHA and SST. In-situ observations on one such eddy based on FORV Sagar Sampada cruise shows that the eddy generation is found to influence the entire north-eastern Arabian Sea dynamics and is a result of baroclinic instability caused due to the strong vertical shear in the horizontal flow. The study describes the CCE dynamics as well as its relative role on the biological processes apart from the basin scale processes during WIM-SIM.

4.10.2 Deep-Sea and Distant Water Fishery (DSDWF):

Taxonomic analysis of the deep sea fishes collected by the FORV Sagar Sampada leads to unwind the taxonomic ambiguity existing among different species of fishes. Indian Peristediids are represented by eight species of which four species were recorded as new from the Indian EEZ. Otolith microstructures are considered to be well known signatures of the micro-environmental variability of a fish. Otolith micro-structure analysis is initiated using ImageJ, for the parameters like area, perimeter, aspect ratio, feret's

diameter, bounding rectangle, centroid, kurtosis and integrated density which are the indices for better understanding of the shape morphometry.

4.10.3 Indian Ocean Biogeographic Information System (IndOBIS):

ESSO-CMLRE is the International Oceanographic Data and Information Exchange (IODE) recognized Regional Node of OBIS for the northern Indian Ocean. An on-line web-based portal – Indian Ocean Biogeographic Information System (IndOBIS) was established to archive all biodiversity information being collected through MLR program. At present the database has about 1,00,978 records of species occurrence from the Indian seas. In addition to the occurrence data, new records and new species reported from Indian Ocean region has been compiled as a database, which currently holds information of 1059 marine species. Using the DNA barcode techniques, two new species has been identified viz. Lyphiraperplexa and Spirulaspirula (Fig 4.14).

Fig 4.14 - Lyphiraperplexa (left); Spirulaspirula (right)

Two rare deep-sea anglerfish species Diceratiastrilobus and Bufoceratiasshaoi have been recorded for the first time from the Arabian Sea. Bufoceratiasshaoi represents the world's fifth known record.

4.10.4 Seawater Quality Monitoring Programme:

Successfully undertaken season wise Seawater Quality Monitoring Programme at Kavaratti hotspots for its Chemical Microbiological and Marine Biological parameters. Pollution

indicating species such as dianophysis caudata have been recorded in abundant numbers at Kochi waters during post-monsoon season.

Among Zoo benthos, Gastropods and Bivalves dominate in Kochi and Mangalore. Fish eggs are found to be declining in Kochi waters as compared to 2013. During summer to pre-monsoon, among the bacterial indicators, Escherichia coli have shown increasing trend in Kochi and decreasing trend in Mangalore, while Streptococcus faecalis has shown a decreasing trend in Kochi and an increasing trend in Mangalore. The presence of Vibrio sp. including cholerae in the Kavaratti coastal waters need surveillance, considering its potential for proliferation. Higher calcium carbonate content of sediment favoured an abundant percentage composition of benthic Foraminiferans such as Spiroloculina depressa and Bolivina tortuosa in the summer season at Kochi and Mangalore. Temporal bloom of Skeletonema coastatum in Mangalore is identified during day hours. Main influencing factor could be limiting nutrients-silicate and inorganic phosphate and comparatively low zooplankton density. In Kavaratti lagoon, phenomenon of bioluminescence is reported during night hours of post-monsoon season.

4.10.5 Technology Development:

A Field Research Station on marine ornamental fish production has been functioning at Agatti, Lakshadweep since 2009. The Centre maintains different variety of ornamental fishes for spawning and rearing experiments apart from clown and damsel fishes whose breeding has been perfected. A 10-day training workshop during the period 15th to 24th July 2014 on "Marine ornamental fish breeding and rearing at Lakshadweep Islands" was conducted for 20 numbers of graduate islanders on different topics of ornamental fisheries. A training manual titled "Hatchery Technology of Marine Ornamental Fishes – Breeding and Rearing at Lakshadweep Islands" was released during the Training Workshop. Around 1500 juveniles of clown fishes produced in the hatchery were handed over to the Society (MATFA), which has been formed under the Aegis of UT of Lakshadweep Administration Department of Women Welfare and Child Development for further rearing and marketing as an alternate source of income generation for islanders.

Fig 4.15 - Training Workshop at Lakshadweep

OCEAN TECHNOLOGY

Ocean Technology program aims at developing reliable indigenous technology to address the issues associated with harvesting of non-living and living resources from ocean, as well as protection of coast, construction of offshore structures and harnessing tidal, wave and thermal energy.

5.1   COASTAL ENGINEERING

5.1.1 Engineering Investigations for the Kalpasar Project:

The Kalpasar project aims at construction of a dam across the Gulf of Khambhat to impound the waters of Narmada river which otherwise drain into Arabian Sea. The numerical modelling for assessing the effect of dam on the hydrodynamics and morpho-dynamics of the Gulf is nearing completion. Based on the survey and model results, the design team has arrived at tentative dam cross-section and construction sequence.

5.1.2 Demonstration of Shore Protection Measures:

Due to natural and anthropogenic activities, the coastline of Tamil Nadu and Puducherry are severely eroded. In order to protect the coastline of Puducherry, a beach nourishment program was suggested after detailed studies, which on implementation by the Puducherry Government resulted in the formation of 60m wide beach. Based on the success of experimental beach nourishment, offshore reef with beach nourishment at Puducherry has been recommended. A detailed numerical study i.e., near shore wave climate, sediment transport and 2D Volume of Fluid (VOF) model

of reef were undertaken to arrive at conceptual design of offshore reef (Fig 5.1).
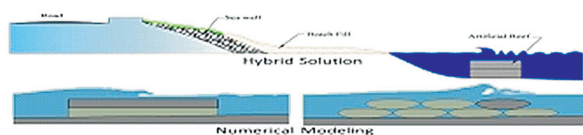
Fig 5.1 - Conceptual design of offshore reef for beach restoration

5.1.3 Technical Criteria Atlas:

Technical Criteria Atlas provides ready reference for parameters like tide, wave and water level in terms of return period/ extreme values required for preliminary planning, analysis and design of coastal infrastructures. The project was envisaged under three components – Tide, Wave and Storm Surge. The wave component was completed and the Wave Atlas of the Indian Coast has been published in September 2014.

5.2   DEEP SEA TECHNOLOGY AND OFFSHORE STRUCTURES

5.2.1 Polar Remotely Operable Vehicle (PROVe):

PROVe, a Polar Remotely Operable Vehicle with a depth rating of 500 m, is a technological tool for carrying out exploration activities in Polar Regions and in water depths up to 500 m. The vehicle weighing 170 kg and designed for a speed of 2 knots has been tested for performance in the Idukki Lake in Kerala in

July 2014, where the vehicle was navigated at a depth of 106 m. The vehicle system is qualified for performance under low temperature. The vehicle is being tested in Antarctica at present.

5.2.2 Integrated Mining System:

Integrated Mining Systems presently is in the process of upgrading the technology to 6000 m. An in-situ soil tester with vibration sinkage system to measure the sinkage in seabed due to vibrations has been developed. Various tests were conducted to establish the traction generated by the nodule mining machine at very low soil strengths. The results obtained will be useful in designing the final mining machine.

A team of scientists from Deep Sea Technology group of ESSO-NIOT retrieved heavy weight torpedo "Varunastra" from sea bed from a depth of 168 m along with personnel from Naval Science and Technology Laboratory (DRDO-NSTL). The operation lasted three days from 21st to 23rd December 2014. A ship-borne deep ocean Acoustic Sub-bottom Profiler (Fig 5.2) was used to locate the torpedo. This is the first time in the country that the torpedo is recovered from such depths.
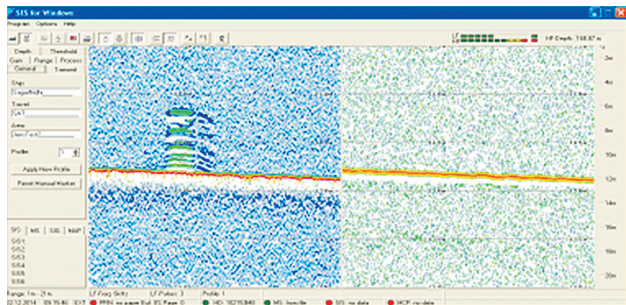
Fig 5.2 - Torpedo shaped object detected using sub-bottom profiler

5.3   OCEAN STRUCTURES

5.3.1   Feasibility Studies on Platform for Fixed and Offshore Wind Turbines:

Offshore wind energy is an ideal solution to meet the increasing energy demand.

Preliminary design of two substructure concepts, monopile and jacket based on static and earthquake analysis are studied. Pile soil interaction studies for Monopile substructure using Finite Element Software Plaxis-3D are completed. A large diameter monopile (6m) for offshore site of Jakhau, Gujarat was completed (Fig 5.3).
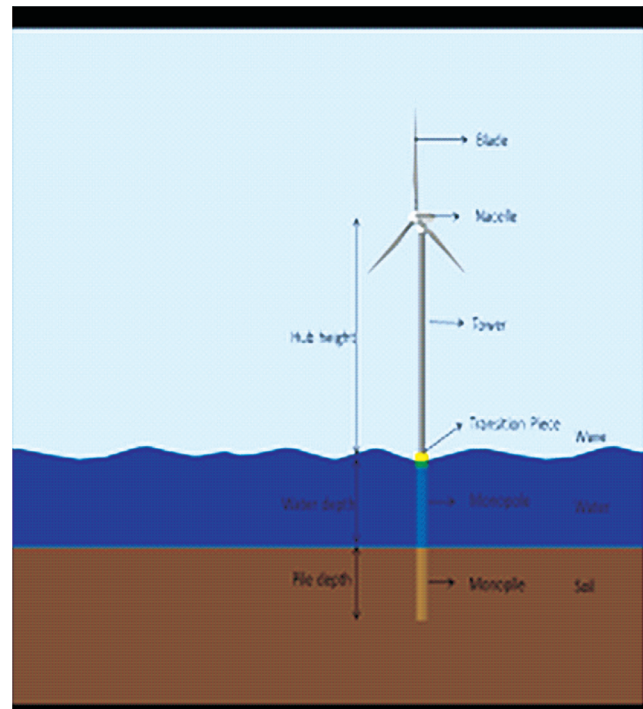
Fig 5.3 - Pile Soil interaction studies for large diameter monopile considering soil conditions at Jakhau

5.3.2 Wave Structure Interaction Studies:

The objective of this study was to estimate wave loads by measuring the wave pressure on caisson and similar structures. This will facilitate development of designs of such marine offshore structures. Full scale experiments are being conducted on intake structure at Agatti since March 2012 (Fig 5.4a) by deploying bottom mounted directional wave recorders to measure incident and reflected waves and array of pressure transducers fixed on the intake structure to measure the incident wave pressure. The wave pressure data analysis was carried out and the total pressure acting on the sump has been estimated for the pre-monsoon,

monsoon and post monsoon seasons. A regional wave model for the Lakshadweep Islands was setup with wind as forcing parameter. The model was validated with available offshore wave data measured by data buoy showing good agreement (Fig 5.4b).
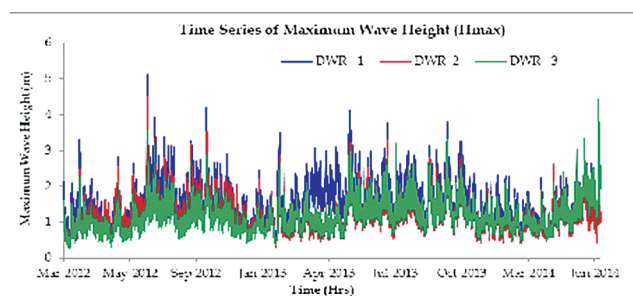
a
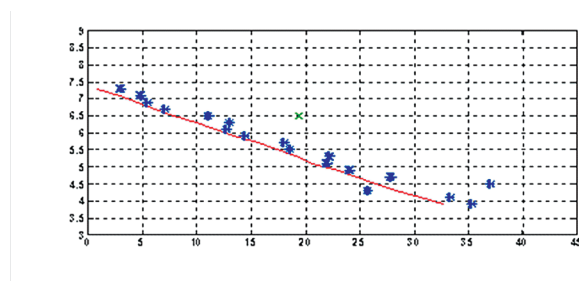
b

Fig 5.4 - Field (a) and numerical study (b) activities for estimation of wave force on caisson

5.3.3 Offshore Numerical Tank:

For the design of offshore structures such as floating plants, the major constraint is development of a platform, riser and its mooring, which has to be studied through various design options, simulations and model studies. It is proposed to establish an Offshore Numerical Tank with physical and technological infrastructure consisting of offshore wave and current basin, dynamic simulator, multi-body dynamic analysis software, 3D visualization facility and High Performance Computing system. Detailed report for design and execution of each component of Offshore Numerical Tank is in progress.

5.4 OCEAN ENERGY

5.4.1 Current Turbines:

With the insight gained from the earlier design and testing, straight bladed and helical current turbines were designed to generate 100 W at water velocity of 1.2 m/s from a permanent magnet generator coupled to the turbine. These turbines were also evaluated using 3D CFD. Through this development, a methodology for design of ocean current turbines has been successfully established. Open sea trials were carried out on Backward Bent Duct Buoy (BBDB) to assess its pneumatic efficiency – with single and multi-point moorings – at different levels of damping of oscillating water column. The data is being used to design improved turbines.

5. 5 MARINE BIOTECHNOLOGY

5.5.1 Marine Algal Biotechnology:

Intergeneric protoplast fusion was successfully done for the first time between the microalga Arthrospira platensis and the unicellular cyanobacterium Synechococcus sp. with a regeneration efficiency of 52%. Intergeneric hybrid obtained from the halophile green micro-algae Dunaliella salina and single-cell green alga Chlorella vulgaris was mass cultured using a custom designed media and a biomass of 3.68 ± 0.09 g/L on day 6 and lutein productivity of 16.43 ± 0.72 mg/L was obtained under phototrophic condition. Following the success of marine microalgal harvest using AC powered electro flocculation technique employing AC to DC power converter system, a solar powered electro flocculation system was developed and the efficiency of the system was tested in the lab as well as in the field for a maximum volume of 300 L/experiment by using direct solar DC power panels and supporting systems. This method reduced the cost of marine micro algal harvest.

5.5.2 Marine Microbial Biotechnology:

A gram positive piezo tolerant bacterium (Bacillus subtilis BBC 173) capable of

producing antimicrobial peptide was collected at a depth of 1400 m from the Bay of Bengal. This bacterial strain showed precise changes in growth profile, phospholipid fatty acid and antibacterial activity when exposed to aerobic conditions at specific pressure ranges (1, 50 and 100 bar) at 20°C and the cell size was found to elongate with increasing pressure and reached a maximum of 6-12 μm at 100 bar pressure (Fig 5.5). The microscopic observations revealed the morphological changes of the cell in the functional property from bactericidal to bacteriostatic activity during growth at high pressure. Filamentous deep sea bacteria Streptomyces sp. was isolated from 2000 m depth showed high pigment production and the GC-MS characterization revealed it as an Astaxanthin derivative.

Cells grown at 1 bar pressure   Cells grown at 50 bar   Cells grown at 100 bar
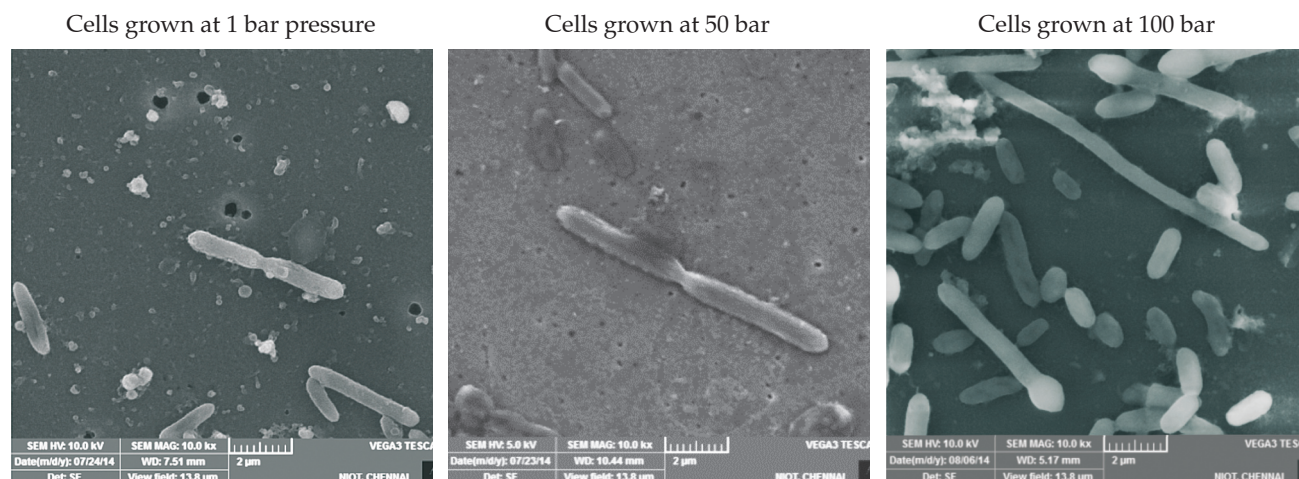
Fig 5.5 - SEM analysis of Bacillus subtilis showing the effect of pressure treatment conditions

5.5.3 Open Sea Cage Culture:

India is among the top 10 nations suitable for mariculture expansion in spite of constraints for technological solutions to develop appropriate culture systems, formulated diets and hatchery produced marine finfish seeds. Following the successful cobia harvest during May 2014 at Olaikuda, the traditional fishermen from Olaikuda were inspired to take up cage farming as their livelihood option. A training programme on open sea cage culture was conducted in November 2014 involving experts and stakeholders of cage farming and a video on the technical knowhow of "Open Sea Cage Culture" was released during the training.

5.6   MARINE SENSORS, ELECTRONICS AND OCEAN ACOUSTICS

5.6.1   Buried Object Scanning Sonar (BOSS):

A Buried Object Scanning Sonar System (BOSS) capable of operation in shallow waters (up to 10-20 m water depth) has been successfully developed in-house for detecting objects buried at a depth of 0-2 m in seabed (sandy/clay/mud).

5.6.2   Autonomous Underwater Profiling Drifter (AUPD):

The AUPD after extensive testing and ballasting, was deployed in the sea, which provided 135 profiles in 2014.

5.6.3   Inter Laboratory Comparison Test for Hydrophone Calibration:

The Acoustic Test Facility (ATF) is the only underwater acoustic facility in the country, which is accredited by the National Accreditation Board for Testing and Calibration Laboratories (NABL) for testing and calibration of transducers. Inter-

Laboratory Comparison Test was carried out with Internationally acclaimed laboratories, (i) Bundeswehr Technical Centre for Ships and Naval Weapons, Naval Technology and Research, Germany and (ii) Federal State Unitary Enterprise "Russian Metrological Institute of Technical Physics and Radio Engineering" (FSUE "VNIIFTRI"), Russia. National Physical Laboratory UK also carried out hydrophone calibration for comparison purpose. The results of comparison found that calibration are in conformity with the International standards and is at par with the internationally acclaimed laboratories.

5.6.4 Development of Vector Sensor and Array for Source Localization and Signal Estimation:

Vector sensors measure the acoustic pressure and the particle velocity components, and are normally configured as Vector Sensor Arrays (VSA). This type of sensor has the ability to provide information in both vertical and azimuthal directions. An accelerometer based vector sensor (inertial type) for measuring particle velocity and acoustic pressure has been developed jointly with M/s Keltron. The prototype vector sensor has been tested in ATF and the results are encouraging.

POLAR SCIENCE AND CRYOSPHERE

Studies in Antarctica, Arctic and in Southern Ocean are undertaken to enhance our understanding of the geological, atmosphere and biological processes and phenomena of the Polar Regions. Polar science has been increasingly contributing to our understanding of the world climate pattern, global oceanic circulation, the processes of the earth's upper atmosphere and phenomena, i.e., ozone hole, past and present climate change, etc. The Cryosphere is considered to be an integral part of the global climate system and is considered to respond to the changes faster than the other parts of the planet. Considering the multiple processes influencing the Cryospheric system, it is crucial to undertake integrated study of glaciers, and the information embedded in the ice core records including biogeochemical processes of the past.

6.1 SCIENTIFIC STUDIES IN ANTARCTICA

The Antarctica programme is a multi-disciplinary and multi-institutional programme. Scientific investigations and researches are undertaken to understand the various phenomena and processes in Antarctica and their link to the Indian region and global processes, particularly those of climate and weather. Various investigations and observations/monitoring for long periods in the icy continent and surrounding oceans have helped to enhance our understanding of tectonic history, and climate change processes.

6.1.1 Studies of Antarctica Cryosphere:

Polar Coastal Index - a new Proxy for Interpreting Sea Ice Variability: The Polar Coastal Index (PCI) study focuses on investigating the impact of regional factors on the interannual and seasonal Antarctica sea ice variability by defining a new PCI. The results suggest that the coupling between PCI and v-component of coastal wind is strong for East Antarctica and decreases along West Antarctica (Fig 6.1). The PCI is positively correlated with westerly zonal and southerly meridional winds in the coastal Ross Sea and along most of East Antarctica.
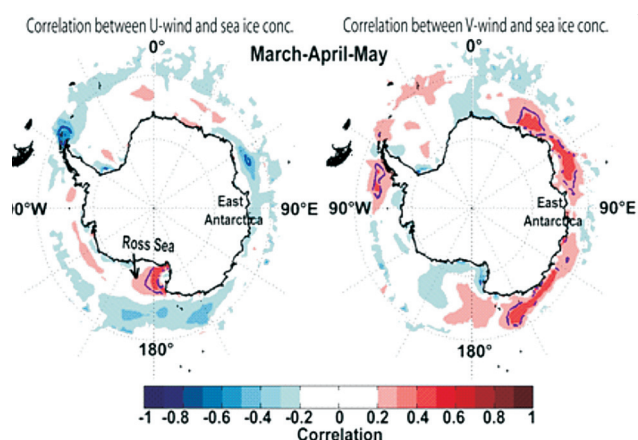
Fig 6.1 - Seasonal correlation of u- and v-wind components with sea ice concentration (SIC) - region where R is significant at 99% level is shown by dashed line

Recent Updates on Antarctica Sea Ice Variability and Trends: Sea ice extent analysis was carried out for five Antarctica sectors - the Weddell Sea, Indian Ocean, western Pacific Ocean, Ross Sea, and Bellingshausen and Amundsen Seas- utilizing the satellite passive-microwave data of 1979-2012 (Fig 6.2). The study reveals that the sea ice extent in the Southern Hemisphere (SH) as a whole has increased over the period by $1.3\pm0.3\%$ (16200 ± 2208 km2yr–1). In the last decade (2003-2012), the magnitude of the yearly-mean sea-ice extent trends is reduced by 68% as compared to the last 34-year trends

for the whole SH. The sea surface temperature (SST) in all the Antarctica sectors suggests that the observed negative SST trends during April – October plays an important role in increasing sea ice extent and concentration for SH.
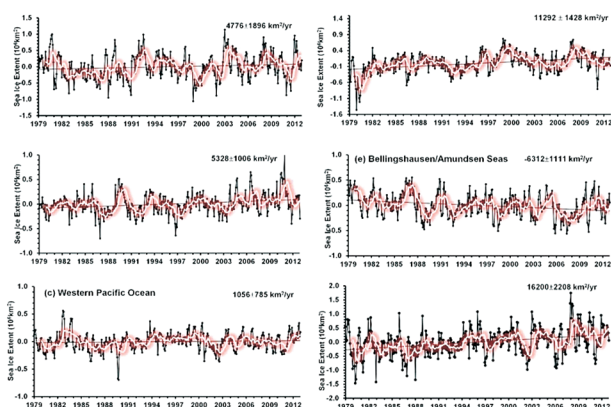
Fig 6.2 - Sea ice extent monthly deviation plots, with the corresponding lines of least squares fit and 12-months moving average, for November 1978 through December 2012, calculated from SMMR, SSMI, and SSMIS satellite data

Ice Core Drilling in the Central Dronning Maud Land: A major field campaign was conducted for the retrieval of ice cores for climate reconstruction. For the first time, 101.4 m ice core was recovered from the central Dronning Maud Land (Fig 6.3); Core - IND 33/B8; Location - 71 30'32.7''N and 10 11'52.3''E; Elevation - 1506 m. The sensors were connected to a multichannel data-logger system that will continuously record the temperatures at various depths throughout the year. The IND 33/B8 ice core site thus not only offers longer climate records, but would additionally provide long-term thermal history in the region.

Fig 6.3 - Ice core drilling at the Dronning Maud Land, Antarctica

Photo-biogeochemical Process Measurements and Snow/Ice Sampling in the Larsemann Hills: To understand the influence of biogeochemical processes influencing the Antarctic Cryospheric system, a systematic campaign involving photo-biochemical field experiments, biogeochemical process measurements and sampling of the cryoconite holes and blue ice regions was carried out during 2013-14 austral summer in the Larsemann Hills, with Bharati as a base station. As part of this, photo-biochemical field experiments were carried out on large numbers of snow cores and surface snow samples that were collected along a coast to inland transect.3

6.1.2 Environmental Records from Marine and Lacustrine Systems

Biogeochemistry and Paleo-environmental Studies in Antarctica: The work was carried out to understand the impact of icebergs and sea-ice on phytoplankton community and their role in biogeochemical cycles in coastal Antarctica, to understand the biogeochemistry of lakes in the Larsemann Hills, to reconstruct the paleolimnological records from the Larsemann Hills lakes and to study the paleoenvironment of the Prydz Bay. Surface water samples were collected along three different transects (Capetown-Larsemann Hills; Larsemann Hills-India Bay and India Bay-Capetown) in order to understand the Southern Ocean biogeochemistry and also to compare with our previous datasets of 2009, 2010 and 2012. At the Larsemann Hills water sampling was carried out in 86 lakes over different islands. Seventeen sediment cores were collected from seven different lakes in the Larsemann Hills (Fig 6.4). The length of the core varied between 30 cm to 2.2 m making this the largest collection of sediment cores in a single expedition and the longest sediment core ever collected from the Larsemann Hills and Schirmacher Oasis by the Indian scientists.
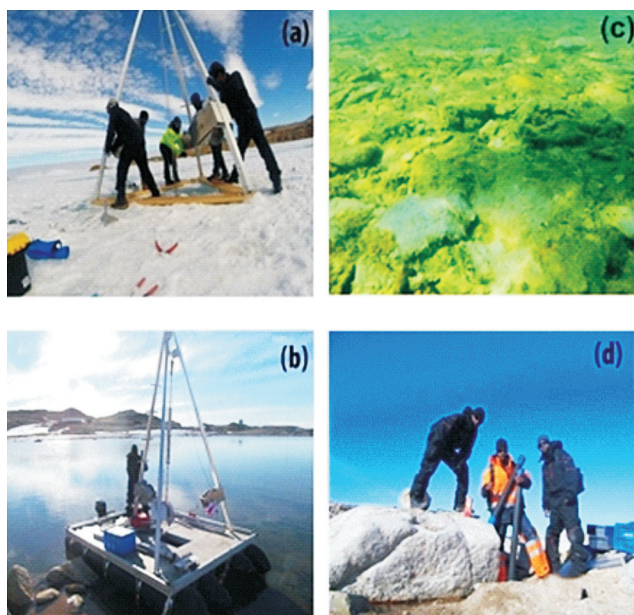
Fig 6.4 (a) Dry coring on the fast-ice in the Quilty Bay region; (b) Piston coring device on the floating platform used for coring the Lakes in the Larsemann Hills; (c) Underwater photograph of a lake in the Larsemann Hills showing widespread cover of algal mats; (d) Two sediment cores measuring 95 cm and 140 cm, respectively, collected from the Stepped Lake near Progress station.

Organic Geochemical Properties of Sediments from the Sandy Lake, Antarctica: With an objective to understand the past environmental conditions, organic and geochemical studies were carried out on sediments from the Sandy Lake, Schirmacher Oasis. The carbon and nitrogen values and their isotopic compositions were determined using stable isotopic ratio mass spectrometer attached with an elemental analyser. The isotopic variations are marginal for the entire glacial period (28 to 15 ky BP) suggesting an intense cold period. The climate has shown abrupt variations between 17 and 11 ky BP suggesting a minor rejig during the deglacial transition to attain the Holocene optimum conditions. The abrupt increase in Corg%, 15N and 13C beginning at ~9 ky BP suggests that the Schirmacher Oasis began to respond to deglaciation only after the onset of warmer conditions, i.e., optimum Holocene conditions. The Corg record is consistent with the summer insolation at 65 S, and along with

other records is indicative of insolation driven productivity over the region (Fig 6.5). The proxy records of productivity further indicate that the warming in the Schirmacher Oasis was coeval with the insolation.
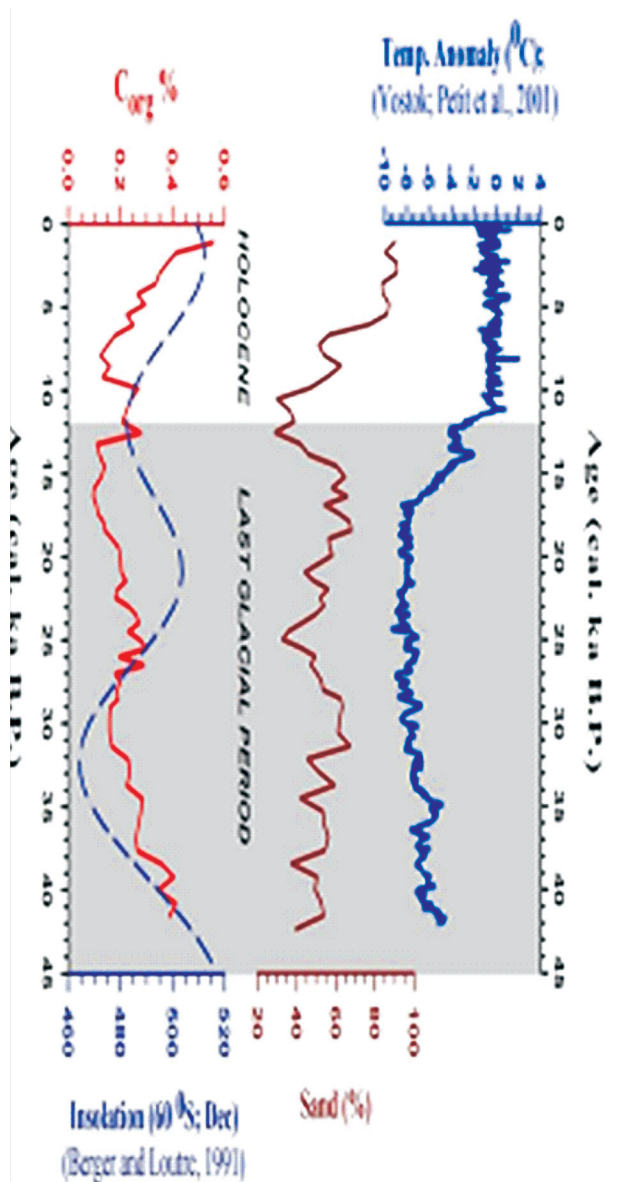
Fig 6.5 - Organic Geochemical Properties of Sediments from the Sandy Lake, Antarctica

6.1.3 Atmospheric Studies in Antarctica

Installation of Moveable Atmospheric Radar for Antarctica (MARA) at Maitri: Atmospheric radar can provide continuous measurements of full height profiles of turbulence, waves, winds and static stability. These information

can be used to identify stable layers, turbulent layers and tropopause folds which can be used to test (and ultimately improve) modeling of the vertical transport and mixing processes between the stratosphere and troposphere, between free troposphere and boundary layer and between the boundary layer and land/ice/ocean surface.

Fig 6.6 - MARA with Maitri in the background

A Moveable Atmospheric Radar for Antarctica (MARA) was installed at Maitri station during the summer season 2013-14, as a collaborative endeavour between ESSO-NCAOR, Swedish Institute of Space Physics, and ISRO-NARL, Tirupati (Fig 6.6). MARA, provides continuous measurements of full height profiles of turbulence, waves, winds and static stability in the boundary layer, free troposphere, lower stratosphere and in the mesosphere near mesopause.

6.1.4 Operations, Management And Research Support for the Antarctica Expeditions

XXXIII Indian Scientific Expedition to Antarctica: The XXXIII (33rd) Indian Scientific Expedition to Antarctica was flagged off from Goa on 31st October 2013. A total of 151 expedition members from 22 different organizations traveled in and out of Antarctica in two round trips of ice class chartered expedition vessel MV Ivan Papanin as well as 10 chartered intercontinental flights and a number of intra-continental flights between Maitri and Bharati under the aegis of DROMLAN

consortium (Fig 6.7). Some of the major projects implemented by the Indian Scientists at Maitri and Bharati during the summer through winter months of 2013-14 comprise (by the agencies indicated against each):

- Continuous Operation of Permanent GPS Tracking Station and the permanent Seismological Observatory at Maitri (NGRI);

- Cosmic Ray Dosimetry (BARC);

- Study of temporal and spatial variations of energy balance of different snow and ice media using RRTS (SASE);

- Geological mapping (1:10000 scale) in the central part of the Schirmacher Range, East Antarctica (GSI);

- Geological and glaciological Investigations of the Larsemann Hills (including all the islands and peninsulas (GSI);

- Temporal and Spatial Variations of meteorological parameters and Energy Budget of Different Snow-Ice Media in Antarctica Using Remote Weather Station and Satellite Remote Sensing data (SASE);

- Observation of meteorological parameters and ozone observations (ESSO-IMD).

Fig 6.7 - A view of the expedition vessel MV Ivan Papanin stationed in the Quilty Bay at a distance of 300 metres away from the Bharati station's fuel farm

Environmental Clean-up of the Maitri Station Premises: In pursuance of Article VII & XIV of the protocol on Environmental Protection of Antarctica Treaty, a taskforce was sent to the Maitri station for its environmental clean-up. The team spent about 106 days and managed to segregate, collect and pack the scrap (metal/ wood/ batteries / clothing / unserviceable spares / plastics etc.) materials of approximately 87 metric tons and 12 old unserviceable vehicles (snowmobile / earth movers/ cranes etc.) weighing about 37 metric tons for back loading.

Visit of Japanese Scientists at Maitri: A team of four Japanese scientists headed by Dr. Masaki Okada (National Institute of Polar Research) visited Maitri to have an overview of the scientific activities at the station with special emphasis on the upper atmospheric sciences and the gravity measurements.

XXXIV Indian Scientific Expedition to Antarctica: As in the previous years, the expedition members were sent in different batches, commencing November 2014. The studies would cover (i) Atmospheric Science & Meteorology, (ii) Biology & Environmental Sciences (iii) Human Physiology Medicine (iv) Earth Science & Glaciology (v) Students Participation Scheme.

6.2   SCIENTIFIC STUDIES IN ARCTIC

6.2.1 Studies of Arctic Cryosphere:

Mass budget and dynamics of one of the glaciers of Ny-Ålesund (Svalbaard, Norway) - the Vestre Broggerbreen glacier - are being monitored to understand the dynamics and mass budget of the Arctic glaciers in the context of climate change. During 2013-14, the stakes installed during the previous years on the glacier were identified and accumulation was measured. During the summer of 2014, few more stakes were installed to increase the data point and to enhance the annual mass balance accuracy. Several pits were made to record the snow stratification and for snow density measurements (Fig 6.8). The

studies carried out on the Vestre Broggerbreen glacier (area 4.69 km2) suggest a negative annual mass balance (0.94 mweq) as compared to the previous year (0.6 mweq).

Fig 6.8 - Snow pit for stratigraphy at the accumulation zone

6.2.2 Environmental Records from Marine and Lacustrine Systems

Kongsfjorden Monitoring Program, Ny-Ålesund, the Arctic: This is a major multidisciplinary and multi-institutional initiative that seeks to understand the response of an Arctic fjord to seasonal, annual and long-term changes in its hydrography, hydrochemistry and biota. As in the previous years, hydrographic, water-column chemistry and biological data were collected from the Kongsfjorden during the summer/early winter seasons (May-November) of 2013. The vertical distribution of the temperature and salinity along the fjord during the summer, 2013 showed a warmer Kongsfjorden compared to the previous seasons of 2011 and 2012. An increased volume of warm Atlantic waters was found inside the fjord compared to 2011 and 2012.

Deployment of India's First Moored Observatory (IndARC) in the Arctic: On the 23rd July 2014, a team of scientists from ESSO-NCAOR, ESSO-NIOT and the Norwegian Polar Institute (NPI) successfully deployed India's first multi-sensor moored sub-surface observatory from the NPI vessel "Lance"

at 78o56'N and 12oE in the inner part of Kongsfjorden, at a water depth of ~180 m.

6.2.3 Atmospheric Studies in the Arctic Regions

Precipitation Studies in the Arctic: Precipitation in form of snowfall and rainfall is an important part of the hydrological system as it modulates the energy, water cycle and ecosystem and thus has a large socio-economic impact as well. Considering the difficulties in measuring the precipitation in the polar regions by conventional methods, a Micro Rain Radar has been installed for the measurement of precipitation at one minute intervals. Combining this information with an accumulation rate will give the information of falling precipitation. The instrument is currently operational for continuous data collection and the data is accessed at ESSO-NCAOR.

6.2.4 Operations, Management and Research Support for the Arctic Expeditions:

During the year 2014, the Indian station "Himadri" was manned for 169 days and a total of 27 scientists visited Ny-Ålesund under 13 different projects. The studies were restricted to the following focus areas:

- Atmospheric Science with special reference to study of aerosols and precipitation measurements over the Arctic.

- Biogeochemical studies in the Kongsfjorden.

- Glacier-Mass balance studies and snow-air flux measurements.

The details of the scientific projects taken up during the Expeditions are: Long term monitoring of the Kongsfjorden system of Arctic region for climate change studies; Investigation of dissolved as well as sedimentary forms of organic matter in the Kongsfjorden, an Arctic fjord; Investigations of atmospheric aerosols and their characterization over the Arctic

during summer season; Past climate variability from the Kongsfjorden sediments etc.

6.3 OCEANOGRAPHY AND BIOGEOCHEMISTRY OF THE SOUTHERN OCEAN

Ever since the pilot expedition in 2004, to date, seven such expeditions have been successfully mounted, essentially as multi-disciplinary, multi-institutional endeavors involving a host of national institutions and universities. Some of the salient results of the studies carried out during the year on the data collected during the previous two expeditions to the Indian Ocean sector of the Southern Ocean are described below:

6.3.1 Compositional Variability of Aerosols over Southern Ocean:

Chemical and mass concentrations of ions measured in nine size classes (0.4 - >10 μm) of aerosols reveal that mass concentrations of coarse aerosols increase towards the Antarctic coast. The concentration of the coarse aerosols is well correlated with humidity, supporting growth of aerosol particles with increased humidity. Results of factor analysis indicates that the Southern Indian Ocean (10 S to 59 S) has the highest loading of anthropogenic and sea salt aerosols, leading to the formation of secondary aerosols through gas to particle transformations.

6.3.2 Glacial-interglacial Variability of Antarctica Sea-ice Extent and Frontal Systems – implications for diatom abundance and size:

Antarctica sea-ice extent along with the Southern Ocean biological productivity varied considerably during the glacial-interglacial periods. From the records of sea-ice diatoms, it may be inferred that there was a seasonal shift in the Antarctica winter sea-ice limit and Polar Front up to the present Polar Frontal Zone during the marine isotopic stage MIS2, late MIS 3 and MIS4. Lower abundance of the sea-ice diatom during MIS1 and 5 is possibly

a result of retreating Antarctica winter sea-ice limit. During glacial periods higher diatom abundance and larger F. kerguelensis length and T. lentiginosa radius are analogous to the variation of winter sea-ice limit. This implies that northward shift of winter sea-ice limit along with circumpolar upwelling belt probably provided nutrient replete condition to the study area and could have fuelled the rise in diatom abundance and size during glacial period.

6.3.3 Inter-seasonal Biogeochemical Changes in Indian Sector of the Southern Ocean:

This study aims at understanding the physical and biological processes controlling the concentrations of pCO_2 and O_2 in the surface mixed layer in the Indian sector of the Southern Ocean. The data obtained for the transition period from austral summer to early winter during three different months January (2012), February (2010) and March (2009) were compared and the results were categorized according to distinct hydrographic regions defined by oceanic fronts. The pCO_2 showed large and contrasting inter-seasonal changes between these three months and the averaged pCO_2 increased from about 286 µatm in January to 337 µatm in March.

6.3.4 Latitudinal Variation of δ13C and δ15N in Particulate Organic Matter (POM) from Surface Waters of the Indian Sector of the Southern Ocean and the Tropical Indian Ocean:

This study was carried out to understand the factors influencing the distribution of 13C and 15N of particulate organic matter (POM) in the surface waters of the Indian sector of the Southern Ocean and the Tropical Indian Ocean. Surface water samples collected at 21 locations between 10 N to 53 S onboard RV Sagar Nidhi were filtered through pre-washed GF/F filters. The isotopic analyses of the surface samples showed higher values of 13C of POM in the subtropical surface waters (40 S – 43 S), mainly due to change in phytoplankton community structure. However, 13C of POM decreased towards the polar waters, and had a linear correlation with temperature and an inverse correlation with tCO_2 beyond 40 S indicating photosynthetic isotopic fractionation in presence of lower temperature, higher dissolution of and availability of nutrients.

6.3.5 Studies in the South-Western Tropical Indian Ocean:

As a part of the Southern Ocean studies, a multi-institutional cruise in the South-western Tropical Indian Ocean (SWTIO, between 5 S to 10 S and 60 E to 75 E) was undertaken on board ORV Sagar Nidhi during 29th May to 27th June 2014. Studies carried out indicate that it is a unique area, which experiences year-round upwelling, which is a response to the upward Ekman pumping prevalent in this region. Satellite data, model results and Argo temperature and salinity data (from 2000 to 2010) were used to study the seasonal surface chlorophyll, a-Chl variability in the SCTR.

6.3.6 Operations, Management and Research Support for the Expeditions to the Southern Ocean:

The Eighth Indian Scientific Expedition to the Southern Ocean is proposed to be taken up during January-March 2015 on board ORV Sagar Nidhi. The projects would be all continuing in nature, except item (vii), given below:

i. Hydrodynamics and Biogeochemistry of the Indian Ocean sector of the Southern Ocean.

ii. Photosynthetic efficiency of phytoplankton in the India sector of the Southern Ocean during austral summer.

iii. Understanding sources of sediments and processes through the study of suspended

particulate matter and surface & sub-surface of the Southern Ocean.

iv. Investigations on the bio-optical characteristics of the Southern Ocean coastal waters using absorption spectra of phytoplankton size fractions.

v. Understanding the impact of global warming on surface and bottom water of Antarctica coastline using sediment core study.

vi. Ecology, diversity and molecular phylogency of marine actinobacteria from STF, PF and AZ of the Indian sector of the Southern Ocean.

vii. Oceanic volatiles and their impact on atmospheric halogens and cloud-forming aerosols in the southern ocean - Indian Institute of Tropical Meteorology - New Study.

viii. Biodiversity studies along Indian sector of the Southern Ocean.

6.4 HIMALAYAN CRYOSPHERE STUDIES

The programme aims at studying the dynamics and the rate of change of selected Himalayan glaciers and their impact on hydrology, ecology and climate and vice-versa. During 2013-14, a network of 33 stakes were established over approximately 30 km2 area of glacier surface of the Sutri Dhaka and the Batal glaciers in Himachal Pradesh for monitoring ablation/accumulation. During the current year, the studies were extended to five more glaciers covering a total of 306 km2 area, which constitutes ~43% of total glacier area of basin. It has been observed that the vertical gradient of ablation rate is contrastingly opposite in the two glaciers, reflecting the significant control of debris thickness and their distribution over glacier surface on the ablation rates. While different thickness of debris have attenuated melting rates up to 70% of total melting, the debris cover <2cm thickness has accelerated melting up to 10% of the total melting. Melt ratio reveals that about 90% and 5% of the ablation area has experienced inhibited melting in the Batal and Sutri Dhaka glaciers, respectively. A terminus retreat of 373 m and 579 m with an average of 7.3ma-1 and 11.4ma-1 have been observed for Batal and Sutri Dhaka glacier for the period 1962–2013, respectively (Fig 6.9).
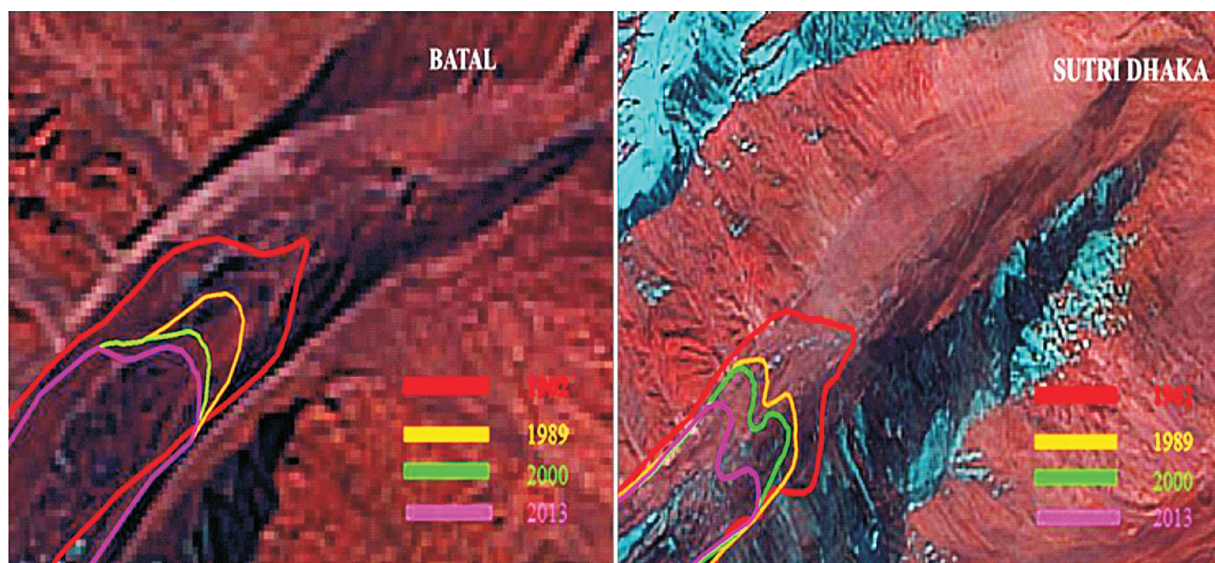
Fig 6.9 - Terminus shifting of Batal and Sutri Dhaka glaciers during 1962-2013

OCEAN SURVEY AND MINERAL RESOURCES

India has a large Exclusive Economic Zone (EEZ) of about two million sq. km. The exploration for energy, minerals and food are prime requirement. A systematic program comprising of bathymetric survey along with gravity, magnetic and seismic surveys, sample collection and analysis of the Indian EEZ and in the Indian ocean has been undertaken.

7.1 GEOSCIENTIFIC STUDIES OF THE EXCLUSIVE ECONOMIC ZONE (EEZ)

The primary objective is to prepare a comprehensive high-resolution seabed bathymetric map of the entire Indian EEZ using the multi-beam swath bathymetric systems. Systematic sampling of the seabed and sub-seabed was carried out to understand sediment characteristics and dynamics, and possibly assess the potential of seabed resources. Since inception of this programme, an area of 9,31,161 km2 in water depths beyond 500 m and 16,262 km2 in shallower depths have been mapped. During the year 2014-15, four cruises were undertaken and a total area of ~ 84,020 km2 of deep-water in the Arabian sea and Bay of Bengal have been covered and over 10 sediment core samples have been collected from the surveyed area.

7.2 DELINEATION OF INDIA'S CONTINENTAL SHELF

The Indian Continental Shelf programme seeks to gather, analyse and document the requisite scientific and technical information that would help define and delineate the country's continental shelf boundaries beyond 200 nautical miles under the provisions of the United Nations Convention on the Law of the Sea (UNCLOS). The activities have been largely confined to providing additional information/clarifications sought by the UN on the first partial submission made by India in 2009, preparation of the first draft of the second partial submission for an extended shelf and providing technical inputs in response to the arbitration proceedings initiated by Bangladesh for maritime boundary delimitation in the Bay of Bengal. Multi-channel seismic reflection data from the Bay of Bengal is also being acquired since November 2014 on board R/v Geo Hindsagar to cater to the additional requirements of the Continental Shelf programme. A total of 3670-line km of data has been collected during November-December 2014.

7.3 INDIAN OCEAN DEEP-DRILLING PROGRAMME (IODP)

A scientific proposal entitled "Deep sea drilling in the Arabian Sea: Discovering the techno-climatic unknowns" has been undertaken under the "International Ocean Discovery Program" for initiation during early March-May 2015 on board D/v JOIDES Resolution. The aim of the project is to recover deep sea cores from four different sites in the Arabian Sea, to address reconstructing the erosion response of the western Himalayas to proposed monsoon strengthening at 8 Ma; to understand offshore extension of Deccan Traps and the Mesozoic sediments beneath them and the nature of crust in the Laxmi basin area of the Arabian Sea (Fig 7.1).
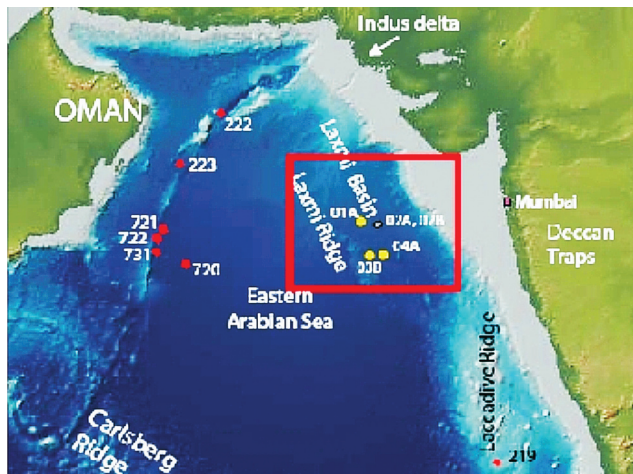
Fig 7.1 - Map showing identified area for deep sea drilling in the Arabian Sea

Multibeam bathymetric surveys have already been carried out at the planned drill sites. 2-d seismic reflection data acquisition covering 2540 line km in the Laxmi Basin area was also carried out.

7.4 GAS HYDRATES EXPLORATION

The following studies were undertaken:

i. <u>Extraction Modelling by Thermal Method</u> – Mathematical modelling was done to estimate the effectiveness of in-suite electro thermal heating technique for methane extraction from gas hydrate reservoirs in the KG basin. Energy balance calculations show that the energy supply to produce is in the ratio of 1:3.5.

ii. <u>Extraction Modelling by Depressurisation</u> – Mathematical modelling was done to estimate the effectiveness of depressurisation based technique for methane extraction. It is identified that a depressurisation with a P of 80 to 90 bar is required for sustained dissociation of gas hydrates.

iii. <u>Appraisal of gas-hydrates and free-gas from acoustic impedance and AVA modelling in fractured media in the Krishna-Godavari (KG) basin</u> – An attempt was made to understand the nature of distribution and estimate the saturation of gas-hydrates in fractured media. Using the well log data, a relation between acoustic impedance and porosity was established. By using the Archie's Law, the saturation of gas hydrates just above the BSR was estimated, which varies laterally between 10% to 28% along the seismic line. The modelling result shows not only varying saturation of free gas (<1.5%) below the BSR but also validates the saturation of gas hydrates estimates from impedance inversion of seismic data.

iv. <u>Gas-hydrates reservoir characterization by determining Q from pre-stack seismic data</u> – The determination of Q is very important to characterize the sediments for hydrates and free-gas. The logarithm spectral ratio (LSR) method was applied to marine seismic reflection data to calculate the interval Qs for three sedimentary layers (A, B and C). The estimated average interval Q (160) for the hydrate bearing sediments (layer B) is much higher than the average interval Q (80) for both the loose clayey sediments (Layer A) and underlying free-gas saturated sediments (layer C). This demonstrates that the gas-hydrates bearing sediments exhibit low attenuation or high seismic Q, which can be used as a proxy for gas-hydrates.

v. <u>Pore-pressure prediction in gas-hydrate bearing sediments of KG basin</u> – Predrill estimate of pore pressure (PP) is important for well design especially in areas containing gas-hydrates. The pressure distribution in hydrate-bearing sediments in the KG basin was predicted from seismic data. The results demonstrate that the pressure remains hydrostatic within the gas-hydrate bearing sediments and is mostly above-hydrostatic below the gas hydrate bearing zone.

vi. <u>Estimation of gas-hydrates from seismic velocity-resistivity transformation in KG basin</u> – A relation between formation-factor and velocity for sediments with and

without gas-hydrates using the log data has been established. The results show relative permeability and gas-hydrates saturation as varying both laterally and vertically up to 0.5 and 28% respectively along the lines.

vii. Wavelet transform based spectral decomposition in gas-hydrates exploration – Spectral decomposition in time-frequency domain based on continuous wavelet transform (TFCWT) is used to demonstrate the potential application for delineating free-gas in KG basin. The results reveal compartmentalized zones of free-gas below the BSR instead of continuous zone that appears on amplitude section (Fig 7.2).

a

b
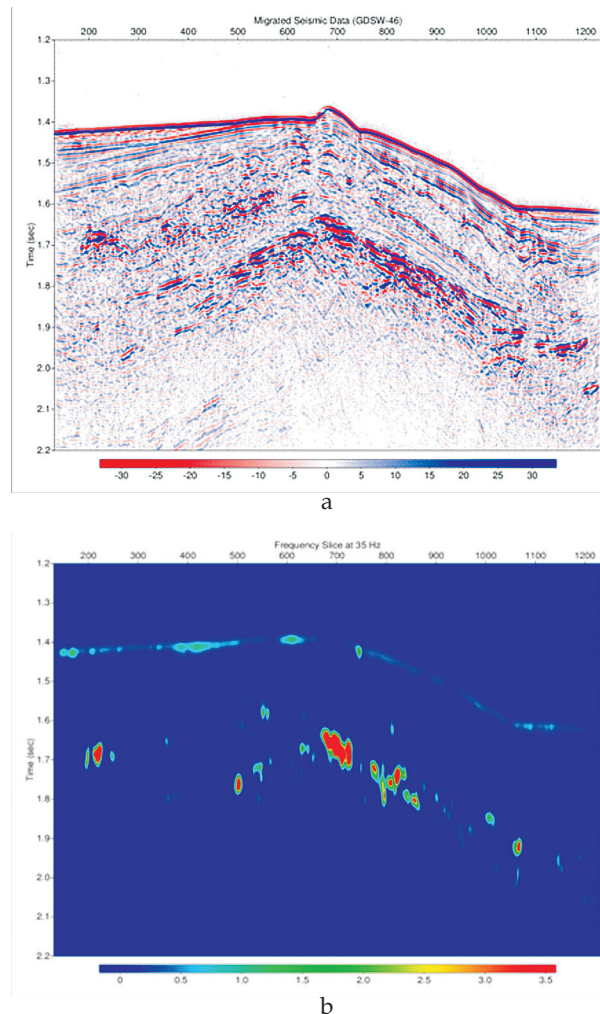
Fig 7.2 – (a) Migrated 2-D seismic section in KG basin; (b) Teager-Kaiser energy section at 35 Hz frequency from TFCWT processing shows the gas pocket (red zone)

viii. Estimation of gas-hydrates in KG basin from ocean bottom seismic (OBS) data – The distribution and quantification of gas-hydrates / free-gas relies heavily on accurate estimation of seismic velocity. Estimation of gas hydrate reserve is made by using both to P-wave velocity (V_p) and S-wave velocity (V_s) derived from ocean bottom seismic (OBS) data acquired in KG basin and found to be varying between 17% to 20% (Fig 7.3) along the seismic line.
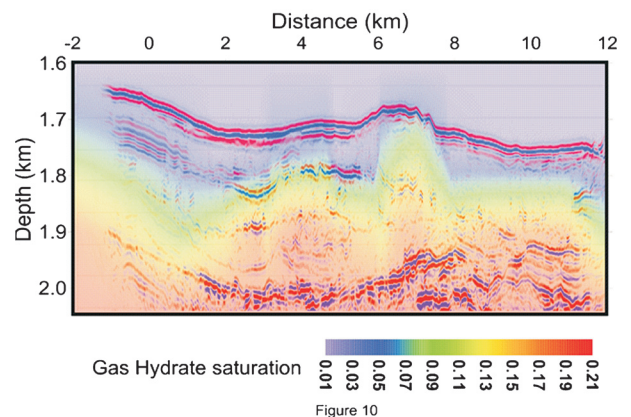
Fig 7.3 - The lateral and vertical saturation of gas-hydrates superimposed over seismic stack section along the seismic line (the saturation below the BSR is to be ignored)

7.5 POLYMETALLIC NODULES (PMN)

Extensive investigation and developmental work has been undertaken in all the four major components, viz. Survey and Exploration, Environmental Impact Assessment (EIA) study, Technology Development for Extractive Metallurgy and Mining of the Polymetallic Nodule Programme (PMN).

7.5.1 Survey and Exploration:

The task of identifying the Test Mining Site (TMS) within the First Generation Mine site (FGM) was revisited during the year. The best five blocks were re-analyzed considering the unminable area and the best block was identified as TMS.

7.5.2 Environmental Impact Assessment Studies (EIA):

Spatial distribution in grain size, geotechnical parameters and benthic fauna in surface sediments from the CIOB were studied. The area covered for spatial variation has mostly siliceous sediments with very few stations with pelagic/red clays. The grain size distribution showed spatial variation in sand and clay contents among 26 surface samples. The sediments can be classified as silty clays. A total of 11 groups of macrofauna and 9 groups meiofauna were observed in the CIOB. Among the macrofauna groups polychaete and tanaidacea (26%) were dominant and nematode (46%) was dominant in meiofauna group.

7.5.3 Technology Development - Extractive Metallurgy:

Gaseous reduction studies were carried out in a fluidised bed furnace using compressed natural gas (CNG). From the preliminary laboratory scale studies, it is observed that both sucrose and glycerol are effective reducing agents at low temperature operation, i.e. 80-90 C. Preliminary work on sulphation roasting and water leaching studies were carried out for manganese nodules. The results showed 95% recoveries for copper, cobalt and manganese and 90% for nickel.

7.5.4 Technology Development - Mining:

The details are described in Chapter on Ocean Technology (Section 5.2.2).

7.6 STUDIES ON HYDROTHERMAL SULPHIDES

India's application for approval of a plan of work for exploration for polymetallic sulphides covering an area of 10,000 km2 was approved by International Seabed Authority in July-August 2014. ORV Sagar Kanya and a chartered research vessel RV Nikolaj Strakhov were deployed in the Central Indian Ridge (CIR) and Southwest Indian Ridge (SWIR) areas to carry out the preliminary geoscientific survey and exploration in the Indian Ocean ridge areas. Systematic geophysical surveys including multibeam eco-sounder (MBES) bathymetric mapping, magnetic, gravity and Sub-Bottom Profiler (SBP) surveys for a few selected blocks in the proposed region were carried out. Sampling was carried out along few selected locations using rock-dredging, grabs and gravity corers and altered rocks, mafic-ultramafics rocks comprising basalts, gabbros, Fe-Mn crusts and metalliferous sediments were recovered (Fig 7.4). Most of the sediment samples collected contains high quantity of metalliferrous minerals, which indicates extensive hydrothermal mineralization in the region.

Fig 7.4 - a) Ultramafic   b) Basalt   c) Fe-Mn crust

Petrographic and SEM-EDS studies of representative rock samples indicate hydrothermal alteration of olivine and pyroxene to serpentine and secondary infilling of opaque minerals (usually Cr-spinel and magnetite) along the fracture planes, veins and within the minerals, which can be considered as a good signature of hydrothermal activity in the region (Fig 7.5). Hydrothermal circulation may have caused deuteric alteration of host minerals to a great extent and could have been responsible for remobilization and transportation of valuable metals flow through the vein channels.
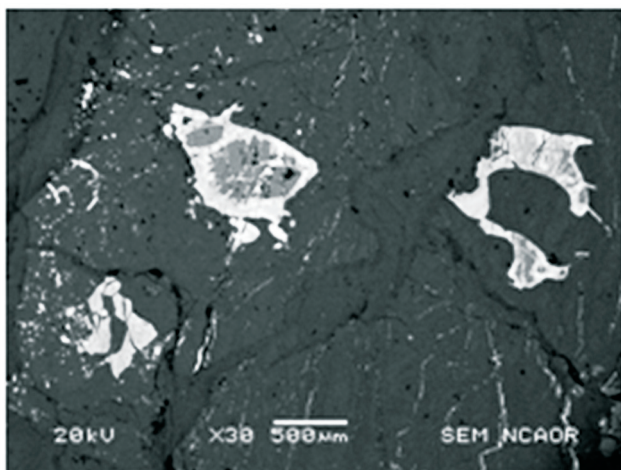
Fig 7.5 - Sulphide inclusions in veins in altered pyroxenites

The Preliminary geochemical data shows that Strontium (Sr) decreases with increasing Loss on Ignition (LOI) values in basalts, indicating that Sr was leached from rocks by hydrothermal alteration. Usually Sr is leached from Ca-minerals, especially plagioclase, which is again an indication for hydrothermal

activity in the region. The observed negative correlation between CaO and MgO, probably reflects the formation of Mg-rich chlorite that replaces Ca-bearing phases such as cpx and glass. Such Cao-MgO exchange is a typical geochemical behaviour during hydrothermal alteration.

Mineralogical and geochemical analyses of selected Fe-Mn crusts recovered from the study area show the presence of fossil worms and framboids. XRD studies show presence of mostly Fe or Mn mineral phases such as todorokite, vernadite, goethite, calcite along with hematite, magnetite, maghemite, maikainite, nontronite, etc. which are indicative of inputs from both hydrothermal and hydrogenous sources (Fig 7.6).
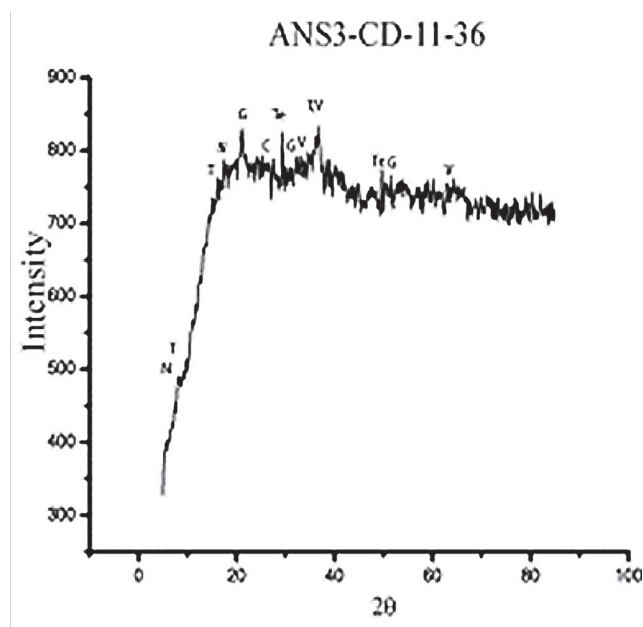
Fig 7.6 - XRD spectra of Fe-Mn crusts from SWIR (V=Vernadite, G=Goethite, T=Todorokite, N=Nontronite, M=Magnetite, H=Hematite, C=Calcite, Te=Tetrahedrite, Ma=Maikainite, Co=Cobaltinite, P=Phyllipsite)

SEISMOLOGY AND GEOSCIENCE

8.1 SEISMOLOGICAL RESEARCH

The seismic activity, in and around the country, is monitored to quickly estimate the source parameters, immediately on occurrence of an earthquake and disseminate the information to all the user agencies including the concerned State and Central Government agencies responsible for carrying out relief and rehabilitation measures. The earthquake information is transmitted to various user agencies including public information channels, press, media etc. using different modes of communication, such as SMS, fax, email and also posted on ESSO-IMD website (www.imd.gov.in). Major achievements during the year are given below.

8.1.1 Geophysical Observational System:

A country-wide seismological network consisting of a total of 82 seismological stations has been maintained. This includes,

a. 16-station VSAT-based digital seismic telemetry system around the National Capital Territory (NCT) of Delhi;

b. 20-station VSAT-based real-time seismic monitoring network in North East region of the country; and,

c. 17-station real-time seismic monitoring network (RTSMN).

All VSAT terminals at 17 field stations and two CRSs of RTSMN have been migrated to the new satellite GSAT-14 during April-May 2014 after the completion of life cycle of INSAT-3E being used earlier. The field stations data is received at CRS at ESSO-IMD HQ at New Delhi and ESSO-INCOIS at Hyderabad. As part of an international commitment, continuous real-time seismic waveform data of three seismic stations, viz., Portblair, Minicoy and Shillong is being transmitted to Incorporated Research Institutions of Seismology (IRIS), Washington, USA and other international agencies.

The National Seismological Network is being maintained. A state-of-the-art Data Centre was commissioned in 2013. During the year 2014, 15 seismological observatories have been installed with digital seismographs and integrated with VSAT for connectivity with Data Centre. The Data Centre has a web portal (http://www.isgn.gov.in), which provides access to the registered users for downloading the waveform data for research purposes. Data from select stations is made available openly to all users for operational use while data from all other stations is shared as per the data sharing policy. Users have the option of requesting data for a chosen time period.

8.1.2 Earthquake Monitoring and Services:

A total of 2576 earthquake events were detected and auto-located during the period January-November, 2014. These include 1547 events of magnitude 5 and above. Information pertaining to significant events were transmitted to all concerned state and central government agencies and also posted to ESSO-IMD website. A software module for issue of bulk SMS messages has been developed and made functional for,

a. issue of earthquake hypocentral parameters (as SMS level-1) to selected designated authorities on auto-location of

an earthquake event by RTSMN system; and,

b. dissemination of final earthquake hypocentral parameters (as SMS level-2) to a large number of users simultaneously in least possible time.

During this period, a moderate earthquake of magnitude 6.1 occurred on 21st May 2014 in the Bay of Bengal region. The earthquake was felt widely in Odisha, coastal parts of West Bengal, Andhra Pradesh and some parts of Tamilnadu, Bihar, Jharkhand, U.P., NCR and other adjoining states.

The seismological data from the network stations is compiled, processed, analysed and archived systematically at the National Seismological Database Centre (NSDC) on a regular basis. Earthquake bulletins are prepared on monthly basis. Archived data is also sent to the International Seismological Centre. Further, seismological data and earthquake related information is supplied to various user agencies dealing with relief and rehabilitation measures, earthquake disaster mitigation and management related matters, seismic zoning, etc. Earthquake data is also being supplied to various scientific, academic and R&D institutions for research purposes. On request basis, earthquake data and site specific seismicity reports are supplied to industrial units, power houses, river valley projects, etc.

A GIS-based decision support system for near real-time assessment of earthquake damage scenario, is being developed for the Indian region in collaboration with Bhaskaracharya Institute of Space Applications and Geoinformatics (BISAG), Gandhinagar,. The product generated shall be useful in decision support and disaster mitigation. The development of Peak Ground Acceleration (PGA) module and its integration with RTSMN system is under progress.

8.1.3 Earthquake Hazard and Risk Assessment:

Seismic Hazard Microzonation of NCT Delhi – The seismic hazard analysis of NCT Delhi on 1:10,000 scale has been completed based on a state-of-the-art Probabilistic Seismic Hazard Analysis (PSHA) using different source models (Line and Aerial) and attenuation relations. Earthquake sources and parameters have been considered for the area covered within a 350 km radius of Delhi, (Latitude 240 – 31.50 N and Longitude 740 – 81.50 E). This area includes part of the Himalayan region in which earthquake of maximum magnitude recorded so for is the Chamoli earthquake (M 6.9) of 1999, which is about 300 km from Delhi and produced horizontal PGA of 11 cm/s2 at Delhi. To incorporate uncertainty associated with different modelling parameters as well as spatial and temporal uncertainties, logic tree approach has been adopted. Based on the investigations and assigning weightages, a seismic hazard microzonation map of Delhi on 1:10,000 scale has been prepared (Fig 8.1).
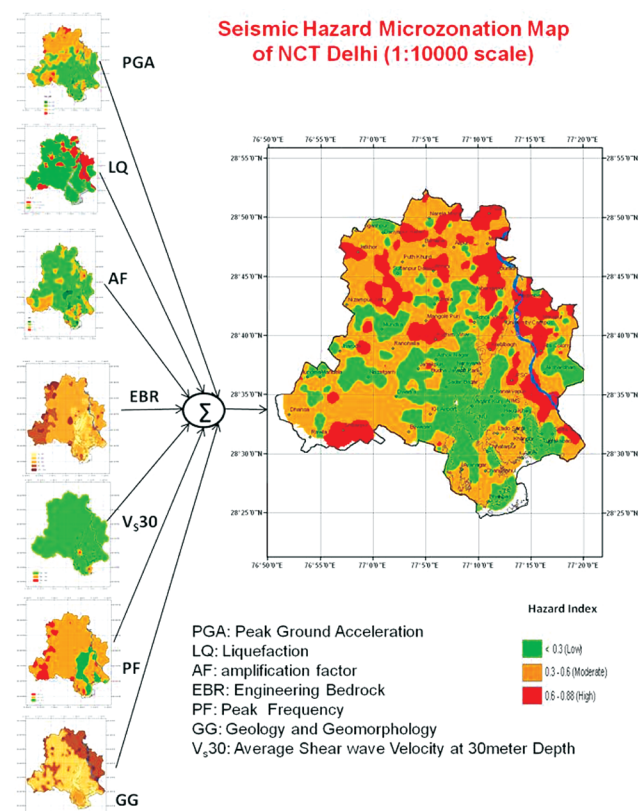
Fig 8.1 - Seismic hazard microzonation map of Delhi on 1:10,000 scale

Demonstration Experiment for Early Warning – A pilot study for development of Earthquake Early Earning (EEW) system in the central Himalayas has been initiated. Under this study, 100 seismic stations will be installed and data shall be transmitted in real-time to a central station for automatic analysis (Fig 8.2). Out of 100 seismic stations, 30 P-alert sensors have been installed which are streaming the data. Software modules in earthworm platform have been developed and are being tested for detection of earthquakes, issuing of warning and extracting time series of earthquakes.
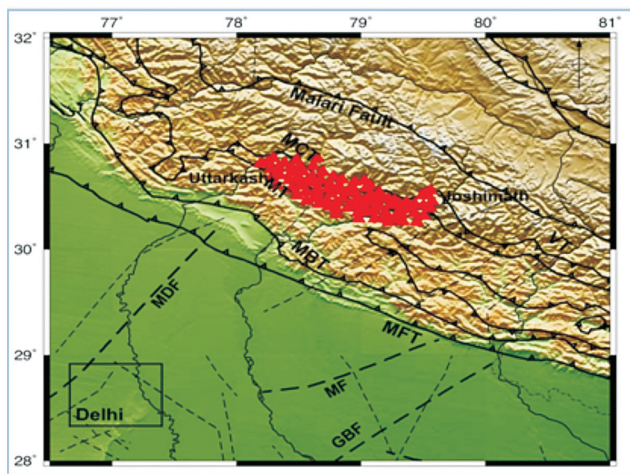
Fig 8.2 - Location of field stations for earthquake early warning system

Earthquake Precursors – A new multi parametric geophysical observatory (MPGO) has been set up in Manipur for generating long term, comprehensive multi-parametric geophysical observations and to establish possible relationship between various earthquake precursory phenomenon and the earthquake generation processes.

GPS Studies – A study of crustal deformation in the Kashmir Himalayas has been taken up which indicates evidence of strain accumulation and oblique convergence @ 14mm/yr. The slip rate of the Karakoram fault is 5mm/y. Two GPS stations have been installed, one at Ranchi in Jharkhand and another at Patna in Bihar for seismic hazard estimation in Bihar – Jharkhand.

8.1.4 Koyna Drilling Project Progress 2014-15:

A total of eight core boreholes have been completed with a maximum depth of 1522 m. The Deccan trap thickness obtained varies from 412 m to 1198 m. In addition to drilling operations, temperature logging was carried out in the boreholes at intermediate stages of drilling as well as at the end of the drilling of each borehole. Thermal and other physical properties of the Deccan basalt, granite and gneiss were measured in the laboratory. Data on thermal, physical and radiometric heat production properties of the basement rocks have been obtained for the first time in the area. The measurements resulted in a reliable heat flow determination and characterization of the subsurface thermal regime beneath the Koyna area, which provides critical inputs for deep scientific drilling. Additionally, geophysical logging and hydrogeological measurements were made in the boreholes.

For the first time, spatially homogeneous Airborne Gravity-Gradiometric and magnetic data across the Western Ghats have been recorded. Modelling of these datasets provided
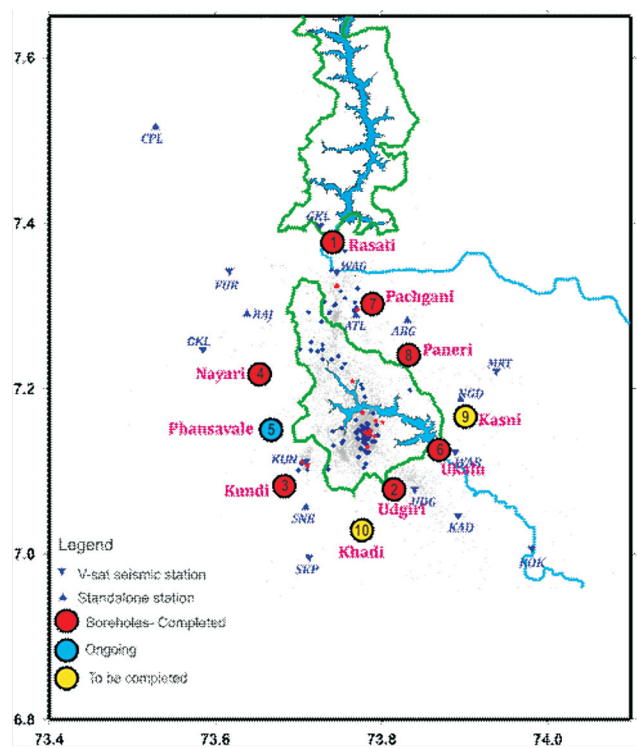
Fig 8.3 - Locations of 10 boreholes and their status of drilling

a 3D structural setting beneath Koyna-Warna region and across the Western Ghats. Modelled thickness of Deccan Trap is found to be consistent with results from drilling. The thickness of the Deccan Trap in the eastern part of the Western Ghats escarpment compared to the western part is higher. Modelling of magnetic data also provides an estimate of volume of normally and reversely magnetized basalts in this region. Majority of earthquakes are located at the contacts between rocks of contrasting densities in the 3D density model.

LiDAR study has been done in adjoining accessible areas to characterize seven prominent lineaments, which emerged from analyses of satellite imagery data. Fractures have been located and measured in sections along these lineaments on the higher hill slopes as well as in the lower reaches to the west of the Western Ghats. Evidences of soft sediment deformation as well as knick points associated with surface drainage have been documented. "Fracturing" of the basalts in the Deccan Traps is recognized in this work as the rupturing of the basalts produced due to tectonic / superimposed stresses as distinct from the 'cooling joints' or the 'weathering or exfoliation joints' in the basalts. Measurements of fracture characteristics at individual locations have been tied up with regional scale linear features based on satellite imagery data.

Preliminary modelling of MT data identified a weak zone near the Udgiri region which coincides well with the bore well observation. Distinct electrical signature in the basement along Koyna and Warna profile suggest presence of fault zone, which might have relevance to the surface tectonics.

Borehole seismometers were installed in two boreholes at depths of 1522m and 1134m. Fig 8.4 shows a clear seismic record from a borehole seismometer as compared to a surface seismometer record for a small event.
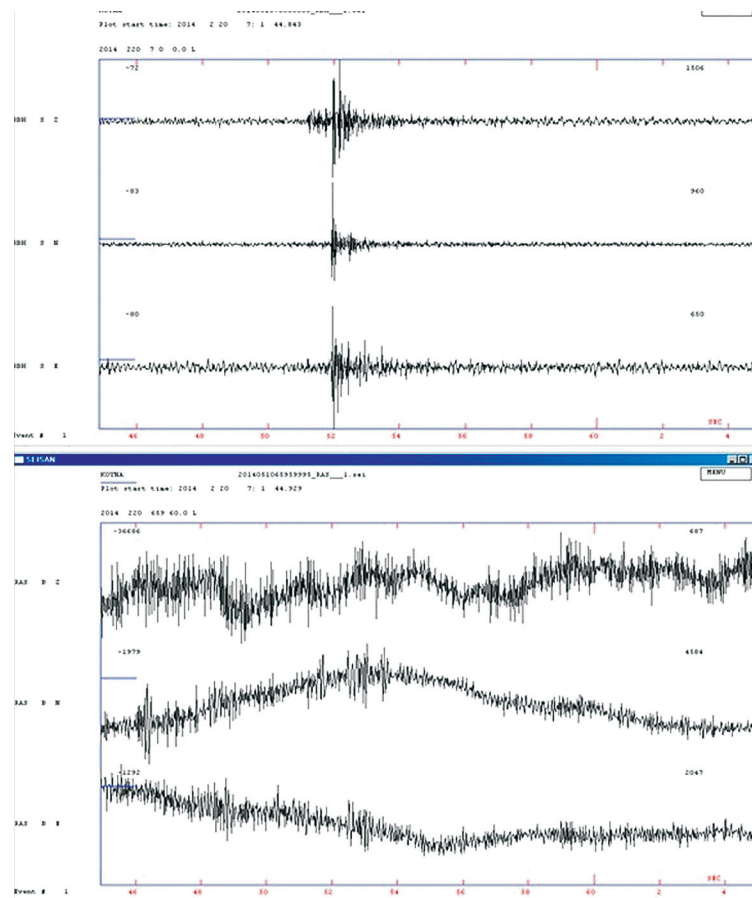
Fig 8.4 - Sample of a borehole seismic record (a) in comparison to a surface seismic record (b) for a small event of M 0.2.

8.2 SOLID EARTH RESEARCH

8.2.1 Crustal Processes:

Magmatic and high-grade metamorphic suites for improved understanding of lithosphere and asthenosphere evolution under the Indian shield – Integrated palaeomagnetic and geochemical investigations on the volcanic flows/sills in the Gwalior, Bijawar sedimentary basins initiated to derive position of the Indian shield during the palaeoproterozoic era and to unravel the petrogenetic history of the continental magmatism and the evolution of the mantle processes. About a hundred oriented cylindrical samples collected from the Bijawar and Gwalior igneous units have been prepared into specimens for measuring natural remanent magnetisations and to determine characteristic magnetisations. Thirteen block samples collected for geochemical investigations have been pulverized and sample preparation done for major and trace element analysis. Thin sections prepared for all the block samples and petrography studies are in progress. In addition palaeomagnetic data on some mesoproterozoic dykes on the Eastern Ghat Mobile Belt front have been analyzed to update the palaeomagnetic poles in the light of recent work on mafic dykes in India.

Following a detailed study on gneissic variant occurrences in the Kerala Khondalite Belt (KKB), chranockite variants have been taken up for further investigation on their disposition, interrelation and genesis, by applying field, petrographic and geochemical analysis and integrating the same with available geochronology to understand their origin. The results suggest general I-type characteristics and two distinct magmatic suites of charnockites. The first type showed typical Tonalite-Trondhjemite-Granodiorite (TTG) affinity and the second showed geochemical resemblance with post-Archaean granites.

Palaeofluid regime of the Cenozoic sedimentary basins off west coast of India – Fluid inclusions are sensitive indicators of diagenetic environments. In petroliferous basins, fluid inclusions may contain oil, gas or water, or a combination of these fluids. These hydrocarbon-bearing fluid inclusions (HCFIs) are useful for understanding the fluid compositions, pressure-temperature conditions in geologic systems and the migration of hydrocarbon fluids in petroleum basins. Cutting samples collected from RV-1 well of the Ratnagiri basin and KK4C-A-1 well from the Kerala-Konkan Basin were studied in detail. The work is being undertaken in collaboration with the Oil & Natural Gas Corporation (ONGC), Government of India.

Laser Raman studies were carried out for the characterization of fluid inclusions. Raman spectra were taken for inclusions from RV-1 well at room temperature set at 20oC. Raman peaks are noticed at 857, 1285, 1386, 2143, 3657 and 2954 cm-1 corresponds to COS, 12CO2, CO2 (L), CO, H2O (vapour) and C2H6 , respectively. OH stretching band of water gives a broad spectral range of about 2900-3700 cm-1due to the symmetric and asymmetric vibrations. All the peaks of quartz around 354, 806, 1159 and peaks of calcite around 285, 1085 cm-1 are always noticed in every spectrum.

Photoluminescence characteristics of oils in HCFIs are being studied and differences in the emission profile noted. Exploration of the possibility of identifying the HC species and quality of oils in HCFIs inclusions is being carried out. The homogenization temperature of the hydrocarbon fluid inclusions, with the available data, indicates that high level of maturity has been achieved in oils. The bluish white fluorescence colour is indicative of commercially viable lighter oils in the HCFIs which were observed from deeper horizons of Palaeocene – Eocene sandstone silt stone reservoir beds in the RV-1 well. Raman studies are continuing for species identification and PL emission studies have been initiated in order to determine API gravity of oils in HCFIs.

Quaternary Cover Sequences and Palaeoclimate – The southwest coast of India is endowed with a series of landform features

that are evolved under fluctuating sea level and climatic conditions. The Western Ghats form the major orographic feature in this region that extends along the coast and rises to 900 – 1500 m above sea level. The coastal lands of Kallada and Achankovil rivers are characterised by the presence of a chain of wetlands close to its eastern margin. Multi proxy studies of borehole cores with depth range of 10 – 26 m revealed that the evolution of coastal lands have been influenced by many local and regional factors like changes in climate, sea level and local tectonics during Late Pleistocene and Holocene periods. The sedimentary archives contain eroded/reworked materials from the Tertiary hillocks in hinterland areas of the Late Quaternary sedimentary basin. The Late Pleistocene sediments contain palynomorphs of evergreen flora including Cullennia exarillata, which is an indication of heavy rainfall and wet climate. The chains of coastal wetlands that are seen in the eastern periphery of the old coastal plains have been carved out during the Late Pleistocene higher sea levels. The peat deposited over the littoral sediments in the wetland systems is a clear indication of receding sea that attained its maximum at around 18 kilo years BP. The interlinking of these wetlands by the Pallikkal river might have taken place in the latter half of Early Holocene era as indicated by the C14 date (7270 ± 250 years BP) of peat sample at 6.9 m below ground level of the Karunagappalli borehole core. The studies on the geological evolution and palaeoclimate of central Kerala have been initiated recently. The available borehole information and C14 dates revealed that the Quaternary deposits in the region is made up essentially of Holocene sediments. A systematic study of borehole cores using multi-proxy analysis will be useful for strengthening our knowledge on climate - sea level histories of the past 10 kilo years.

Shallow Crustal Processes – Landslides and land subsidence incidences are frequent in the highlands of Kerala during high rains. The investigations carried out revealed that the subsidence incidences are due to soil piping. The resulting "pipes" are commonly a few millimeters to a few centimeters in size, but can grow to a meter or more in diameter. They may lie very close to the ground surface or extend several meters below ground. The cavities and pipes developed below the ground grow with respect to time and affect large extents of land in the form of subsidence. Both physical intervention methods and chemical amelioration techniques are being tried to minimize or arrest this process.

8.2.2 Natural Resources And Environment Management:

In-Situ Bioremediation of Landfill Pollutants - Maximising the Remediation Potential of Select Indigenous and Exogenous Microorganisms – The safe disposal of Municipal Solid Waste (MSW) is an important issue. Sanitary landfilling is the predominant waste disposal alternative, but raises environmental concerns in the form of generation of landfill gas (LFG) with methane as a major component and leachate, which is an obnoxious effluent with many toxic compounds. The study estimates the quantity and quality of landfill gas and leachate produced from each of the landfill models; the oxygen/air requirement for optimal remediation of landfill pollutants; the growth rate of select indigenous and exogenous microorganisms in the system; the correlation of bacterial growth rate with the treatment efficiency; the bacterial kinetics of select species and the group performance of the exogenous bacteria with the indigenous bacteria. The results show a decreased production of methane as well as enhanced bioxidation of generated methane in the aerated models. The model with methanotrophic microorganism inoculation without leachate recirculation shows much lower methane generation and a higher bioxidation than the other aerated models.

GIS Database and Urban Information System – The main focus of the programme is to generate and disseminate spatial/non-spatial digital database in 1:4000 scale including socio economic data through a customized

information system developed with the state-of-the-art techniques of Remote Sensing (World View 2 satellite data) and Geographic Information System, supplemented by field survey. By integrating the thematic layers and attribute data of societal importance, a web based user-friendly customized information system has been designed and developed in open source platform. The decision support modules provide flexible environment for data handling, resource query, update analysis and provide inputs into the master/zonal planning and utilities management.

Environmental Effects of Human Interventions in the Periyar River Basin – The present study carried out in the Periyar river basin encompassing draining the Kochi city, reveals that the basin environment has been impaired severely by human intervention particularly due to haphazard mining and quarrying operations. Rampant hard rock quarrying has become a major threat to the different environmental components including the surface and sub-surface water resources of the basin.

Sand Audit of Periyar River – The need for sand and gravel is rising exponentially over the years to meet its ever increasing demand in the construction sector. At the same time, the availability of construction grade sand is decreasing year after year. As a result of indiscriminate sand mining, almost all the rivers in Kerala that are generally small in size and resource capability, are degraded. The study carried out in the Periyar river flowing through Idukki district revealed that sand availability in the river is very limited. However, the river stretch of the Periyar between Neriyamangalam and Karimanal contain a mineable sand reserve of 0.4 million tonnes. The other parts of the river in the district are practically devoid of mineable sand with the exception of a few river stretches in Konnathadi, Vellathooval and Mankulam Grama Panchayats.

CAPACITY BUILDING AND HUMAN RESOURCE DEVELOPMENT

The scientific understanding of the earth system processes is interdisciplinary in nature and specialized manpower in the field of earth system sciences is thus an important and integral part for the success of such programs. It is thus pertinent to establish institutional mechanism for continuous development of such manpower for ongoing programs as well as for all future endeavors of the country. In view of this at present, there are three training schools that have been established, with an aim to develop adequate training modules with focus on operational and service-delivery oriented responsibilities.

There is a need to continuously upgrade knowledge through assimilation of new ideas and application of new knowledge in the field of earth system sciences for improvement of weather and climate forecast and sustainable development of resources. This can be effectively done through adoption of multi-institutional and multi-disciplinary approach involving amalgamation of expertise existing in various R&D institutes of the country. These are achieved through supporting focused R&D through networked projects involving various institutes within India and abroad, initiation of academic programmes, establishment of chair professors, establishment of National Lab facilities for benefit of researchers, opening of Centers of Excellence at various Universities with state-of-the-art research facilities and establishment of Earth Science and Technology Cells.

9.1 CENTRE FOR ADVANCED TRAINING IN EARTH SYSTEMS SCIENCES AND CLIMATE (CAT ESSC)

The Centre for Advanced Training in Earth System Sciences and Climate (CAT-ESSC) established in 2011 as a world class job-linked training program in ESSO-IITM has its main objective as to create a pool of trained and dedicated earth and climate system scientists with in-depth hands-on expertise on physical processes of the land, ocean, atmosphere, biosphere and cryosphere, with special emphasis on modeling. On successful completion of the induction-training program, trainees are placed in the institutions of ESSO, as scientists in suitable grades based on their qualification.

The 3rd batch of 23 trainees inducted in Aug 2013 have completed their 18 month induction training and 11 of these trainees participated in Targeted Training Activities (TTA): Challenges in Monsoon Prediction held in ICTP, Trieste, Italy, during 23rd June to 4th July 2014. The trainees are encouraged to pursue Ph.D. program after placement for career enhancement.

9.2 TRAINING IN OPERATIONAL METEOROLOGY

The Training School in Operational Meteorology has been implemented at ESSO-IMD, Pune with an aim to reorganize the existing training with introduction of concepts like continuous learning and self-development; e-learning, etc. Four short term tailor made advanced refresher training courses (DWR, NWP, Operational Climate Service and Tropical Cyclone) have been organized and four regular training courses namely (i) Advanced Meteorological Training Course; (ii) Forecasters Training Course; (iii) Ab-initio Integrated Meteorological Training

Course; (iv) Intermediate Training Course were conducted during 2014-15.

9.3 INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANOGRAPHY

The International Training School for Operational Oceanography (ITCOOcean) has been set up under ESSO-INCOIS, to enable support for capacity building activities in the field of operational oceanography in the Indian Ocean Rim (IOR) and Islands Region as well as Africa. Seven training courses were conducted during 2014-15 including three international training courses of one-week duration that were held in June, August and November 2014 and which involved international faculty with participation from nine Indian Ocean Rim countries. The courses were on Ocean Modeling, Remote Sensing of PFZ and Ocean State Forecast, Tsunami Early Warning Centre Operations and Standard Operating Procedure for Tsunami Warning and Emergency Response for northern and western Indian Ocean Countries. A two-day workshop on "Ocean Information Services for Cyclone Forecasters" was conducted during 2014-15 and was attended by participants from India and abroad. Two courses on "Assessment and Management of Marine Biological Resources" and "Tide Data Analysis and Applications" was organized jointly with NIO, Goa during January 2015.

9.4 ESTABLISHMENT OF INDIA AFRICA CENTRE FOR MEDIUM RANGE WEATHER PREDICTION

An India-Africa Centre for Medium Range Weather Forecasting has been planned to fulfill India's commitments made at the second Africa-India Forum Summit in the area of capacity building in Africa. ESSO-NCMRWF is the nodal agency responsible for generating and establishing a complete end-to-end medium range weather prediction system suitable for Africa. The African Union is yet to decide about its location. However medium range forecast products over the African region are being generated and uploaded on ESSO-NCMRWF website.

9.5 BIMSTEC-CENTER FOR WEATHER AND CLIMATE

Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) Member Center for Weather and Climate (BCWC) has been established at the ESSO-NCMRWF to enable enhanced regional cooperation on observing systems, forecast information, early warning systems and capacity building. Forecast products including the extreme rainfall forecasts for the BIMSTEC countries are regularly being generated and the forecast verification of the same is being carried out. The BCWC is also monitoring the observation data received from BIMSTEC countries. A pilot project has been undertaken for examining the Interannual Variability of Myanmar rainfall. Program activities of the BIMSTEC Centre for Weather and Climate was launched formally on 26th August 2014. A training workshop on "Improved Weather and Climate Predictions" was held during 26th August to 1st September 2014 at ESSO-NCMRWF and three IOA countries participated in the workshop.

9.6 R&D FUNDING IN EARTH AND ATMOSPHERIC SCIENCES

To improve the understanding of the earth system (the atmosphere, ocean, solid earth, biosphere) and their response to the natural and human induced changes, research projects in academic and research institutes in the various areas of Earth System Sciences namely, (i) Atmospheric Science including Climate Science; (ii) Geoscience; (iii) Ocean Science and Resources; (iv) Hydrology and Cryosphere; (v) Earth System Technology, are supported. Activity areas are,

1. Focused research projects of national importance;

2. Building indigenous capability through joint collaborative programs;

3. Human resource development through opening of Centers of Excellence, initiation of academic programmes, establishment of Chairs;

4. Setting up of specialized labs as national facilities;

5. National and international collaboration in the field of Earth System Sciences;

6. National coordinated projects.

Four Project Appraisal and Monitoring Committees (PAMCs) and a Technology Research Board have been constituted for appraisal, review and monitoring of the various projects for consideration for funding. An Apex committee chaired by Secretary has also been constituted to consider specific proposals recommended by these committees.

9.6.1 Focused Research:

The following research projects in focused research areas were funded in 2014-15:

Atmospheric Research –

• Estimation of Carbon Sequestration Potential of Trees in Southern Eastern Ghats of Tamil Nadu, India - Pachaiyappa's College, Chennai

• Size-resolved measurements and modeling of cloud condensation nuclei (CCN) in Indian continental and marine air – IIT, Madras

• Aligned Carbon Nanotubes as Porous Materials for Selective Carbon Dioxide Adsorption and Deabsorption: Effect of pressure and charge – IIT, Kanpur

Cryosphere and Hydrology –

• Delineating physico-chemical dynamics of discharging groundwater to sea in coastal areas of the Bay of Bengal - IIT, Kharagpur

• Modeling of soil moisture in a changing climate using the potential of probabilistic hydro-meteorological approach - IIT, Kharagpur

• Establishing the reference condition on the Ganga River with Corona archival imagery - IIT, Kanpur

• Seasonal Hydrologic Predictions based on Regional Forecasts of Monsoon Rainfall with CWRF and Statistical Downscaling - IIT, Bombay

• Near-Real-Time Urban Flood Forecasting System – IIT, Bombay

• Assessment of Environmental Flows for Himalayan Rivers - National Institute of Hydrology, Roorkee

• Isotope techniques to evaluate the seasonal and inter-annual variation of glacial and snowmelt discharge in the Ganges River at Gomukh and Mana – IIT, Kanpur

• Resistance characteristics of alluvial channel with mobile bed vegetation – IIT, Guwahati

Geo-science Research –

• Phosphorus fractionation in surface sediments: An Implication in Restoration and Conservation of Govind Ballabah Pant Sagar, Singrauli, M.P. - Department of Environmental Science and Engineering, Indian school of Mines, Dhanbad

• Delineation of groundwater potential zone and identification of Artificial recharge sites in Ramanagaram taluk, Karnataka - Ghousia College of Engineering, Ramanagaram, Karnataka

• Evaluating Structural Control on Gold Mineralization in Gadag Region (Karnataka) – A Study Based on Fabric Quantification and Kinematic Analysis - Department of Geology and Geophysics, IIT, Kharagpur

- Petrogensis of mafic and ultramafic magmatism at Madawara Igneous Complex, Bundelkhand Craton: Implications for Platinum Group Elements (PGE) Metallogeny - National Geophysical Research Institute, Hyderabad

- Characterization and genesis of gas hydrate zone in Krishna-Godavari (KG) Basin, Bay of Bengal using benthic foraminiferal and geochemical studies - Indian School of Mines, Dhanbad

- Rare Earth Metal abundances in certain Pan-African granitoids of Karbi Hills, Assam: their prospect examination - Dibrugarh University, Dibrugarh, Assam

- Geochemical and Isotopic studies on Archaean greenstone belts and Proterozoic Cuddapah Basin: Implications for Biogeochemical and Palaeo environmental variations during the evolution of Dharwar Craton - National Geophysical Research Institute (NGRI), Hyderabad

- Migmatization, melting, leucogranite generation and exhumation of the higher Himalayan crystallines (HHC), Sikkim Himalaya - Department of Earth Sciences, IIT, Roorkee

- Luminescence Chronology of Paleoflood and Aeolian dunes deposit in Kaveri Basin: Implication to Holocene climate reconstruction to be implemented - Department of Earth Sciences, Indian Institute of Science Education and Research, Kolkata

    Ocean Science and Resources –

- Bioremediation of oil spills and removal of aromatic hydrocarbons using marine microorganisms with nanoparticles: Treatment efficiency, optimization, modeling and simulation studies - NIIT, Durgapur

- Diversity and adaptive strategies of the microbial flora inhabiting the HBRA in Chavara - Neendakara placer deposits (Kerala) - VIT, Velluore

- Eddies in the Bay of Bengal in relation to the Upper Ocean Thermal Variability and the Life Cycle of Tropical Cyclones - Andhra University, Vishakhapatnam

- Assessment of heavy metal pollution in the Bay of Bengal using ichthyofauna as a tool, east coast of India - Bharthidasan University

- High resolution simultaneous PIV-PLIF measurements of flow dynamics and turbulent mixing in buoyant stratified jets and plumes - IIT, Bombay

- Prediction of Surfzone rip currents – numerical model validation and implementation - National Institute of Oceanography, Goa

- Insecticidal and Antimicrobial Activity of Biologically Manufactured Nano Materials from Ocean Resources for agricultural use - Indian Institute of Chemical Technology, Hyderabad

- Sustainable Development of India's Coastal and Island Ecosystems - Centre for Ocean and Environmental Studies, New Delhi

- Bioinventorying of higher marine fungi colonizing decomposing mangrove plant substrata in Muthupet, Tamil Nadu, East coast of India - Pondicherry University, Pondicherry

9.6.2 Building Indigenous Capability:

In order to promote and encourage indigenous technology development, proposals are encouraged from various organizations/ institutions of the country in form of projects. The Technology Research Board funded/ approved the following projects:

- Solar Multi-effects Desalination System - Dr. Mani, IIT, Chennai

- Development of Ka Band Polarimetric Doppler Radar for cloud profiling-Society for Applied Microwave Electronics Engineering and Research (SAMEER) IIT Campus, Powai, Mumbai

9.6.3 Human Resource Development:

- Supported Human Resource Development through Sponsorship of eight M.Tech. and nine Ph.D. students in various fields of Earth Sciences at IIT Delhi, IIT Madras, Amrita University, etc.

- Two students joined Norwegian Polar Institute (NPI) under the Ph.D. fellowship programme in Glaciology. The two candidates Shri Vikram Goel and Shri Ankit Pramanik were selected through an intense screening and selection procedure for carrying out Ph.D. in the fields of Antarctica Glaciology and Arctic Glaciology. This is done under an MoU between ESSO-NCAOR and NPI to facilitate modalities of implementation. Shri Vikram Goel received the best oral presentation award at the International Glaciological Society's Nordic brunch meeting, at Iceland, during October, 2014.

- Guidelines for establishing ESSO-Distinguished Professor/Fellow at ESSO institutes have been formalized. Under this, ESSO proposes to establish five ESSO Distinguished Professors, eight ESSO Professors and fourteen ESSO Distinguished Fellows in the ESSO institutes. In addition it will also establish ten ESSO Visiting Chair Professors at premiere institutes of the country. The eligibility, tenure, selection procedure and other details have been laid out in the guidelines.

- Pisharaoty Chair in Atmospheric Science and Climate Change has been established at IISER Pune.

9.7 PROGRESS OF ONGOING PROJECTS

9.7.1 Focused Research

(a) National Partners

i. "Design and Development of a Unified Modeling System for Seamless Weather and Climate Predictions of Monsoon" by IIT, Delhi - The aim of the project is to formulate and design a new forecasting system on Icosahedral-Hexagonal grid for seamless predictions and to develop efficient code for exploiting GPU computing potential for a unified model designed on these grids. CUDA implementation of the base model LMDZ has been accomplished; development of Dynamical core of Icosahedral-Hexagonal model, 4D data assimilation for the LMDZ5 has been achieved.

ii. "Establishment of Pulsed Laser Photolysis - Laser Induced Fluorescence spectrometer and measurement of atmospheric lifetimes of volatile organic compounds in the Earth's atmosphere" by IIT, Madras - The project aims to establish Pulsed Laser Photolysis – Laser Induced Fluorescence (PLP-LIF) facility to investigate the mechanistic studies and to measure the kinetic parameters of the OH and NO3 radicals. The PLP-LIF facility has been established and the facility will be used to measure the kinetic parameters of the reactions of OH radicals with volatile organic compounds (VOCs).

iii. "Development of a mid-IR Cavity Ring-Down Spectrometer for High-Precision Real-Time Continuous Monitoring of Multiple Trace Gases and Stable Isotopic Species in the Atmosphere" by S.N. Bose National Centre for Basic Sciences, Kolkata - The focus of the project is on the development and implementation of a new generation atmospheric chemical sensing technology for simultaneous real-time detection, quantification and continuous monitoring of numerous atmospherically

relevant key molecules in the Earth. Cavity-ring down system has been developed which has been coupled with mid-IR continuous wave (cw) quantum cascade laser (QCL) operating at ~7.8 micron. Several important parameters of the QCL system have been systematically checked for the optical measurements of trace species.

iv. "Assessing the Impacts of Climate and Land Cover Changes on Hydrology" by University of Kashmir, Srinagar - The procured historical and climate data for 24 watersheds of the Jhelum basin has been digitized and statistically analyzed for trend analysis. The PRECIS Regional Climate Model at a resolution of 50 km has been completed. Participatory Rural Appraisal (PRA) surveys, using a questionnaire, have been initiated in Lidder watershed of the Jhelum basin to research how the communities are adapting to the climate change in the basin.

(b) International Partners

i. BELMONT Forum: Under the existing MoU with members of the Belmont Forum to support Indian Scientists for international collaborative research through joint calls in the area of global environmental change and extreme hazardous events, four projects with Indian PIs under the "Coastal Vulnerability" Collaborative Research Area (CRA) have been accepted for funding. The projects are,

• Coastal Adaption Research, a Trans-disciplinary Transnational Community and Policy Centre Approach (ARTISTIC) by CUSAT, Kochi.

• DELTAS: Catalyzing Action towards sustainability of deltaic systems with an integrated modeling framework for risk assessment by National Centre for Sustainable Coastal Management (NCSCM).

• Transformation and Resilience on Urban Coasts (TRUC) by National Centre for Sustainable Coastal Management (NCSCM).

• Global Learning for local solutions: Reducing Vulnerability of marine dependent coastal communities (GULLS) by the Central Marine Fisheries Research Institute, Kochi.

These projects are at various stages of implementation.

ii. Changing Water Cycle Program:

The following five projects are running under the Changing Water Cycle Program jointly funded by the Ministry and Natural Environment Research Council (NERC), UK.

• **Hydrologic and carbon services in the Western Ghats - response of forests and agro-ecosystems to extreme rainfall events:**

The analysis of extreme rainfall events during the monsoon indicates that some forest cover is buffering extreme rain events better than those that are completely devoid of them. Initial result from the Aghnashini basin indicate both soil and stem CO_2 efflux rates were high at the end of the rainy season in September, declined steadily until early April, followed by a steady increase in respiration rates after April. In the Nilgiris, flux rates during the dry season (February – early May) were higher in shola forests when compared to grasslands, pine plantations and wattle. CO_2 efflux rates appear to be more tightly coupled with temperatures rather than soil moisture availability in this system.

• **South Asian precipitation - A seamless assessment - SAPRISE:**

Maps of climatological average rainfall in India during the Summer Monsoon season prepared using different data sets

shows significant differences indicting uncertainty in the observed rainfall in the region. Analysis of anomalies in Indian-regional rainfall over the 19th and 20th centuries in CMIP5 climate model experiments indicate that there should have been an increase in monsoon rainfall, but the aerosols force a reduction in rainfall that counteracts that increase.

- **Hydro-meteorological feedbacks and changes in water storage and fluxes in Northern India:**

  Using the Landsat satellite data for the time period 1973, 1980, 2000 and 2011; LULC maps were prepared for the Upper Ganga Basin and change analysis was performed to identify the direction and magnitude of change that has taken place in the basin in last 4 decades. Integrated hydrological modeling was initiated using Variable Infiltration Capacity (VIC) and JULES Model.

- **Mitigating climate change impacts on India agriculture through improved Irrigation water Management:**

  Large-scale rainfall-runoff model of the Beas River basin was used to assess the impacts of climate perturbations on the runoff. Crops yield response to the climate perturbations were simulated with a SWAT model of the basin. Extensive field scale experimentations on various crops were carried out at four locations to calibrate and validate a root water uptake model. Optimal reservoir operating policies for the Pong multi-purpose reservoir were developed.

- The structure and dynamics of groundwater systems in northwestern India under past, present and future climates:

  Paleo-channel within the Ghaggar river basin have been surveyed and the aquifer geometry based on 2D resistivity

have been mapped. Groundwater level observations from 2915 wells (1974-2010) and additional 997 wells (2002-2011) in the states of Punjab and Haryana have been compiled. 3 wells have been constructed for the pumping test site.

9.7.2 Building Indigenous Capability

Advancing Integrated Wireless Sensor Networks for Real-time Monitoring and Detection of Disasters" by the Amrita Vishwa Vidyapeetham, Kerala had been funded during 2012-13 with an aim to develop and deploy an integrated landslide and flood monitoring and detection system using wireless sensor network technology. Initial planning for identifying highly vulnerable landslide sites with due consultation with district magistrates has been done at Aizawal (Mizoram), Gangtok and a few other localities/towns in Sikkim and Uttarakhand. Soil samples have been collected from the sites and tested. Preliminary results were presented to an expert group who through consensus have concluded that Chandmari site in Sikkim should be taken on priority for various experiments.

9.7.3 National Coordinated Program

Continental Tropical Convergence Zone (CTCZ) involving multi-institutes is a National Coordinated Program and aims to understand the variability of convection/rainfall over the Indian monsoon through various field observations and modeling studies during monsoon.

Some of the findings from the projects are:

➢ Under the study of observed cloud microphysical characteristics over the Indian region and its surroundings from TRMM satellite estimates of cloud liquid water (CLW) and cloud ice (CLI), seasonal and intra-seasonal differences of CLW and CLI over

land and ocean parts of South Asia has been characterized and found interesting regional and temporal differences.

➤ Structural evolution of monsoon clouds in the core monsoon region of India was examined using multi-sensor remote sensing data and found that Structural evolution of monsoon clouds is highly influenced by dynamical and microphysical processes.

➤ 3-D structure of cloud properties in view of the aerosol distribution over Indian Monsoon region was studied for all the seasons which revealed that multilayer clouds persist throughout the year over the Indian CTCZ.

➤ In the cloud climatology study using multi data, the inter comparison between three passive sensors (MODIS, MISR and ISCCP) and one active sensor (CALIOP) revealed that stereo and radiometric technique from passive sensors complement each other and their combination provides the true cloud vertical structure as revealed by the active sensor.

9.7.4 Human Resource Development

* **Text-Book Series for the Graduate Students in Earth Sciences:** The proposal on writing of "Text-Book Series for the Graduate Students in Earth Sciences" was funded with an aim to fill in knowledge gaps for the Earth Science Graduate Students by providing a set of 14 affordable and illustrative text books with examples that are India-centric. Following the publishing and release of two textbooks in January 2014 on "Crystallography and Mineralogy" and "Elements of Palaeontology", a third

textbook on "Structural Geology" was released by Honorable Minister of Earth Sciences (HMoES) on 27th July 2014.

* **ICSP, Kolkata:** Indian Centre for Space Physics (ICSP) has been given recurring grants for five years to support manpower for carrying out research in areas of direct relevance to the ESSO activities. ICSP has recruited 13 scientific personnel to carry out research in ionospheric activities, propagation of radio waves in earth-ionosphere wave-guide and earthquake prediction. Research carried out by the scientific personnel recruited under the project has resulted in publishing of seven papers.

* **National Institute of Advanced Studies (NIAS)** has been given an annual grant for five years to support the various research and development activities including Ph.D. programme in particular in the area of environment, climate change and energy sector. NIAS carried out a study "The extent to which Karnataka's future electricity demand can be met with renewable energy without storage". Using data for daily load curves for 2013, NIAS has estimated that depending on the season, Karnataka's electricity sector could have absorbed 600-700 MW of additional wind capacity and 700-1400 MW of additional solar PV capacity.

* **ESSO Chairs/Visiting Chairs:** Some of the activities undertaken by the existing ESSO Chairs and Visiting Chairs are as follows:

- ESSO Panikkar Chair – Shri Rasik Ravindra was awarded coveted SCAR Medal-2014, for international cooperation and coordination in Antarctica science by Scientific Committee on Antarctica Research, ICSU. He was unanimously elected as Member to the United Nation Commission on Limits of Continental Shelf in June

2014. He is actively participating in the Himalayan Cryosphere Program and is a part of the Committee on Antarctica Legislation for formulating Antarctica legislations in respect of India.

- MoES Samdragupta Visiting Chair at IIT Kharagpur–ProfAvijitGangopadhyay:As IIT, Kharagpur is a mentor institute for IIT Bhubaneswar, the MoES Chair is helping in several activities of IIT, Bhubaneswar and is teaching an undergraduate course on Ocean Circulation and Modeling at IIT, Bhubaneswar and IIT, Kharagpur. He formulated a proposal for a Digital Earth Institute at IIT, Kharagpur, which is under consideration. The Chair was also a part of the proposal on Bay of Bengal coastal observatory to study the Bay of Bengal dynamics, which has to come up as a joint IIT, Bhubaneswar-MoES center.

- MoES D.N. Wadia Chair at IIT, Kanpur – Prof S.K. Tandon, introduced some new aspects in the teaching program of M.Tech. (Engineering Geosciences) and B.Tech. (Geosciences), designed a course on "River Science", mentored the development of a B.S.-M.S. Program in Earth Sciences and mentored the establishment of a Department of Earth Sciences at IIT, Kanpur.

9.7.5 National Facility

- Laser Diamond Anvil Cell - IISER Kolkata

  The Laser Diamond Cell (LHDAC) was established at IISER, Kolkata as a national facility. The proposal aims to develop a Laser Diamond Anvil Cell and generate and maintain states of matter at high pressures (ranging above 150 GPa) and temperatures (more than 5000 K) to enable measurements of material properties in these extreme conditions. Micro-driller for precision hole drilling on tungsten gaskets important for achieving high temperatures is tested. The facility for laser heating samples inside the DAC has been set up. A 100-watt YFL-Fibre laser has been installed for generation of high temperature at high pressures. High pressure Raman and X-ray diffraction experiments have been carried out up to about 70 GPa. High pressure Raman experiments have shown a non-linear pressure evolution of Raman modes.

- Research, Education and Manpower Development in the Discipline of Earth processes - IISc, Bangalore: IISc, Bangalore has established six basic laboratories namely (i) Geochemistry laboratory (ii) Petrology laboratory (iii) Sample preparation laboratory (iv) Seismology/GPS/computational facility (v) Airphoto/GIS/Remote sensing laboratory (vi) Sedimentology laboratory and Library. 50 papers have been published under this project by utilizing the laboratory facilities and three students awarded Ph.D. An M.Tech. programme initiated in 2013-14 with an annual intake of five students uses the facilities established using the Ministry support.

- Accelerator Mass Spectrometry (AMS) Measurement Facility for 14C at IUAC, New Delhi: The dedicated AMS facility will be used to measure ultra-low concentrations of the isotope 14C for applications in radiocarbon dating and earth sciences. 500 kV based ion accelerator based AMS system has been installed. IUAC has entered into an MoU with ETH Zurich for development of an automated graphitisation system. An expert committee met at IUAC to assess the progress of the establishment of the National facility and also identified research areas and researchers who could use the national facility.

9.8 EARTH SYSTEM SCIENCE AND TECHNOLOGY CELLS (ESTC)

ESTC are being put up in various Universities to encourage and develop theme based network projects with participation of different researchers from various universities, colleges and academic institutions.

An ESTC has been established at M.K. Bhavnagar University for network project on "Marine Coastal Ecology of West Coast of India", involving nine universities. The network project comprises of 12 sub-projects in the fields pertaining to marine bio-diversity and marine pollution.

Outcomes of ongoing projects of previous ESTCs have been satisfactory. Three Ph.D.s were awarded from the project "Coastal processes and hazards in the coastal zone of Dakshin Kannada and Udipi districts - An integrated approach through field measurements, remote sensing and GIS techniques" and one from the project "High resolution mesoscale prediction of land falling Bay of Bengal Cyclones for Coastal disaster Preparedness". In addition, two Ph.D. thesis were submitted.

Seven papers were published/accepted in international and national journals with average Impact Factor above 1.0 and six papers are communicated with revisions.

INFRASTRUCTURE DEVELOPMENT

To improve the quality of atmospheric, oceanic, polar and geosciences services, it is essential to develop infrastructure like high performance computers, ocean research vessels and aircraft facility. Significant efforts were made to improve the infrastructure capability, which will ultimately improve the quality of services rendered. The details of infrastructure development made during the year are given below:

10.1 HIGH PERFORMANCE COMPUTING (HPC)

Improved and reliable forecast of weather and climate requires use of very high-resolution dynamical models with high complexity (e.g. coupled ocean-atmosphere-biosphere-cryosphere models). Integrations of these models and the necessary R&D to improve them requires Petaflops capacity. This helps to enhance resolution of numerical models to resolve clouds, improvement of monsoon forecasting at various spatial and temporal ranges as well as climate system modeling, interpolation and interpretation of sparse data in dynamically consistent way to produce 'nowcast' or analysis. This also helps in studies related to observation simulation experiments (OSE), observation system simulation experiments (OSSE) and targeted observation experiments, ensemble predictions for weather, ocean state, cyclone track, short and medium range weather forecast, satellite and in-situ data assimilation, understanding of the science of climate change and climate variability etc. As a matter of policy, two constituent units of ESSO, viz. ESSO-IITM and ESSO-NCMRWF have been identified to host such large computing facility

so that the constraints of managing such huge computing infrastructure can be minimized.

Based on the detailed deliberation and the road map for augmenting the infrastructure facility in phased manner, 790 Teraflop of high performance computing has been successfully made available after complete testing on 5th September 2014 and subsequently released to the user community. The system has successfully maintained close to 100% uptime since made available. Additional HPC facility of 350 Teraflop at ESSO-NCMRWF will be made available by April 2015. Remote access to the HPC is enabled through the Closed User Group network available with all ESSO units through the National Knowledge Network (NKN). All the application and operational suites of the two most important units viz. ESSO-IMD and ESSO-INCOIS have been successfully ported on the HPC. Additionally, a wide array of open source and propriety applications necessary for executing, post-processing and visualization of data and applications pertaining to earth system sciences have been installed and deployed. Software stack is designed to be extremely flexible keeping in mind the requirements of end users from various backgrounds. High-end post-processing and visualization servers are made available to end-users.

The present HPC augmentation shall further enable to conduct extensive research and development activities in the area of seasonal and extended range weather prediction, more reliable and fine resolution weather and ocean state forecast, WCRP-CORDEX production runs, CMIP6 experiments, etc.

10.2 OCEAN RESEARCH VESSELS

ESSO has six research vessels viz. Oceanographic Research Vessel (ORV) Sagar Kanya, Fishery Oceanographic Research Vessel (FORV) Sagar Sampada, Technology Demonstration Vessel (TDV) Sagar Nidhi, Buoy Tender Vessel (BTV) Sagar Manjusha and Coastal Research Vessels (CRVs) Sagar Purvi and Sagar Paschmi (Table 10.1).

Table 10.1 - Utilization of Vessels in 2014-15 (April 2014 – December 2014)

Name of Vessel	Days at sea/ utilization	Maintenance/ Inspection/ Scientific Logistics/ Cruise Preparation	Number of Cruises
ORV Sagar Kanya	224	51	8
FORV Sagar Sampada	148	127	7
TDV Sagar Nidhi	190	85	9
BTV Sagar Manjusha	116	159	15
CRV Sagar Paschimi	84	111	14
CRV Sagar Purvi	86	189	9

Oceanographic Research Vessel (ORV) Sagar Kanya – ORV Sagar Kanya is the country's flagship vessel equipped with state-of-the-art scientific equipment for carrying out geoscientific, meteorological, biological, physical, oceanographic and chemical research in the tropical deep ocean. During the year 2014-15, the vessel was deployed for several national missions including Topographic Surveys in Exclusive Economic Zone (EEZ) of India, Hydrothermal Programme, Geotraces, Ocean Observations System (OOS) mooring operations, etc.

Fishery Oceanographic Research Vessel (FORV) Sagar Sampada – FORV Sagar Sampada undertook cruises in the Northern and Southern Arabian Sea and the Indian coast area of the Bay of Bengal for Assessment of Pelagic and Demersal Fishery, Myctophid resources, Physical, Chemical and Biological Oceanography, Zooplankton Studies, etc. The vessel was utilized by the Central Institute of Fisheries Technology (CIFT), Central Marine Fisheries Research Institute (CMFRI), Kerala University for Fisheries and Ocean Studies (KUFOS) and to undertake the various activities of Marine Living Resources Program (MLRP).

Technology Demonstration Vessel (TDV) Sagar Nidhi – TDV Sagar Nidhi was used for deployment and retrieval of Tsunami, Meteorological and OMNI buoy for Ocean Observation Systems, deployment and retrieval of tsunami buoy, Tropical Indian Ocean (TIO) Cruise Programme, Ocean Mixing and Monsoon Cruise and 8th Southern Ocean Expedition. The vessel was successfully used to recover sunken torpedo / underwater system from the Bay of Bengal for the Indian Navy.

Buoy Tender Vessel (BTV) Sagar Manjusha – Buoy Tender Vessel (BTV) Sagar Manjusha was utilized for implementing various projects/ missions viz. for sampling in the Bay of Bengal and the Arabian Sea Ocean Observations System, for successful deployment and retrieval of Buoys in the Arabian Sea and the Bay of Bengal, Wave Rider Buoy Deployment off Lakshadweep, for Coastal Ocean Monitoring And Prediction System (COMAPS) Sampling in the Arabian Sea, Ocean Acoustics for testing of equipments in the Bay of Bengal and for Geo-scientific studies of the Exclusive Economic Zone in Bay of Bengal.

Coastal Research Vessels (CRVs) Sagar Purvi and Sagar Paschimi – CRVs Sagar Purvi and Sagar Paschimi were mainly used for the implementation of Coastal Ocean Monitoring and Prediction System (COMAPS) and Geo-scientific studies of the Exclusive Economic Zone in Bay of Bengal. In addition, Sagar Purvi was used by National Institute of Oceanography (NIO) for sampling in Arabian Sea and by National Centre for Sustainable Coastal Management (NCSCM) for water and sediment sampling to analyses of natural radioactive and biological parameters in the Arabian Sea and the Indian Ocean. Sagar Paschimi was used by the Anna University for sampling in the Arabian Sea, IIT-Madras/ESSO-INCOIS for sampling in the Bay of Bengal, Andhra University/ESSO-INCOIS for sampling in the Bay of Bengal, Indian Maritime University (IMU) Vishakhapatnam for emission test and ship behaviour study and surface water sampling in the Bay of Bengal.

National open e-tender was floated for design, construction and delivery of two coastal research vessels.

Polar Research Vessel –. All pre-construction activities related to the identification of a shipyard for construction of Polar Research Vessel (PRV) were completed.

10.3 AIRBORNE PLATFORMS

Atmospheric observations are required for better understanding of the complex atmospheric processes involving aerosols, clouds and their interaction, for their accurate representation in weather and climate models. Ground based and satellite observations have some limitations in making targeted atmospheric observations and thus highlight the need for airborne measurements. With this motivation, a programme of the National Facility for Airborne Research (NFAR) has been initiated. It is proposed to procure a twin turbo-prop engine aircraft along with a host of observational sensors for measurement of atmospheric processes including weather parameters, aerosol, trace gases, radiation, atmospheric electricity and microphysics of clouds. The proposed aircraft will also be equipped with a weather radar and atmospheric LiDAR.

AWARENESS AND OUTREACH PROGRAMMES

The objective of the programmes is to propagate and bring awareness about the activities among the public, student and user communities. This is ensured through participation in National and International exhibitions, sponsoring seminars, symposia, workshops in the area of earth system science, with a view to develop scientific temperament among masses and to provide platform to academicians, scientists, students, researchers, etc.

11.1   EXHIBITIONS

During the year we participated in 24 International and National Exhibitions. The important among then were,

a.   "India International Trade Fair-2014", 14th – 27th November 2014 at the Pragati Maidan, New Delhi.

b.   "Indian Science Congress-2015" from 3rd – 7th January 2015 in Mumbai.

c.   "Vibrant Gujarat - 2015" from 7th – 13th January 2015 in Gandhinagar.

Fig 11.1 - India International Trade Fair 2014, New Delhi

Fig 11.2 - Indian Science Congress 2015, Mumbai

Fig 11.3 - Vibrant Gujarat 2015, Gandhinagar

Some National Exhibitions were,

a.   Foundation Day of the Ministry, 27th July 2014, Vigyan Bhawan, New Delhi.

b.   6th Edition of Agrovision - 2014, 4th – 7th December 2014, Nagpur.

c.   Aavishkar Expo 2014 - The Rural Technologies Fair, 14th – 16th December 2014, Kangra.

d. International Conference and Exhibition on Materials Engineering, Technology + Heart Treatment - Met + HTS - 2014, 4th – 6th December 2014, Gandhinagar.

e. 21st MTNL Perfect Health Mela - 2014, 15th – 19th October 2014, New Delhi.

f. WaterEX + Chemtech World Expo - 2015, 28th – 31st January 2015, Mumbai.

g. Northern India International Trade Fair - 2014, 11th – 15th October 2014, Dehradun.

h. Vibrant India - 2014, 17th – 19th October 2014, New Delhi.

i. India-U.S. Technology Summit and Knowledge Expo - 2014, 18th – 19th November 2014, Indian Expo Centre, Greater Noida Delhi NCR.

Fig 11.5 - 18th National Science Exhibition on the theme of Service to the Nation for the progress of India held from 20th – 26th September 2014 at Kolkata

The activities were showcased in following rural exhibitions as well:

a. "Acharya Satyendranath Basu Smarak Bijnan O Prajukti Mela-2015", 28th January – 1st February 2015, Hedua, Kolkata.

b. "Vigyan Mela", 09th – 11th December 2014, Mahatma Gandhi P.G College, Gorakhpur.

c. "i-STEM: a Science, Technology, Engineering and Mathematics Demonstration Exhibition", 18th – 20th September 2014, Saharsa, Bihar.

d. "Indian National Exhibition-Cum-Fair-

Fig 11.4 - Vibrant India 2014 held from 17th – 19th October 2014 at New Delhi

2014, theme India as a Great Nation, Advancing Towards", 20th–26th September 2014, Science City Ground, Kolkata.

e. "18th National Science Exhibition on the theme of Service to the Nation for Progress of India", 3rd – 7th September 2014, Amarabati Maidan, Kolkata.

The Mobile Exhibition Vehicle to display earth system science activities to create awareness amongst students and general public in rural areas including School, College, Universities at Villages, Mandals, Talukas, District Headquarters, Cities, etc. has been undertaken. An 'Exhibition on Wheels' was launched in 2012, which covered 29 locations in Gujarat, 37 locations in Maharashtra, 14 locations in Goa, 21 locations in Karnataka, 20 locations in Kerala and 34 locations in Tamil Nadu.

Fig 11.6 - Exhibition on Wheels in Maharashtra, Goa and Karnataka

11.2   EARTH DAY CELEBRATION - 2014

"Earth Day" has been celebrated across the country on 22nd April 2014. The event was organized at 90 locations across the country including schools, colleges and universities. The theme was "Celebrating Our Planet". The organizers arranged various competitions like drawing and painting, debate, essay, cycle rally amongst various age groups and cash prizes were offered to the students. Popular lectures were delivered by eminent scientists/local scholars on Earth Science related topics. About 5000 children participated, prizes at National level were distributed on Ministry's foundation day.

Fig 11.7- Painting Competition, Tree plantation, lectures, debate competitions, street play etc. were organized in different parts of the country as part of Earth Day Celebration – 2014

11.3 OZONE DAY CELEBRATION - 2014

"Ozone Day" has been celebrated across the country on 16th September 2014 and the event was organized at 15 locations across the country in the similar manner. About 2500 children participated in this event.

Fig 11.8 - Ozone Day Celebration – 2014 in different parts of the country

Fig 11.9 - Awards for Painting Competitions of Earth Day 2014 at Vigyan Bhawan

11.4 PARTICIPATION IN INTERNATIONAL EARTH SCIENCE OLYMPIAD

8th International Earth Science Olympiad 2014 was held at Spain, in September 2014. Children from 27 Countries participated in the event with 90 students, including 11 guest-students. Indian team won three silver medals and one bronze medal.

Fig 11.10 - International Earth Science Olympiad

11.5 SEMINAR, SYMPOSIA, CONFERENCE AND WORKSHOP

230 events are being supported in area of Earth System Science to provide platform to scientists, engineers, technologists, experts, social scientists and user communities. The beneficiaries are National Institutes, CSIR labs, Universities, Non-Governmental Organizations, government bodies, etc. Few major areas supported include climate change and impact on health; weather modification technology; disaster management; coastal dynamics; aquaculture; environmental pollution and its effects on agriculture and human health; marine ecosystem; agro meteorological services, space technology and applications; geological science; snow and avalanches processes; mathematical modeling and simulation, etc.

INTERNATIONAL COOPERATION

Research and development in the Earth System Science is global in nature and thus require international participation. Engaging with the best institutes overseas in the field of earth system science broadens the scope of trans-national research through linking researchers with different skills and expertise in various countries and enriching the experience with overseas partners, introducing them to new skills and ideas. This also enables participation in large-scale research and observational programs that require international participation. This is facilitated by bringing together the best researchers and facilities wherever they are placed in the world. This in turn helps in intelligent and cost-effective use of infrastructure required for research, and sharing of ideas. Therefore ESSO regularly engages with scientists overseas for furthering its research capabilities for better delivery of reliable services. Towards this direction ESSO has undertaken collaboration with various International organizations. The progress under various collaborations is as follows.

12.1   COOPERATION WITH NOAA, USA:

Under this MoU originally signed in 2008, ten joint research and development activities have been undertaken with identified PIs from India and US with well defined objectives and deliverables in the field of monsoon, ocean observations, tropical cyclone, tsunami, INSAT 3D, Predictive Capabilities on Marine Fisheries and Harmful Algal blooms etc. Considerable progress has been made on the Statement of Intent (SOI) for "Operational Wave Modeling and Assimilation" that was signed on 14th

November 2014 during the Indo-US Joint meeting. The SOI will enable undertaking development of an ocean wave modeling and assimilation system for the Indian Ocean Region and enhance the capability towards a skillful global wave model systems especially for monsoon conditions.

12.2   COOPERATION WITH UK MET OFFICE (UKMO):

The MoU with UKMO was signed in 2008 for exchange of technical knowledge, resources and obtaining software on "Unified Model (UM)" for weather and climate forecast that was subsequently extended. In order to have a more robust collaborative partnership on joint developmental programs among all the international partners of the UM system (UK, Korea, Australia, India) under a common governance structure, a Consortium Agreement for Core partnership at an Annual Contribution of £100,000 is being undertaken. ESSO-NCMRWF is in the process of becoming a core UM partner. The agreement will enable a mechanism to decide on joint programs for development of UM.

12.3   COOPERATION WITH NATIONAL SCIENCE FOUNDATION (NSF), USA:

Signed in July 2014, the cooperation will enable participation of India in the International Ocean Discovery Program as a member of JOIDES Resolution Consortium. This involves scientific work in the ocean, which uses drilling and logging to undertake research on earth system processes ranging from changes in the earth's

climate to the rifting and drifting of continents. Drilling in the Lakshmi basin, Arabian sea will commence during 2015.

12.4 COOPERATION WITH JAPAN AGENCY FOR MARINE EARTH SCIENCE AND TECHNOLOGY (JAMSTEC), JAPAN:

Signed in August 2014, the cooperation will enable undertaking activities in the field of earth system sciences with special emphasis on enhancing technical capabilities on research survey and exploration of ocean science phenomena.

12.5 COOPERATION WITH UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH, USA:

Under this MoU signed on 24th September 2014, enhanced cooperation involving various academic institutes in both countries for capacity building in the field of earth system sciences will be taken up. Few areas of cooperation include: Wind Profiler System Development; Radar Meteorology; Airborne platforms and Aircraft facilities; nowcasting of severe weather events; Hydrometeorology; Satellite /Remote Sensing data related research and development; Oceanographic and Climate research; Capacity Building through scientific lectures and distance learning etc.; Urban Flooding.

12.6 COOPERATION WITH KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH (KISR), KUWAIT:

Signed in November 2014, this cooperation is aimed at undertaking Scientific Research and Technology Development in field of earth system sciences.

12.7 COOPERATION WITH WOODS HOLE OCEANOGRAPHIC INSTITUTION (WHOI), USA:

Signed in February 2015, this cooperation is aimed at undertaking joint work in the field of ocean science and technology.

12.8 COOPERATION WITH NERC (NATURAL ENVIRONMENTAL REGIONAL COUNCIL):

The Ministry and the Natural Environmental Research Council (NERC) of UK, entered into an MoU with the objective of articulating a set of high priority research initiatives towards addressing the seminal issues raised by the changing Water Cycle with special emphasis on South Asia. Five joint projects awarded are showing good progress. Monsoon research is another initiative undertaken under this MoU where there is commitment of about three million euro from UK side with matching funding from the Ministry.

12.9 COOPERATION WITH BELMONT FORUM COUNTRIES:

An MoU was signed with the Belmont forum countries, which is a group of the world's major and emerging funders of global environmental change research and international science councils, to support Indian scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. Presently India is participating in four Collaborative Research Areas (CRAs) namely Coastal Vulnerability, Food Security and Biodiversity. The CRA on Climate Services and Inter-regional linkages as proposed by the Ministry is scheduled for launch in April 2015.

12.10 COOPERATION WITH RESEARCH COUNCIL OF NORWAY (RCN):

An MoU was signed on 14th October 2014 during the state visit of Honorable President of India to Oslo, Norway. Under this MoU, joint programs on common areas of interest will be developed through joint calls in the field of earth system sciences. Following two workshops on geo-hazards and polar research in India in 2013, joint call inviting proposal with Indian and Norwegian participants side is being launched in February 2015 to submit proposals on the above two themes. Following

a joint review mechanism, the full proposal is likely to be funded by October 2015.

12.11 COOPERATION WITH UNESCO/ IOC:

Following the agreement signed in 2013, on activities related to capacity building through International Training Centre for Operational Oceanography, three international training courses of one week duration were held in June, August and November 2014. This involved international faculty with participation from nine Indian Ocean Rim countries.

12.12 BIMSTEC CENTER FOR WEATHER AND CLIMATE:

Following the signing of MoA in March 2014 for establishment of the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation BIMSTEC) Center for Weather and Climate, a training workshop on "Improved Weather and Climate Predictions" was held during 26th August – 1st September 2014 at ESSO-NCMRWF and three IOA countries participated in the workshop.

12.13 FINANCIAL SUPPORT:

International special scientific events are financially supported by the Ministry that has direct relevance and linkage with the Ministry's activities and vision. It also includes encouragement of young researchers to participate in these events. The following financial support was provided by the Ministry during the year:

- Financial support of USD 5000.00 to Committee on Space Research (COSPAR) was given to sponsor certain scientific events for the 40th COSPAR Scientific Assembly and Associated Events and to support participating needy scientists whose papers were accepted for presentation. The event was held during 2nd – 10th August 2014 in Moscow, Russia.

- Provided financial assistance of USD 10,000.00 towards supporting the meeting of SPIE Asia-Pacific Remote Sensing Event in Beijing, China held on 13th – 16th October 2014 and to cater to travel of some young needy scientists and researchers from developing countries.

PUBLICATIONS

RESEARCH PAPERS

Atmospheric and Climate Processes and Modeling

1. Abhik S., Mukhopadhyay P., Goswami B.N., Evaluation of mean and intraseasonal variability of Indian summer monsoon simulation in ECHAM5: identification of possible source of bias, **Climate Dynamics**, 43, July 2014, DOI:10.1007/s00382-013-1824-7, 389-406 **(Impact Factor 4.231)**

2. Abhilash S., Sahai A. K., Pattnaik S., Goswami B.N., Arun Kumar, Extended range prediction of active-break spells of Indian summer monsoon rainfall using an ensemble prediction system in NCEP Climate Forecast System, **International Journal of Climatology**, 34, January 2014, DOI:10.1002/joc.3668, 98-113 **(Impact Factor 2.886)**

3. Abhilash S., Sahai A.K., Borah N., Chattopadhyay R., Joseph S., Sharmila S., De S., Goswami B.N., Does bias correction in the forecasted SST improve the extended range prediction skill of active-break spells of Indian summer monsoon rainfall?, **Atmospheric Science Letters**, 15, June 2014, DOI:10.1002/asl2.477, 114–119 **(Impact Factor 1.750)**

4. Abhilash S., Sahai A.K., Borah N., Chattopadhyay R., Joseph S., Sharmila S., De S., Goswami B.N., Arun Kumar, Prediction and monitoring of monsoon intraseasonal oscillations over Indian monsoon region in an ensemble prediction system using CFSv2, **Climate Dynamics**, 42, May 2014, DOI:10.1007/s00382-013-2045-9, 2801-2815 **(Impact Factor 4.231)**

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AWARDS AND HONOURS

1. Indian National Tsunami Early Warning System, ESSO-INCOIS has been awarded the Sustainability Award of CSI-Nihilent e-Governance Awards 2013-2014 on Saturday, 13th December 2014 at Jawaharlal Nehru Auditorium, JNTU, Kukatpally, Hyderabad as part of 49th Annual Convention of Computer Society of India (CSI-2014).

2. A paper titled "A study of deep sea channels in the Arabian Sea: a GIS approach", authored by Prerna R., Dhananjai K. Pandey and Ravi Mishra of ESSO-NCAOR has been awarded the 2nd runner-up position for Best Student Paper Presentation.

3. Dr. Anish Kumar Warrier, Research Scientist 'B' of ESSO-NCAOR has been elected as the Secretary of the International Geoscience Education Organisation (affiliated to the IUGS) for a tenure of four years (2014-2018).

4. Ms Sahina Gazi, Scientific Assisstant Grade 'A' of ESSO-NCAOR received the Microscopy Award for the First Best SEM Life Science Micrograph during an International Conference on Electron Microscopy and XXXV Annual Meeting of the Electron Microscope Society of India, jointly organised by University of Delhi and Electron Microscope Society of India (EMSI), held at Delhi during 7-11 July 2014.

5. Dr. R. Ajayakumar Varma, Scientist 'G' of ESSO-NCESS has been nominated as Member of the Technical Support Group of Solid Waste Management by Government of Tamil Nadu.

ADMINISTRATIVE SUPPORT

15.1 CITIZEN'S CHARTER

The Charter is given below. The potential areas of services are:

i. To improve dissemination of weather forecast to various sectors like agriculture, aviation, sports, urban areas, defence, etc.

ii. To provide wide-range ocean information services for sectors like fisheries, shipping, navy, coast guard, etc.

iii. To develop technology for exploring and harnessing marine resources in a sustainable way.

iv. To undertake and support cryospheric research in the Antarctica, the Arctic and the Himalayas.

v. To monitor earthquakes, conduct seismological and geosciences research.

vi. To provide early warning on natural disasters like cyclone, storm surge and tsunami, etc.

vii. To assess the coastal and ocean marine living resources.

viii. To encourage formulation of research and development schemes in the earth system science, create capacity building and promote human resource development.

ix. To extend support to seminars, symposia, conferences, exhibitions, etc. and process applications for grants to organize seminars/symposia/conferences/exhibitions.

x. To create awareness about earth system science sector by participation in educational programmes, exhibitions and trade fairs and through partnership with NGOs.

xi. This Charter is a declaration of vision, mission, values and standards and commitment to act in manner to achieve excellence for improving forecast for weather, climate and hazards as well as the exploration and exploitation of vast marine resource for the socio-economic benefit of the society. All the centres of ESSO have been directed to adopt the Citizen Charter in toto.

15.2 IMPLEMENTATION OF THE 15 POINT PROGRAMME ON MINORITY WELFARE

The proper implementation of the 15 point programme on minority welfare including inter-alia, ensuring adequate representation of minority community while making recruitment, of forming Selection Committee set up for filling up of vacancies in Group A, B, C including MTS has been ensured.

15.3   BUDGET AND ACCOUNTS

Table 15.1 – BUDGET AND ACCOUNTS

(Rs. IN CRORES)

S. No.	Major Head of Account	2012-13 Actuals			2013-14 Actuals			2014-15 Budget Estimates			Expenditure 2014-15 up to 28.02.2015		
		Plan	Non-Plan	Total	Plan	Non-Plan	Total	Plan	Non-Plan	Total	Plan	Non-Plan	Total
REVENUE SECTION													
1	3403 - Oceanographic Research	467.14	52.41	519.55	438.63	46.70	485.33	560.00	54.75	614.75	410.02	36.30	446.32
2	3425 - Other Scientific Research	135.62	28.69	164.31	227.14	22.39	249.53	314.00	31.95	345.95	237.27	27.54	264.81
3	3451 - Secetariat Expenditure	0.00	21.71	21.71	0.00	23.53	23.53	0.00	26.67	26.67	0.00	23.85	23.85
4	3455 - Meteorology	89.62	258.53	348.15	120.13	274.62	394.75	220.00	304.57	524.57	151.75	290.15	441.90
CAPITAL SECTION													
1	5403 - Capital outlay on Oceanograpic Research	4.99	0.00	4.99	5.24	0.00	5.24	15.00	0.00	15.00	0.25	0.00	0.25
2	5425 - Capital outlay on Other Scientific and Enviromental Research	9.03	0.00	9.03	7.84	0.00	7.84	35.00	0.00	35.00	15.23	0.00	15.23
3	5455 - Capital Outlay on Meteorology	104.60	0.07	104.67	77.02	0.05	77.07	137.00	0.06	137.06	29.47	0.01	29.48
	Grand Total	811.00	361.41	1172.41	876.00	367.29	1243.29	1281.00	418.00	1699.00	843.99	377.85	1221.84

15.4   REPORT OF THE CONTROLLER AND AUDITOR GENERAL OF INDIA

Table 15.2 – Report of the Comptroller and Auditor General of India

The number of Action Taken Notes (ATNs) pending for Ministry of Earth Sciences taken from various C&AG reports.

S. No.	Year	No. of Paras/ PAC reports on which ATNs have been submitted to Monitoring Cell after vetting by Audit	Details of the C&AG paras/PAC reports on which ATNs are pending			No. of ATNs with Audit
			No. of ATNs not sent by the Ministry even for the first time	No. of ATNs sent but returned with observations and audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by Audit but have not been submitted by the Ministry to PAC	
1	2007	NIL	NIL	One- Para 5.1 Report No. CA 2 of 2007 "Wasteful Expenditure of Rs. 33.08 lakh by IMD for procurement of precision Ni-span 'C'- India Meteorological Department (IMD).	NIL	NIL
2	2008	NIL	NIL	One- Para 7.1 Report No, CA 3 of 2008 "Non-achievement of the objectives of Modernizing the Accounting & Personnel Management Functions".	NIL	NIL
3	2009	NIL	NIL	One - Para 7.1 Report no. CA 16 of 2008-09 "Construction of Residential Quarters and Hostel Units without demand".	NIL	NIL
4	2013	NIL	NIL	One - Para 8.1 Report No. CA 22 of 2013 "Irregular Introducation of pension scheme and diversion of funds at INCOIS, Hyderabad".	NIL	Nil

15.5   STAFF STRENGTH

The sanctioned strength of the Ministry of Earth Sciences including attached offices and autonomous institutions is 1126 during the year 2014-2015. The detailed break up is given below:

Table 15.3 – Staff Strength

Ministry/ Attached Offices	Scientific/ Technical Posts	Non-Technical Posts	Grand Total
Ministry Headquarters	41	123	164
National Centre for Medium Range Weather Forecasting (NCMRWF), Noida	57	33	90
Centre for Marine Living Resources and Ecology (CMLRE), Kochi	23	10	33
Integrated Coastal and Marine Area Management (ICMAM), Chennai	19	7	26
National Center for Seismology (NCS)	11	0	11
National Institute of Ocean Technology (NIOT), Chennai	144	24	168
Indian Institute of Tropical Meteorology (IITM), Pune	230	84	314
National Center of Antarctica and Ocean Research (NCAOR), Goa	53	34	87
Indian National Center for Ocean Information Services (INCOIS), Hyderabad	63	11	74
National Center for Earth Science Studies (NCESS), Thiruvananthpuram	101	58	159
Total	**742**	**384**	**1126**

15.6 REPRESENTATION OF SCS/ STS/ OBCS IN GOVERNMENT SERVICES IN RESPECT OF MINISTRY

Table 15.4 – SCs/ STs/ OBCs Representation

Group	Representation of SCs/ STs/ OBCs as on 1.1.2015				Number of appointments made during the calendar year 2014											
					By Direct Recruitment				By Promotion				By Deputation			
	Total Employee Count	SCs	STs	OBCs	Total	SCs	STs	OBCs	Total	SCs	STs	OBCs	Total	SCs	STs	OBCs
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Group A	49	9	3	5	0	0	0	0	0	0	0	0	0	0	0	0
Group B	41	8	3	2	1	1	0	0	0	0	0	0	0	0	0	0
Group C including MTS	59	22	4	7	1	1	0	0	0	0	0	0	0	0	0	0
Total	149	39	10	14	2	2	0	0	0	0	0	0	0	0	0	0

15.7 REPRESENTATION OF PERSONS WITH DISABILITIES IN GOVERNMENT SERVICES

Table 15.5 – Persons With Disabilities Representation

Group	Direct Recruitment								Promotion							
	No. of vacancies reserved				No. of appointments made				No. of vacancies reserved				No. of appointments made			
	VH	HH	OH	Total	Unidentified Posts	VH	HH	OH	VH	HH	OH	Total	Unidentified Posts	VH	HH	OH
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Group A	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Group B	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Group C	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

15.8 OFFICIAL LANGUAGE IMPLEMENTATION

Efforts are made constantly for the promotion of the Official Language. Under the Prithvi Vigyan Mantralya Maulik Pustak Lekhan Yojana-2013, the Ministry awarded third prize (Rs 30,000/-) to the book titled Paryavaran Chetna (Part-2) by Dr. Chandrawatijee and Dr. Gajendra Dev Sharma. A Hindi Fortnight was organized from 1st to 15th September 2014. During this period, various Hindi Competitions were organized to create an atmosphere conducive to use of Hindi in the official work. The Cash Incentive Scheme for original work in Hindi introduced by the Department of Official Language has been implemented and cash awards were awarded to 10 employees. An Incentive Scheme for officers for giving dictation in Hindi is in operation. The Committee of Parliament on Official Language inspected the Regional

Meteorological Centre, Chennai office on 13th February 2015. On 22nd December 2014 one Hindi Workshop was also organized on the topic of "Computer and Hindi" for all the officers/employees. One official Language inspection of Indian National Centre for Ocean Information Services, Hyderabad was done on 11th to 13th November 2014.

15.9   IMPLEMENTATION OF ORDERS OF CAT / COURT JUDGEMENTS

All the judgements/ orders of Hon'ble CAT and any other court have been implemented or contested in proper fora within the stipulated period of time.

15.10   PARLIAMENT MATTERS

The Parliament Section, which caters to the correspondence with the Parliament Secretariats, replied Lok Sabha (53 questions) and Rajya Sabha (24 questions) questions last year.

15.11   VIGILANCE ACTIVITIES AND ACHIEVEMENTS

Consequent to the retirement of Dr. S.K. Das, Scientist G and CVO on 31-12-2014, Dr. M.P. Wakdikar, Scientist G has taken over as the CVO of the Ministry with effect from 01-01-2015. Senior level officers have been appointed as VOs in attached/ subordinate offices and autonomous bodies. A preventive as well as punitive vigilance monitoring is rigorously pursued through the CVO and VOs.

A standing committee to deal with cases of sexual harassment at workplace, in line with extant instructions is in existence. No complaints of sexual harassment have been reported last year. No case has been disposed off during the year. No case has been pending for more than 90 days. No live complaints at present exist.

15.12   SIGNIFICANT AUDIT POINTS PRINTED IN AUDIT REPORTS OF 2014

15.12.1 National Data Buoy Project

National Institute of Ocean Technology achieved limited success in achieving the objective of indigenising technology for production and deployment of buoys in the ocean even after 12 years of implementation. Low cost meteorological buoys developed indigenously to supplement the buoy project were not being used for intended purpose. Attempts to establish communication through Indian satellite remained at the trial stage as of July 2014. A dedicated vessel procured for deployment of data buoys was barely used for intended purpose. (Paragraph 5.1)

15.12.2 Irregular Payment of Gratuity

Ministry of Earth Sciences irregularly permitted its autonomous bodies to change the service conditions of their regular employees from those envisaged under the provisions of CCS Pension Rules, 1972 to the Payment of Gratuity Act, 1972. Based on this permission, National Institute of Ocean technology, Chennai paid gratuity of Rs. 68.88 lakh to 54 regular employees who had resigned from service, with retrospective effect. (Paragraph 5.2)

PERFOMANCE EVALUATION REPORT

Performance Evaluation Report for Ministry of Earth Sciences [Achievement Submitted] (2013-2014)

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)	Achievement	Raw Score	Weighted Score
1	To improve the understanding of Polar Science and its implications for climate change	12	Planning, Coordination and Implementation of Indian Antarctic Program	Launching of the 33rd Expedition	Date	4.6	20/11/2013	01/12/2013	15/12/2013	31/12/2013	15/01/2014	11/12/2013	82.86	3.81
				Submission of reports of 32nd Expedition	Date	0.39	10/10/2013	15/10/2013	20/10/2013	25/10/2013	31/10/2013	10/07/2013	100	0.39
				Publication of results in peer-reviewed journals	num.	0.56	15	13	12	10	9	14	95	0.53
			Planning, Co-ordination and Implementation of the Scientific Expeditions to the Arctic	Launching of the 7th Expedition in the Arctic region during the summer (S) and winter (W) 2013-14	Date	2.1	06/06/2013	20/06/2013	25/06/2013	30/06/2013	07/07/2013	06/08/2013	0	0
				Submission of 6th Expedition to the Arctic	Date	0.39	10/10/2013	15/10/2013	20/10/2013	25/10/2013	31/10/2013	10/10/2013	100	0.39

Performance Evaluation Report for Ministry of Earth Sciences (2013–2014)
[Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
				Publication of results in peer-reviewed journals	num.	0.27	6	5	4	3	2	4	80	0.22
			Planning, Co-ordination and Implementation of the scientific studies in the Indian Ocean sector of the Southern Ocean	Launching of 7th Southern Ocean Expedition (2013-14)	Date	2.78	15/01/2014	25/01/2014	05/02/2014	10/02/2014	15/02/2014		N/A	N/A
				Completion of analytical work of data collected during the previous expedition and submission	Date	0.64	15/11/2013	18/11/2013	22/11/2013	30/11/2013	15/12/2013	15/11/2013	100	0.64
				Publication of results in peer-reviewed journals	num.	0.27	8	6	5	4	2	8	100	0.27
2	To provide a wide range of ocean information advisories including fishery information	10	Strengthening of Ocean Observational network	Number of deployments	num.	3	250	200	175	125	100	248	99.6	2.99

Performance Evaluation Report for Ministry of Earth Sciences   (2013–2014) [Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)	Achievement	Raw Score	Weighted Score
			Potential Fishing Zone Advisory Services	Potential Fishing Zone Advisory	num.	3	250	240	230	220	210	297	100	3
			Ocean State Forecast Services	Ocean State Forecast	num.	4	365	328	292	255	219	365	100	4
3	To improve weather forecast and provide advisory to agriculture, aviation, shipping, sports including the Extended, Long Range Seasonal Monsoon forecast	21	Integrated Agro Advisory Services	Number of Districts covered by Agro Advisory	num.	2	620	610	600	575	550	600	80	1.6
				Grameen Krishi Mausam Seva (SMS)	num.	3	3700000	3500000	3400000	3300000	3100000	4000000	100	3
			Improve Operational Weather Services	Augmentation of High Performance Computing system (Tera flops from 115 to 600)	num.	3	600	540	480	420	360	790	100	3

Performance Evaluation Report for Ministry of Earth Sciences [Achievement Submitted]   (2013-2014)

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
				Strengthening of Observational Network (AWS, ARGs)	num.	4	2025	1825	1650	1500	1350	2051	100	4
				Quality Research Publications (Impact Factor) operational services	num.	2.5	240	216	192	168	144	260	100	2.5
				Operationalize higher resolution Global Numerical Models	num.	2.5	22	25	28	30	35	22	100	2.5
				Completion of Admission process of the third batch of students for the advanced training program in Earth System Sciences & Climate	num.	1.5	25	20	13	11	9	23	96	1.44
				Research Publications for operational forecast	num.	2.5	120	108	96	84	72	120	100	2.5

Performance Evaluation Report for Ministry of Earth Sciences (2013-2014)
[Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)	Achievement	Raw Score	Weighted Score
4	To assess coastal marine productivity and marine ecosystem	4	Establishment of Indian Ocean Biogeographical Information System (IndOBIS)	No. of records	num.	2	6000	4000	3000	2000	1000	4000	90	1.8
			Monitoring of levels of marine pollution at 20 locations along Indian coast	Data on all pollution parameters	num.	1	20	17	14	12	10	17	90	0.9
				Dissemination of water quality status to costal state pollution boards	num.	1	12	11	10	9	8	11	90	0.9
5	To improve understanding of climate change science	5	To set up Centre for Climate Change Research (CCCR) at IITM with dedicated research facilities	Regional Climate Projections (Scenarios)	num.	1	2045	2035	2025	2020	2015	2045	100	1
				Cumulative Impact Factor of the Research Papers	num.	2	60	54	48	42	36	100	100	2

Performance Evaluation Report for Ministry of Earth Sciences [Achievement Submitted] (2013-2014)

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
				Number of the Research Papers	num.	1	30	27	24	21	18	50	100	1
			To acquire airborne platforms for studying montoring upper air parameters	Obtaining the approval of EFC	Date	1	30/09/2013	31/10/2013	01/12/2013	28/02/2014	31/03/2014	25/05/2013	100	1
6	To provide early warning of natural hazards viz. cyclone, tsunami, sea level rise	5	Issues of Earthquake Bulletin	Timely release of Earthquake Bulletin - within 12 minutes after the earthquake	num.	2.5	12	15	18	20	25	12	100	2.5
			Issue of Tsunami Warning	Timely release of Tsunami Bulletins issued within 30 minutes after the earthquake	num.	2.5	30	35	40	45	50	30	100	2.5
7	To conduct survey for assessing non-living resources	6	Survey, Exploration for Hydrothermal Sulphides	Deployment of Research Vesse l- data collection	Sq. km.	0.51	10000	9000	8000	7000	6000	10800	100	0.51

Performance Evaluation Report for Ministry of Earth Sciences [Achievement Submitted] (2013-2014)

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
			Survey, Exploration for Exclusive Economic Zone	Completion of processing, analysing and interpretation of data collected	Date	0.85	27/03/2014	28/03/2014	29/03/2014	30/03/2014	31/03/2014	30/04/2013	100	0.85
				Deployment of Research Vessel - data collection	Sq. km.	0.35	150000	140000	130000	120000	110000	187861	100	0.35
				Completion of processing, analysing and interpretation of data collected	Date	0.51	27/03/2014	28/03/2014	29/03/2014	30/03/2014	31/03/2014	31/03/2014	60	0.31
			Survey, Exploration for CLCS	Conduct geophysical survey	line km	0.86	5000	4000	3000	2000	1000	4500	95	0.82
				Completion of report for partial claim	Date	0.35	23/03/2014	25/03/2014	29/03/2014	30/03/2014	31/03/2014		N/A	N/A

Performance Evaluation Report for Ministry of Earth Sciences   (2013-2014)
[Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
			Integrated Ocean Drilling Program (IODP)	Expert review and response to the Indian IODP proposal, Participation of Indian scientists in IODP expeditions, Liaisoning with international program agency towards IODP activities	Date	1.53	30/06/2013	31/07/2013	31/08/2013	30/11/2013	31/03/2014	01/01/2014	67.36	1.03
			GEOID	Workshop to proper seismic plan	Date	0.7	30/09/2013	31/10/2013	30/11/2013	31/12/2013	31/01/2014		N/A	N/A
			Publications	Publication of results in peer-reviewed journals	num.	0.34	10	8	6	4	2	4	70	0.24
8	To promote basic research including capacity building in the Earth System Science	4	Develop new project in Earth System	Projects supported science	num.	2.5	40	35	30	24	20	30	80	2

Performance Evaluation Report for Ministry of Earth Sciences (2013-2014) [Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
			To set training centres in the field of Operational Oceanography, Meteorology	Award of Construction of the hostel and Procurement of training equipment, e-classrooms	Date	1.5	01/10/2013	01/11/2013	01/12/2013	01/01/2014	01/02/2014	01/02/2014	60	0.9
9	To promote awareness and educate the public by extending support to seminars, symposia, conferences and conduct workshops with stakeholders	2	Recieving Proposals	No. of proposals supported	num.	2	10	9	8	7	6	7	70	1.4
10	To conduct research in Seismology and Geoscience	4	Strengthening of Seismic Observational Network	Deployment of broadband seismographs	num.	1.5	40	39	38	37	36	40	100	1.5
			To setup a National Centre for Seismology	Obtain the approval and launch of the programe of NCS	Date	1.5	31/10/2013	30/11/2013	31/12/2013	31/01/2014	28/02/2014	13/12/2013	85.81	1.29

Performance Evaluation Report for Ministry of Earth Sciences (2013-2014) [Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Performance	
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)		Raw Score	Weighted Score
11	To developing technology for harnessing marine resources	12	Understanding of seismic process	Preparation of DPR and circulation EFC for deep bore hole drilling in Koyna region	Date	1	15/04/2013	30/04/2013	31/05/2013	30/06/2013	31/07/2013	15/04/2013	100	1
			Technology Development for Gas Hydrates - Development of Autonomous Coring System and Sea trials	Sea trials of Autonomous Coring System (ACS) at 1500 m depth	Date	7	30/09/2013	31/12/2013	31/01/2014	28/02/2014	31/03/2014	30/04/2013	100	7
			Development of Deep-sea Mining Equipment for 6000 m – Phase-I	Realization of large Bentonite tank test set up and under carriage testing. Deep-sea subsystems testing for higher pressure.	Date	5	15/02/2014	28/02/2014	15/03/2014	28/02/2014	31/03/2014	28/02/2014	90	4.5
*	Efficient Functioning of the RFD System	3	Timely submission of Draft RFD 2014-15 for Approval	On-time submission	Date	2	05/03/2014	06/03/2014	07/03/2014	08/03/2014	11/03/2014	05/03/2014	100	2

Performance Evaluation Report for Ministry of Earth Sciences (2013-2014)
[Achievement Submitted]

S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)	Achievement	Raw Score	Weighted Score
			Timely submission of Results for 2012-13	On-time submission	Date	1	01/05/2013	02/05/2013	03/05/2013	06/05/2013	07/05/2013	30/04/2013	100	1
*	Transparency/ Service delivery Ministry/ Department	3	Independent audit of implementation of Citizens'/ Clients' Charter (CCC)	% of implementation	%	2	100	90	80	70	60	61	61	1.22
			Independent audit of implementation of Public Grievance Redressal System	% of implementation	%	1	100	90	80	70	60	79.19	79.19	0.79
*	Administrative Reforms	6	Implement mitigating strategies for reducing potential risk of corruption	% of implementation	%	1	100	95	90	85	80	100	100	1
			Implement ISO 9001 as per the approved action plan	% of implementation	%	2	100	95	90	85	80	100	100	2

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S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Target/Criteria Value					Achievement	Raw Score	Weighted Score
							Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)			
			Identify, Design and Implement major innovations	Timely submission of Action Plan for enabling innovation	Date	2	15/05/2014	16/05/2014	19/05/2014	20/05/2014	21/05/2014		N/A	N/A
			Identification of core and non-core activities of the Ministry/Department as per 2nd ARC recommendations	Timely submission	Date	1	24/03/2014	25/03/2014	26/03/2014	27/03/2014	28/03/2014	24/01/2014	100	1
*	Improving Internal Efficiency/Responsiveness	2	Update departmental strategy to align with 12th Plan priorities	Timely updation of the strategy	Date	2	10/09/2013	17/09/2013	24/09/2013	01/10/2013	08/10/2013	10/09/2013	100	2
*	Ensuring compliance to the Financial Accountability Framework	1	Timely submission of ATNs on Audit paras of C&AG	Percentage of ATNs submitted within due date (4 months) from date of presentation of Report to Parliament by CAG during the year	%	0.25	100	90	80	70	60	75	75	0.19

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S. No.	Objective	Weight	Action	Success Indicator	Unit	Weight	Excellent (100%)	Very Good (90%)	Good (80%)	Fair (70%)	Poor (60%)	Achiev-ement	Raw Score	Weighted Score
			Timely submission of ATRs to the PAC Sectt. on PAC Reports	Percentage of ATRS submitted within due date (6 months) from date of presentation of Report to Parliament by PAC during the year	%	0.25	100	90	80	70	60	62	62	0.16
			Early disposal of pending ATNs on Audit Paras of C&AG Reports presented to Parliament before 31.3.2014	Percentage of outstanding ATNs disposed off during the year	%	0.25	100	90	80	70	60	65	65	0.16
			Early disposal of pending ATRs on PAC Reports presented to Parliament before 31.3.2014	Percentage of outstanding ATRS disposed off during the year	%	0.25	100	90	80	70	60	60	60	0.15

*Mandatory Objective(s)

ACKNOWLEDGEMENTS

Earth System Science Organization
Ministry of Earth Sciences
Government of India

ESSO