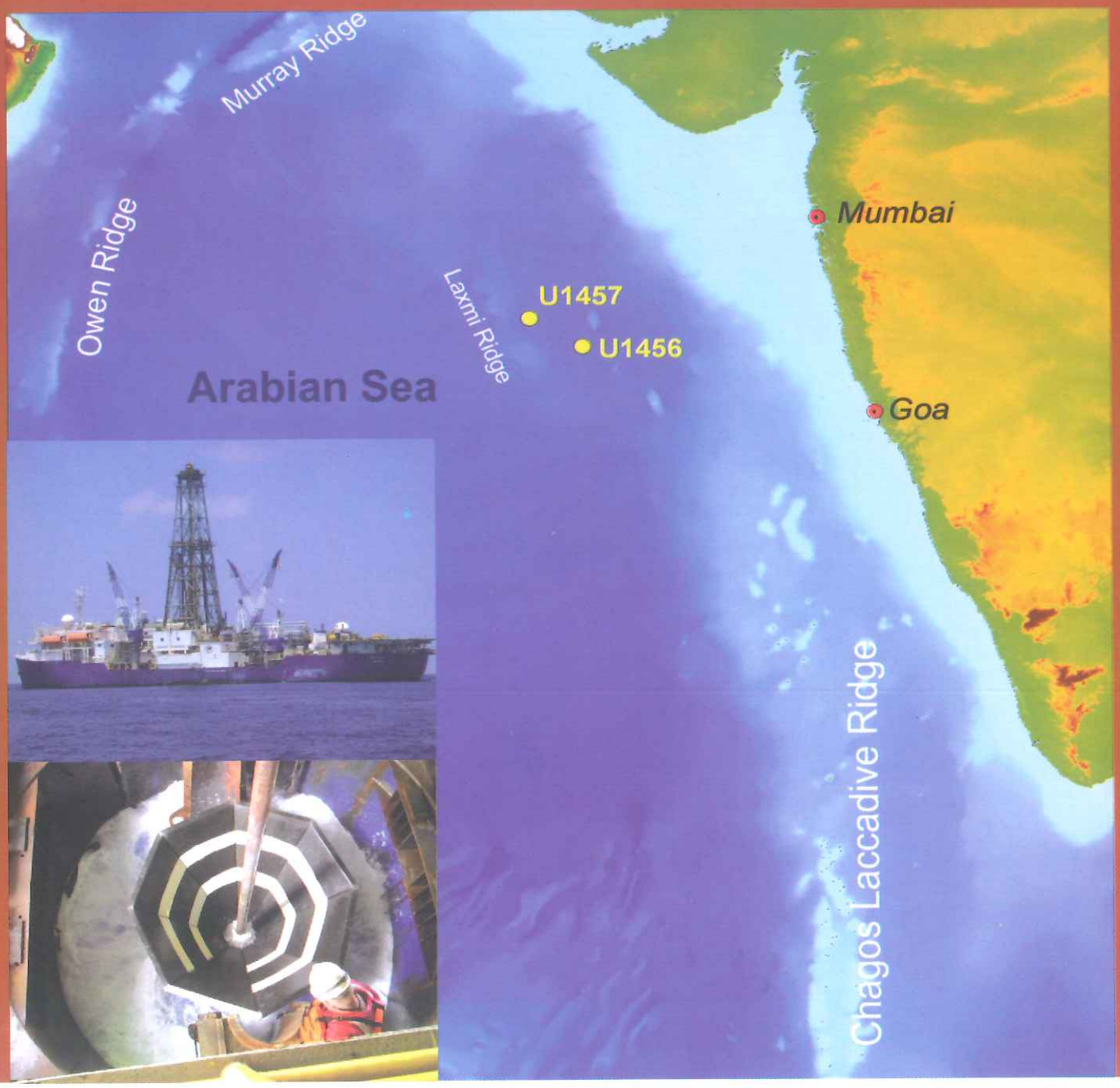
ANNUAL REPORT
2015-2016



सत्यमेव जयते

Government of India
Ministry of Earth Sciences

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ANNUAL REPORT 2015-2016

ESSO

Earth System Science Organization
Ministry of Earth Sciences
Government of India

CONTENTS

Chapter – 1

OVERVIEW

Ministry of Earth Sciences has been striving to address a wide range of issues relating to earth system science with a view to study the complex interactions among various components of the system namely, atmosphere, oceans, cryosphere, geosphere and biosphere. The objective of this endeavor is to improve our understanding of the earth system and its components leading to improvement of the services for socio-environment benefits of the country. In 2015, several major milestones have been accomplished and it has been overall a productive year. The important achievements include (i)International Indian Ocean Expedition (IIOE) (ii)International Ocean Drilling Program (iii)Strengthening of the Polar Observations (iv)Ocean Mixing Monsoon Experiments (v) Improved weather Forecasts and the seasonal monsoon forecast for the year 2015 (vi) Winter Fog Campaign 2015-16 (vii)Borehole Geophysical Research Laboratory (BRGL) (viii) Nepal Earthquake Monitoring (ix)Ocean State Forecasts.

The salient features of the activities carried out under the various schemes are summarized as under.

1.1 Atmospheric and Climate Research, Observations Science Services (ACROSS)

2015 Southwest Monsoon Forecast vis-à-vis Actual Precipitation: The seasonal forecasts for monsoon rainfall were provided with good accuracy. For the first time, deficient monsoon rainfall during the 2015 season was predicted accurately. The forecast of the monsoon season for the country as a whole was 88% with a model error of ±4% of Long Period Average (LPA) against the actual rainfall of 86% of LPA. The predictability of active and break cycles has been improved. Quantitative Precipitation Forecast (QPF) for different river basins is provided for flood forecasting. Dynamic models were employed on experimental basis to predict quantitative precipitation associated with the monsoon.

Out of the total 36 meteorological subdivisions, 18 subdivisions constituting 55% of the total area of the country received normal seasonal rainfall and 17 subdivisions (39% of the total area of the country) received deficient seasonal rainfall. One subdivision (West Rajasthan) constituting 6% of the total area of the country received excess rainfall. Monthly rainfall over the country as a whole was 116% of LPA in June, 84% of LPA in July, 78% of LPA in August, and 76% of LPA in September. The monsoon onset over Kerala for this year was on 5th June against the forecast of 30th May ± 4 days.

Agro-Meteorological Advisory Services (AAS): The AAS services have been extended to district level from the agro-climatic zone level (cluster of 4-6 districts) and now covers 608 districts of the country. Currently, over 11.54 million farmers are receiving crop specific advisories under the AAS services in regional languages. Block level forecast for 37 districts (342 blocks) has been initiated in pilot mode.

Winter Fog Campaign 2015-16: Recognizing the importance of fog forecasting for Aviation sector, an observational campaign was launched to understand different physical features of fog and factors responsible for its genesis, intensity and duration. For the first time, an observational campaign was conducted at the Indira Gandhi International Airport (IGIA) and at ICAR Institute at Pusa during this winter season (2015-16) in pilot mode.

1.2 Ocean Services, Technology, Observations, Resources, Modeling and Science (O-STORMS)

Autonomous Coring System (ACS) sea trials were conducted and drilling qualification trial was conducted at 1057m water depth in KG basin, Bay of Bengal with drilling up to 24m below the sea floor. Similar trial was conducted at 816m water depth, offshore Chennai with drilling up to 40m below the sea floor. The Corner Stone Laying function of ESSO-National Institute of Ocean Technology (NIOT), Nellore was held on 25th April 2015. A baseline survey for analysis of physico-chemical and biological parameters of the water from Buckingham Canal, Swarnamukhi River and open sea of Pamanji coast at the newly inaugurated seafront facility near Nellore, Andhra Pradesh has been successfully completed for a period of one year. As part of marine algal biotechnology, biodiesel was extracted and with this fuel, ESSO-NIOT vehicle was successfully operated from Nellore to Chennai on 25th April 2015.

Towards feasibility studies on fixed and floating platform for offshore wind turbine, activities were initiated to carry out geotechnical investigations at 10m water depth at Jakhau and Navlakhi, Gujarat for the installation of offshore LIDAR platform. Drifter buoy with INSAT communication has been working satisfactory with good data transmission. A vector sensor has been developed and sea trial conducted successfully in shallow waters off Chennai. Olaikuda fishermen self-help group successfully cultured and harvested 7.0 tonnes of cobia in the open sea cage with the technical guidance of NIOT.

Ministry has taken up the responsibility of guarding Indian sea waters from invasive species. With this, India will soon join select club of nations like Singapore and Japan to have its own ballast water treatment and testing facility, a pre-requirement as per the International Maritime Organization (IMO), to prevent attack of invasive species both in Indian and international waters.

Ocean Science and Services: The Indian Tsunami Early Warning Centre (ITEWC) kept the watch of all tsunamigenic earthquakes in and around the Indian Ocean and issued appropriate messages in the event of any threats from potential tsunamis. The early warnings by the ministry on the wind-waves and storm surges during the occurrence of cyclone 'Ashoba' (during 8-10 June, 2015) helped the authorities to reduce the damages to the property and loss of life. The Coast Guard appreciated the timely assistance that helped in the search of missing Coast Guard aircraft off-the coast of Karaikal on 11th June 2015. MoES extended the ocean forecast services to two other Indian Ocean Rim countries, Sri Lanka and Seychelles. The Ocean State Forecast

services for neighbouring countries, Seychelles and Sri Lanka was inaugurated on 10th July 2015 by the Union Minister for Earth Sciences, Dr. Harsh Vardhan in New Delhi. The potential fishing zone (PFZ) advisories and specific advisories (Tuna) to fishermen were also continued. An atlas of the PFZ advisories was prepared for ready reference.

The observational network was augmented by installing 11 additional Automated Weather Stations (AWS) in the vessels operated by Shipping Corporation of India and deploying 20 additional Argo floats in the Indian Ocean. Periodic maintenance were carried out to the observational platforms - RAMA moored buoy array, Wave Rider Buoy network, coastal and equatorial ADCPs, Tsunami buoy network and tide gauge network.

A cruise onboard ORV Sagar Nidhi organized during 21st August – 15th September 2015 in the northern Bay of Bengal as part of the Ocean Mixing and Monsoon (OMM) program collected very high resolution data to study the upper ocean mixing processes. Several state-of-the art instruments, including Sea Glider, underway CTD (uCTD) and Inherent Optical Profiler (IOP) were used in this observational campaign.

The second very high-resolution operational ocean forecasting system was setup for the south-eastern Arabian Sea, now covering for the entire west coast of India, as part of the ongoing High-resolution Operational Ocean Forecast and Reanalysis System (HOOFS) project. This system is capable of accurately forecasting the three dimensional structure of ocean at a spatial resolution of approximately 2.25 km x 2.25 km. R&D efforts are progressing well to setup the HOOFS for the Bay of Bengal.

Large scale fish production through mariculture is the viable alternative to cope up with the ever increasing demand for fish proteins. Towards this, an open sea cage culture mooring system was designed and developed for commercially important marine fishes in different sea conditions with the available marine engineering and biological expertise. The open sea cage culture technology seems to be an ideal alternate livelihood option for the coastal fisherfolk, generating a considerable employment opportunity in the country and pave way to achieve the fish food production targets of the nation.

A Wave Atlas for the Indian coast has been published which acts as a reference for basic wave related information, viz. design wave height, wave approach, period etc. in the public domain, hitherto not readily available. It presents the statistics derived from past information using simulated wave data. The simulation domain covers major portion of the Indian Ocean including the Bay of Bengal and the Arabian Sea.

Towards commemorating the 50th Anniversary of IIOE, the Ministry has taken a lead in launching the IIOE-2 in the Indian Ocean in coordination with Intergovernmental Oceanographic commission of UNESCO. As part of the celebration, an International Symposium on "Dynamics of the Indian Ocean: Perspective and Retrospective" was organized during 30th November to 4th December 2015 at National Institute of Oceanography (NIO) Goa. The international symposium was a grand success, in which

a total of 559 abstracts were presented by scientists from more than 38 different countries.

1.3 Polar and Cryosphere Research (PACER)

The Indian Arctic observatory deployed in July 2014 was successfully retrieved on 15th July 2015. The observatory that is designed and deployed by NIOT-OOS has functioned well and recorded one year data continuously which is a major achievement in the area of in-situ observation. New Arctic observatory (Ind ARC II) with additional biogeochemical and acoustic sensors was deployed successfully by NIOT-OOS / OA team along with NCAOR on 19thJuly 2015 in the Arctic. The next generation Tsunami surface buoy which was indigenously designed, developed and deployed as a part of Sagar Bhoomi buoy system in Bay of Bengal, was retrieved after successful functioning for more than a year and found to be in order.

The technology for the demonstration in the Polar regions has been achieved with the development of Polar Remotely Operable Vehicle (PROVe). PROVe was deployed on 9th and 10th of February 2015 at Priydarshini Lake, Antarctica. System functionality was successfully tested and it recorded the lake bed videography by black & white, color and HD camera showing the abundance of algal mats.

1.4 Seismology and Geoscience Research (SAGE)

In May 2015, two sites (U1456 and U1457) were drilled in Laxmi Basin in the eastern Arabian Sea to document the co-evolution of mountain building, weathering, erosion, and climate over a range of timescales. A set of two sediment cores were recovered from Sites U1456 and U1457 in the Laxmi Basin, penetrating 1109.4 and 1108.6 m below seafloor (mbsf), respectively.

The National Centre for Seismology with the help of its nationwide network of seismographs reported the occurrence of the 25th April 2015 Nepal earthquake (M 7.9) which occurred 80 km northwest of Kathmandu. This event was also felt in all northern, eastern and some parts of central India. The main shock produced lots of seismological and geodetic data. The strong motion accelerograph network in India has produced remarkable data which provides constraints on the attenuation relations, site response and source dynamics.

A **Borehole Geophysics Research Laboratory (BGRL)** has been set up at Karad, Maharashtra to carry out Scientific Deep Drilling Investigation in Koyna-Warna region of Maharashtra. The Koyna region located close to the west coast of India is the most outstanding example of Reservoir Triggered Seismicity (RTS). A major national project, “Scientific Deep Drilling in the Koyna Intra-plate Seismic zone of Maharashtra”, has been undertaken for directly measuring the in-situ physical properties of rocks, pore-fluid pressure, hydrological parameters, temperature and other parameters of an intra-plate, active fault zone in the near-field of earthquakes – before, during and after their occurrence.

The National Center for Seismology (NCS) was established as an attached office of the Ministry, with the objectives of inter-alia (i)provide earthquake (M≥3) related information to all user agencies in the shortest possible time (ii)earthquake hazard and risk related products of specific regions required by various agencies as mitigative measures (iii)carry out research in pure and applied seismology and earthquake precursory phenomena, earthquake processes and modeling. A project of upgradation of 44 existing seismological observatories and establishment of 34 new seismological observatories has been initiated. A total of 23 seismological observatories have been upgraded and one new observatory has been established. NCS is also involved in the microzonation studies and has just completed the seismic hazard microzonation analysis of NCT Delhi on 1:10,000 scale. NCS has taken an initiative to carry out the seismic microzonation studies for additional 30 Indian cities having population more than half a million and lying in seismic zone III, IV and V.

1.5 REACHOUT

The Regional Integrated Multi-Hazard Early Warning System (RIMES) was established for cooperation for exchanging information to deal with natural, technological and human-induced disasters particularly to minimize the loss of life and property. Twenty-three countries of the Indian Ocean are currently members of RIMES viz., Afghanistan, Armenia, Bangladesh, Bhutan, Comoros, India, Lao PDR, Maldives, Mongolia, Mozambique, Myanmar, Nepal, Papua New Guinea, Pakistan, Philippines, Seychelles, Sri Lanka, Tanzania, Thailand, Timor-Leste, Uzbekistan, and Vietnam. The 2nd RIMES Ministerial Conference held in the Ministry on 7th July 2015 reviewed the update on the status of implementation of the first RIMES Ministerial Conference recommendations and provided guidance to RIMES policies and programs and adopted the second Master Plan for the 2016-2020 period which was attended by over 29 countries.

National Facility: The dedicated Accelerator Mass Spectrometry (AMS) Measurement Facility for 14Carbon has been established at IUAC, New Delhi in March 2015 with Ministry support. The facility will be used for the measurement of 14Carbon and to measure ultra-low concentrations of the isotopes of Carbon for applications in radiocarbon dating and earth sciences. The facility has been named as MoES-IUAC AMS facility. The facility will enable researchers in India to analyze their samples for 14Carbon and radiocarbon dating.

The International Training Centre for Operational Oceanography (ITCOcean) had conducted four short term training programmes in the past one year. More than 135 participants from India and three neighboring countries attended the courses.

1.6 High Performance Computing System (HPC)

The HPC system *Bhaskara* at ESSO-NCMRWF with a peak computing power of 350 Teraflops and 67 Terabytes of memory was dedicated to the nation by the Minister for Science and Technology and Earth Sciences on 2nd June 2015. With the commissioning

of *Bhaskara*, the overall ESSO HPC Facility has increased to a peak computing power of 1.1 Petaflops.

1.7 International Interface: During the last one year, a total of six MoUs have been signed with USA, China, State of Qatar, Germany, Sweden and Bangladesh, respectively for cooperation in the field of marine scientific research and other earth system science related subjects. Several actions have been taken for implementation of programs under the respective MOUs.

1.8 Scientific Publications: There has been an exponential growth in the scientific publications of the Ministry during the past few years. In 2015-16, the number of publications and its impact factor has been 337 and 890 respectively.

1.9 Budget Expenditure: The plan outlay for the Ministry for the year 2014-15 was Rs. 1179 crores which had been reduced to Rs. 1013 crores at the RE stage. The major sector-wise allocations for the year and expenditure profile for the last nine years have been depicted in the chart below.

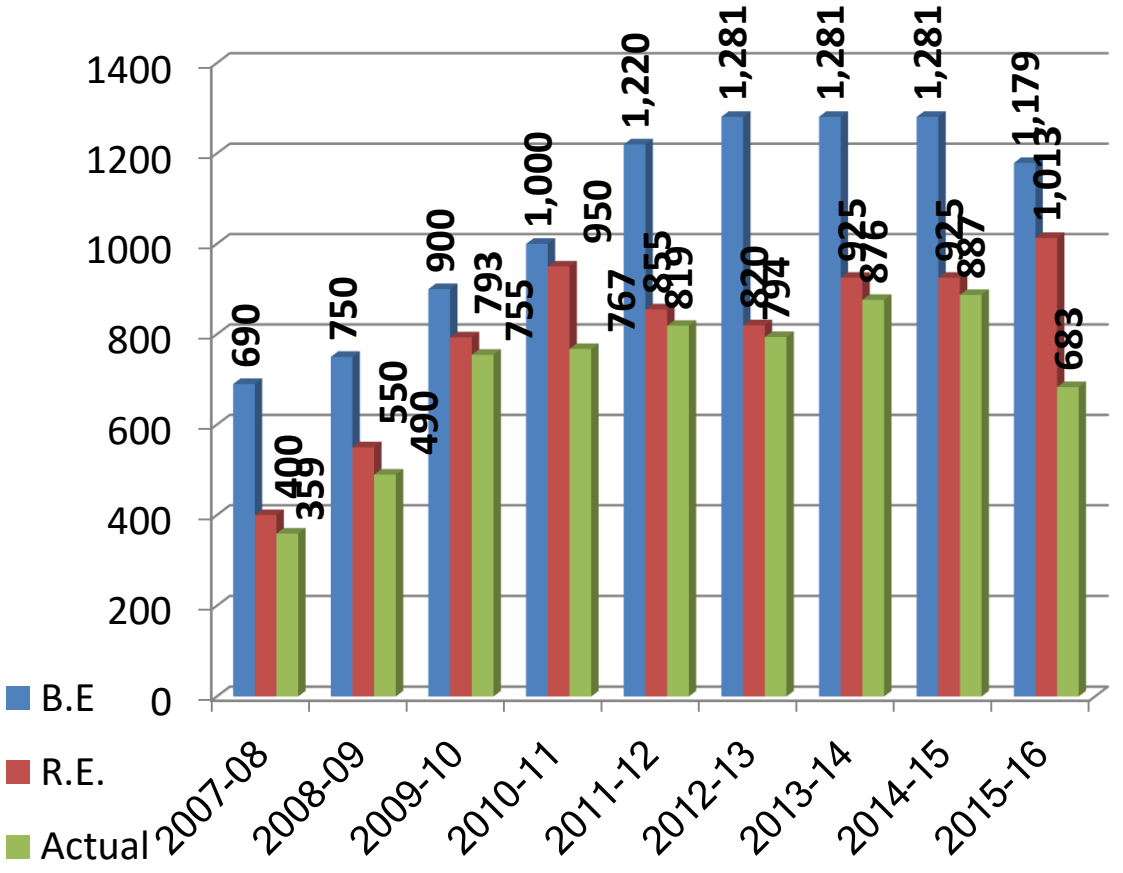

Fig. 1.1 Expenditure profile of the Ministry during the last nine years

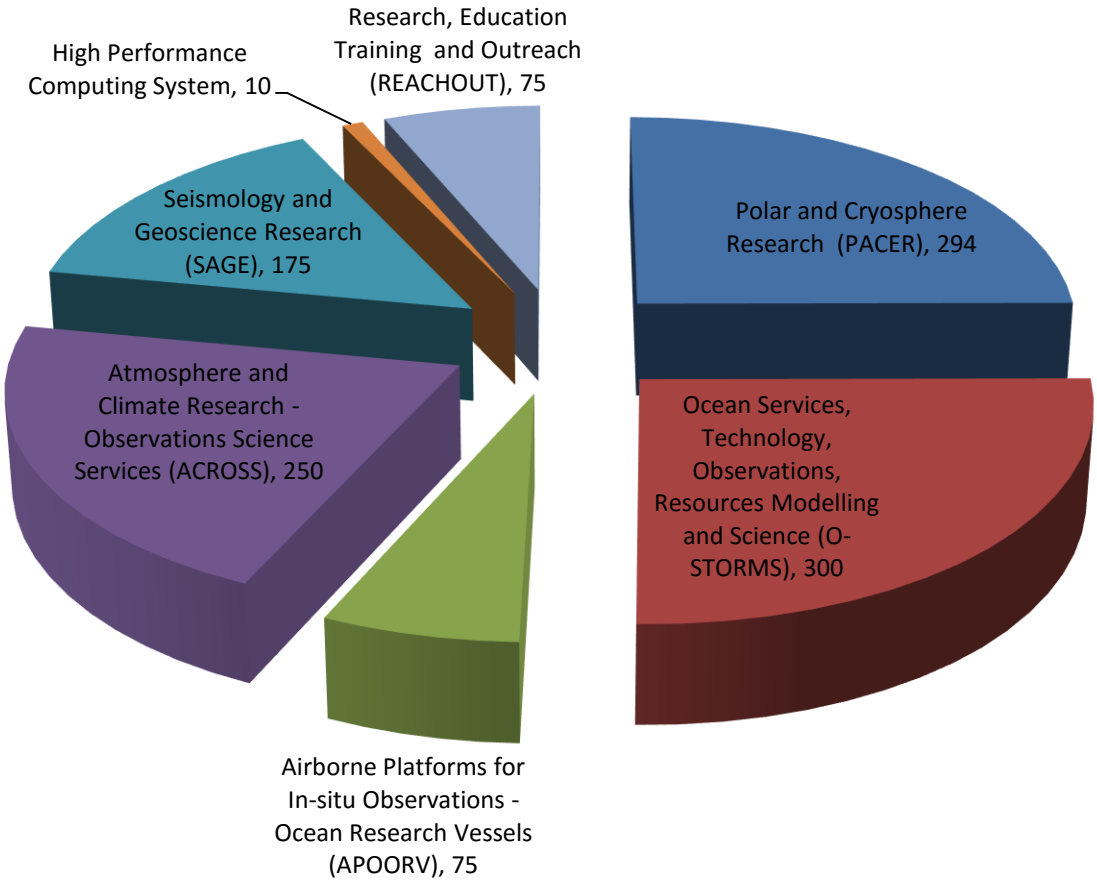

Fig. 1.2 Major Scheme-wise allocation of the Ministry for the year 2015-16 (in crores)

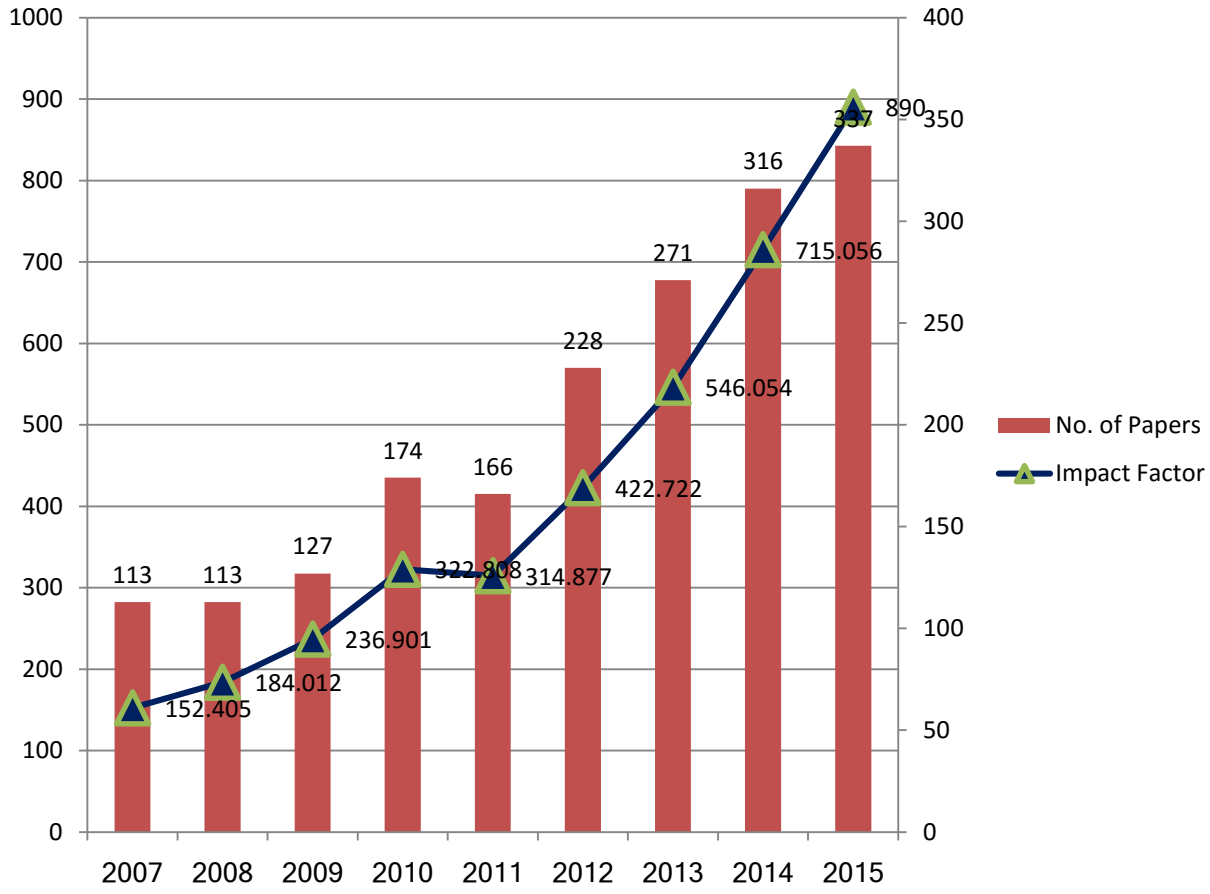

Fig. 1.3 A *snapshot of peer reviewed research publications and impact factor*

Chapter – 2

Atmosphere and Climate Research, Observations Science Services (ACROSS)

India Meteorological Department (ESSO-IMD) has continued its efforts for the improvement of observing, warning and dissemination systems all through 2015. Its improved services rendered in respect of very short (up to 6 hrs), short (up to 3-days in advance), medium (up to 7-10 days in advance), extended (up to 15-days in advance), long (monthly and seasonal) range and severe weather (cyclones, thunderstorms, extreme rainfall) forecasts have been built to meet the demands of the user agencies, disaster managers, emergency response groups and other stakeholders in an organized manner.

The year 2015 has been an eventful year in respect of extreme events experienced at various parts of the country throughout the year. World Meteorological Organization (WMO) has described 2015 as one of the warmest years on record with strong El-Nino. Performance of the South-West Monsoon was below normal, ending up with significant rainfall deficit of -14%, while North-East Monsoon was above normal in the states of Tamil Nadu (+52%) and Kerala (+28%) during October-December 2015. Country had experienced severe thunderstorm events with unseasonal rainfall during March 2015 over north west of India, thereby affecting Rabi crop production adversely. Severe heat wave conditions swept many parts of the country particularly Andhra Pradesh, Telangana and Odisha and led to the more than 2200 reported deaths. Heavy rainfall occurred over Gujarat, south Uttar Pradesh, Madhya Pradesh, Maharashtra and Chhattisgarh and associated run-off resulted into floods in many parts of the country. South east India, especially Tamil Nadu and Puducherry have in particular experienced unprecedented rainfall activity during November and early December 2015. The megacity of Chennai was the worst affected during the end of November and early part of December 2105 leading to large scale damage to life and property apart from causing severe disruption of lifeline services. It is important to mention that the accurate assessment of large seasonal deficit of monsoon rainfall for 2015 in as early as June had greatly helped the planners and economy of the country in tiding over the crisis by adapting to various appropriate contingency strategies. Notable forecast service level enhancements of 2015 include extension of city forecasts upto 7-days in advance to 324 cities and to 106 tourist destinations.

2. 1 NUMERICAL WEATHER PREDICTION – RESEARCH AND MODELING

i) The Gridpoint Statistical Interpolation (GSI) scheme of global data assimilation in the Global Forecast System (GFS) has been upgraded to a Hybrid-Ensemble version (HEnsGSI). Experimental runs with GFS (Eularian) and GFS (Semi-Langrangian) versions of the forecast models and runs with 80 member Ensemble Kalman Filter (EnKF) ensembles scheme have been subjected to quantitative performance evaluation for assessing the improvement in the quality of assimilated fields and forecast skill scores.

ii) Processing of radiances from satellite instruments onboard the Indian satellites (Megha-Tropiques and INSAT-3D) have been successfully completed in the Unified Model. Test runs were conducted with the assimilation-forecast system to assess the impact of radiance data assimilation of Indian satellites.

iii) Implementation of triple nested (27, 9 and 3 km) Hurricane WRF (HWRF) model with improved product generation module was completed.

iv) A new version of the Earth System Model (IITM-ESM2.0) with further improvements to obtain a closer radiative-balance of model global climate, has been tested successfully through improved treatment of radiative effects of natural and anthropogenic aerosols. Improved performance of ESM2.0 over ESM1.0 has been noticed in terms of simulating sea ice distribution, ocean biogeochemistry and mean precipitation over the Asian monsoon region. Accordingly, India would be participating in Climate Model Inter-comparison Project-6 (CMIP6) with stipulated test runs using ESM2.0 in the global arena.

v) Provision of Regional Climate Information scenarios for various applications across different sectors has been one of the important responsibilities taken by India to serve the region through generation and hosting of Coordinated Regional Downscaling Experiment (CORDEX) South Asia as an Earth System Grid Federation (ESGF) partner. During the year, in addition to the suite of climate change scenarios, the following Data sets have been added to the CORDEX ESGF Server hosted by India:

- Rossby Centre regional Atmospheric (RCA) Model of Swedish Meteorological and Hydrological Institutte (SMHI), Sweden, and,
- Regional Climate Model Version 4 (Reg CM4) of the International Centre for Theoretical Physics (ICTP), Italy.

vi) An objective criterion has been developed for the real-time extended range prediction of Monsoon Onset over Kerala (MOK) using circulation as well as rainfall information from the 16th May initial conditions of the Grand Ensemble Prediction System based on the coupled model – CFSv2. Three indices are defined – one from rainfall measured over Kerala, and others based on the strength and depth of low level westerly jet over the Arabian Sea. It has been found that the predicted MOK dates match well with the MOK date declared by ESSO-IMD for the years 2001-2014.

vii) New research version (at T-382 horizontal spectral resolution) of the coupled ocean-atmospheric model (CFSv2) has also been used to generate the experimental forecast for the North East Monsoon season-2015 rainfall (over the peninsular Indian region) using the September initial conditions with 48 ensembles and October initial conditions with 40 ensembles. The experimental forecast indicated above normal rainfall and above normal temperatures over India for November-December-January (NDJ), and December-January-February (DJF) months.

viii) Real time prediction of the active/break spells of the 2015 monsoon season was generated by using the newly developed CFS based Grand Ensemble Prediction System (CGEPS). The CGEPS could predict the large scale enhanced and suppressed phases of convection associated with monsoon intra-seasonal oscillations reasonably well.

ix) The updates for El-Nino status and predictions were provided using the coupled ocean-atmospheric model framework during 2015. It was predicted in advance that 'the El-Nino effect is expected to be moderate to strong during the monsoon season (June to September 2015) and it is likely to cause decrease in seasonal (June to September 2015) rainfall over Indian region'. A strong El-Nino was experienced during 2015 monsoon season.

x) Using a state-of-the-art global climate model with high-resolution zooming over South Asia (LMD AGCM), simulations demonstrated that a juxtaposition of regional land-use changes, anthropogenic-aerosol forcing and the rapid warming signal of the equatorial Indian Ocean is crucial to reproduce the observed mean monsoon rainfall weakening over India as a whole in recent decades.

xi) An Extended Kalman Filter (EKF) based land data assimilation system has been tested for assimilation of soil moisture. Six hourly soil moisture analysis, at four soil levels covering three meter depth, produced by this system will be used to initialize the soil moisture conditions in the ESSO-NCMRWF global 17 km Unified Model (NCUM) for generating global medium range weather forecasts. This land data assimilation system is capable of assimilating the soil temperature and surface skin temperature as well.

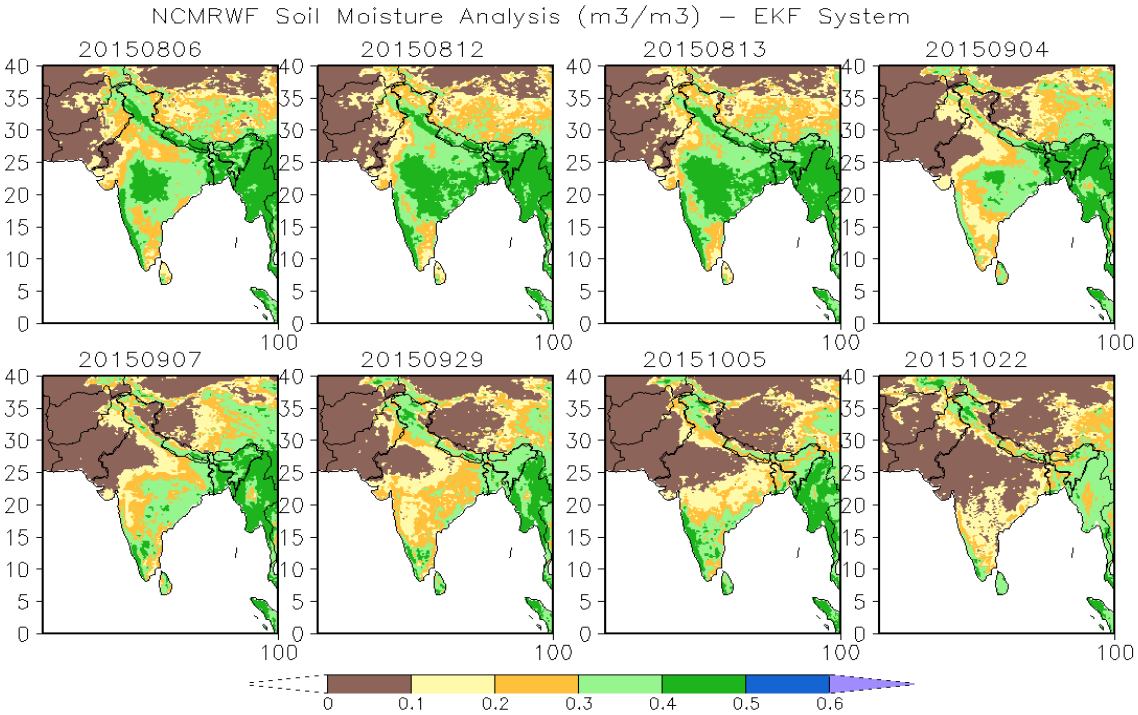

Fig. 2.1 Soil Moisture analysis (1-10 cm layer) variations of different time scales

xii) The DWR derived horizontal wind velocity and directions in a vertical column above the DWR site (VVP winds) and radial wind velocities (verses azimuth angle for a fixed elevation and fixed slant range) gives more frequent observations of the wind field compared to radiosonde observations. A preprocessing system for assimilation of VVP winds in the 4D-Var assimilation system of the ESSO-NCMRWF Unified Model (NCUM) has been developed.

xiii) A regional version of the data assimilation system also was configured and tested during the cyclone events. A new tropical cyclone vortex initialization scheme was successfully tested with global and regional NCUM assimilation-forecast system. Experiments have been carried out with fast radiative transfer model of RTTOV to simulate (NCUM background) the cloudy (all-sky) radiances of Megha-Tropiques SAPHIR microwave channels for its assimilation in the NCUM system. Currently microwave cloudy radiances are not used in the assimilation. Our experiments shows that, it is possible to include much larger footprint of meteorologically active weather conditions in the analysis with the inclusion of all-sky radiances in the assimilation system. This may improve the analysis, especially over regions of disturbed weather. Satellite Observation Simulation Package (COSP) has also been implemented at ESSO-NCMRWF for the understanding of model clouds and cloud-related processes by comparing it with satellite observation. The simulated radiance using NCUM forecasts are being compared with A-Train satellite observations (CloudSat/CALIPSO) of cloud related variables during severe weather conditions.

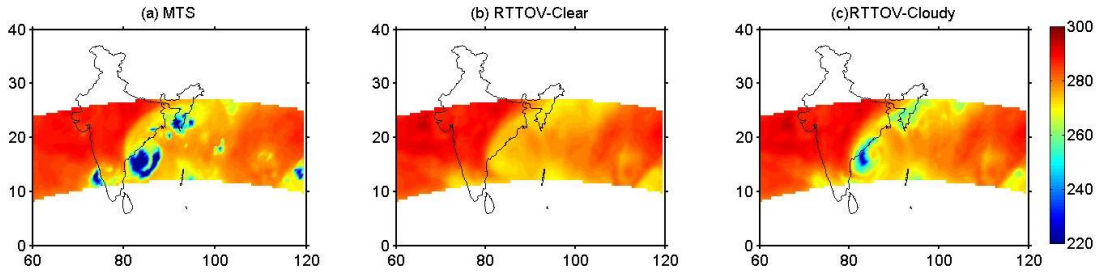

Fig. 2.2 Comparison of RTTOV clear and cloudy simulations using NCUM forecast with MT-SAPHIR observed (MTS) brightness temperatures (in K) for tropical cyclone HUDHUD

xiv) The horizontal resolution of the Global Unified Model (GUM) has been increased from the existing N512 (~25km) to N768 (~17km) upon commissioning of the new Bhaskara HPC system. The new version of the model resolves finer details in surface features like orography and allows smaller scale features in the free atmosphere. The associated 4-D VAR data assimilation scheme has also been made operational. The model could predict well the heavy rainfall associated with low pressure area over Uttar Pradesh and adjoining areas in one of the several cases of intense rainfall events of 2015.

xv) A regional version of Unified Model (GUM-R) at 4 km resolution has been implemented. The model domain covers approximately the Indian region between 65^{o}-101^{o}E, 4^{o}-40^{o}N. Currently the regional higher resolution model runs with initial and boundary conditions interpolated from latest 17 km resolution Global Unified Model (GUM-G). 3-day forecasts are generated every day from 00 UTC initial conditions. A much finer resolution version of the model was tested at 1.5 km resolution and studies with deep cumulus convection are being carried out to assess its suitability for operational use for extreme rainfall events.

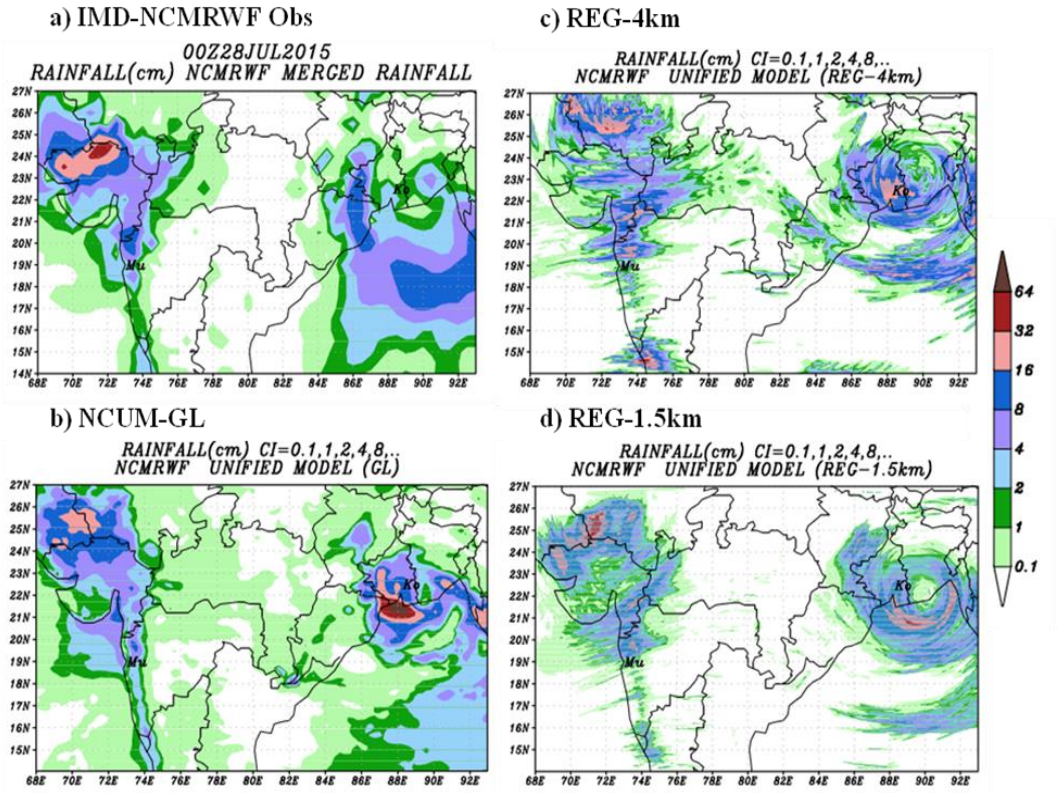

Fig. 2.3 (a) IMD-NCMRWF observed 24 hour accumulated rainfall for 28th July 2015 and day-3 forecast rainfall valid for the same date from (b) NCUM Global model (17km) and high resolution regional models (c) 4km and (d) 1.5 km

xvi) A module to generate the ensemble based early warning products of extreme weather event (rainfall) was implemented. The extreme weather event (rainfall) is identified by comparing the forecasts from the Global Ensemble Forecasting System (GEFS) with the model forecast climatology which is based on the 30 year (1985-2014) reforecast V2 climatology. This early warning product also indicates if the forecast rainfall is,

Extreme Wet [Rainfall > 90th percentile of climatology]

Extreme Dry [Rainfall < 10th percentile of climatology]

The following image shows the actual observed rainfall and the rainfall departure products from the day-4 forecasts from GEFS for the November 2015 Puducherry heavy rainfall event. Panel (d) shows that the extreme rainfall event over north Tami Nadu coast was captured very well by the GEFS.

xvii) An ensemble prediction system (EPS) based on GUM was implemented. The main features of this system are:

- Model resolution – N400L70 (~33 km at Mid-lat; 70 vertical levels)
- No. of ensemble members – 44
- Initial condition perturbation method – Ensemble Transform Kalman Filter (ETKF)
- Model Perturbation – Stochastic Physics (SKEB2) and Random parameters

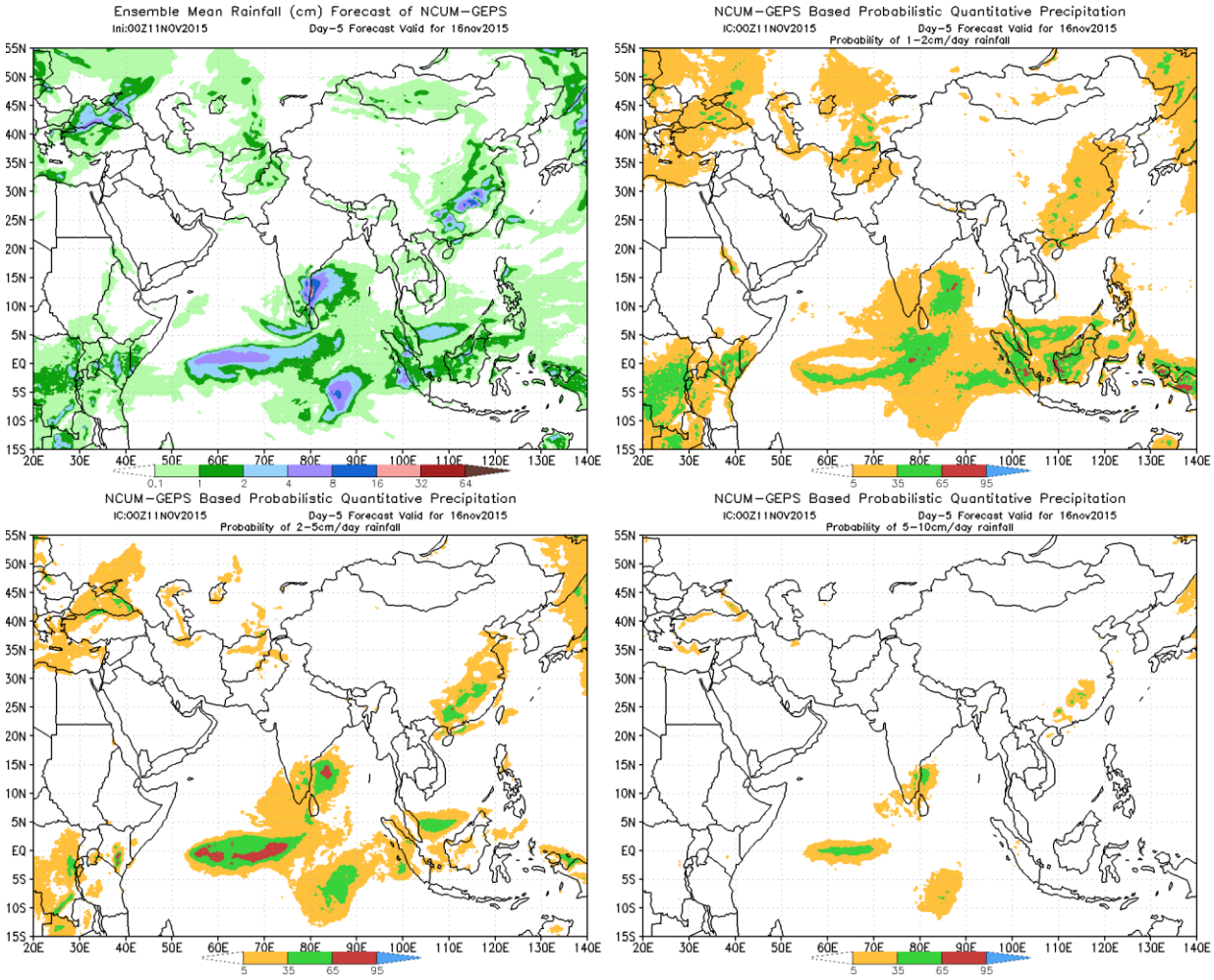

Fig. 2.4 Many products of the present GUM based EPS, depicting the day-5 forecast of ensemble mean daily rainfall and the probabilities of rainfall ranges of 1-2 cm, 2-5 cm and 5-10 cm based on the initial condition of 11th Nov 2015

xviii) Following the launch of the Global Precipitation Mission (GPM) satellite, an advanced high resolution precipitation product was released in early 2015. Quality evaluation shows that GPM rainfall estimates represent the mean monsoon rainfall and its variability more realistically than Tropical Rainfall Measuring Mission (TRMM). Representation of low and moderate precipitation rates have improved in GPM. IMD-NCMRWF operational daily merged satellite-gauge rainfall analysis procedure was modified and tested for new GPM satellite data. The GPM data coupled with improved resolution from 0.5° to 0.25° latitude/longitude grids is a better product for rainfall forecast verification and application studies. The updated IMD-NCMRWF merged rainfall analysis algorithms were made operational at ESSO-IMD Pune center from 1st October 2015.

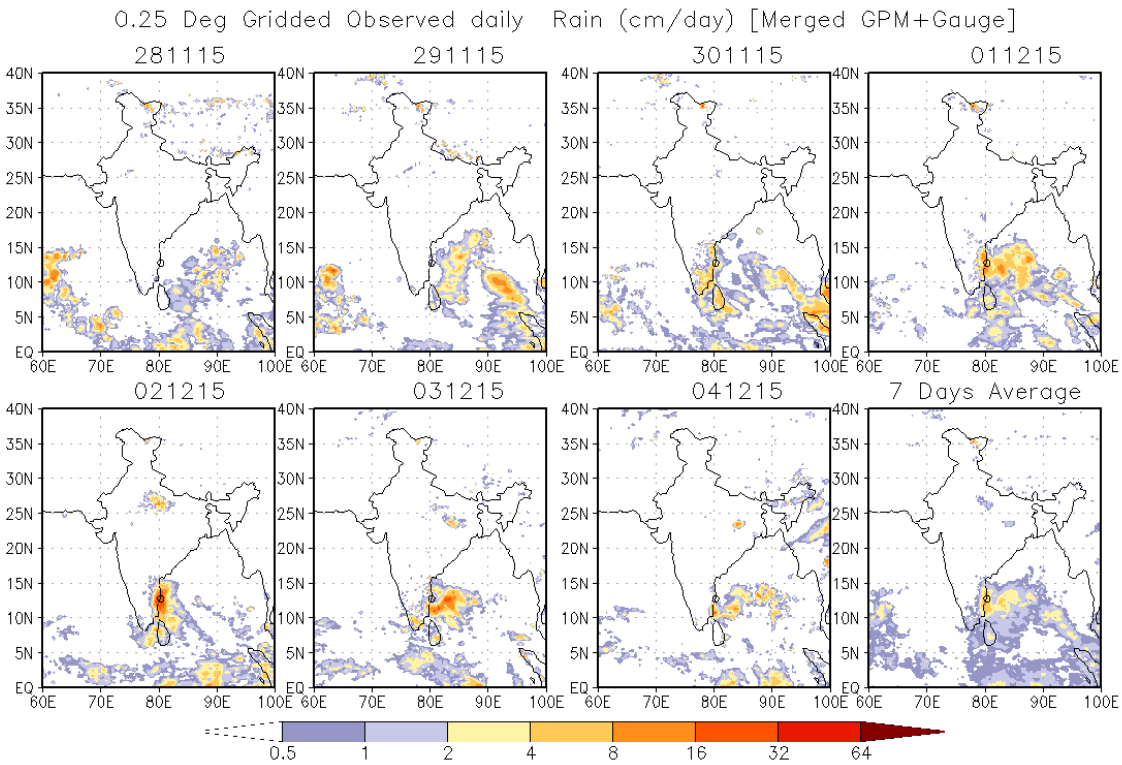

Fig. 2.5 The heavy rainfall case of Chennai (2015)

xix) As a new initiative, snow and rain associated with western disturbances in the form of significant weather forecast summary (SWFS) were communicated by to Snow and Avalanche Study Establishment (SASE). The four cases on 14th, 22nd, 26th January 2015 and 2nd February 2015 which generated rain/snow over North India were predicted about 5-6 days in advance. The forecast for probability of snow over Jammu and Kashmir and adjoining regions were included in SWFS for the first time and subsequently were provided in a routine way.

xx) System of providing forecast products to the Indian Coast Guard had been initiated. The products include (1) Meteogram for Daman, (2) forecasts of Geopotential height, wind, MSLP and rain up to 10 days and (3) Probabilistic rain forecast upto 10 days over the domain of their interest (15º-25ºN & 66º-75ºE).

xxi) Customized weather forecast products were developed for the Antarctica region for use by ESSO-NCAOR. These forecast products include winds at 10m, 925, 50 and 500 hPa levels, rainfall and cloud cover are generated and put on the ESSO-NCMRWF website every day.

xxii) Forecasts of upper air weather parameters have been provided to Satish Dhawan Space Centre, SHAR for launch of PSLV-C27 mission carrying the Indian Regional Navigation Satellite System (IRNSS-1D) satellite.

xxiii) Real time Quantitative Precipitation forecasts (QPF) over Krishna-Bhima Basin (15-20ºN/72º-81ºE) are being provided to Basin Study Division (BSD), Water Resources Department, Government of Maharashtra for real time flood forecasting applications by ESSO-NCMRWF. The operational forecast data in digital and graphical form are provided at 6 hours interval up to 72 hours.

xxiv) Modules for generation of Global and Regional NWP products including EPS Grams for several important cities in the countries over the domain 10°S to 45°S and 45°E to 110°E as a part of WMO project on Severe Weather Forecast Demonstration Project-Bay of Bengal (SWFDP-BOB) to provide severe weather guidance on cyclones, heavy rainfall, thunderstorm, waves etc. have been implemented.

2.2 OBSERVING SYSTEMS AND SERVICES

ESSO-IMD has been augmenting its observing system networks during 2015 as per the details given below:

- Three Doppler Weather Radars at Srinagar, Karaikal and Paradip.
- Eight Drishti Transmissometer Systems (LED Based) for airport run-way visibility range measurement at various airports.
- Four GPS based Solar Trackers at Chennai, Thiruvananthapuram, Visakhapatnam and Shillong.
- Two UV-B radiometers at Sri Ganganagar and Guwahati.
- Two diffuse shading ring assembly at Machalipatnam and Rahuri.
- Four pyranometers at Thiruvananthapuram, Visakhapatnam, Shillong and Rahuri.
- Thirty Nine WMO compliant GPS Sonde based upper air observations.
- Forty Seven Automated Rain Gauges (ARG).
- Twelve Nephelometers.
- Sixteen Aethalometers for Block Carbon measurements.
- 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 (Customised Rainfall Information System): A GIS based system for processing real-time rainfall data to generate rainfall products.
- Installation of a System for Air Quality Forecasting And Research (SAFAR) at Mumbai.
- Development of version 2 of mobile application named "Indian Weather" for Android with addition of upto 300 cities and nowcast warning for Thunderstorm.
- Development of All India Nowcasting system for Thunderstorms that facilitates the forecaster to generate forecast in Nowcast mode and display on the public portal on real time basis.
- The SAFAR-Air Application (Android and iPhone compatible) has been launched on 17th February 2015.

The performance of the satellite data reception and processing system during the current year has been maintained to the level of 98% operation efficiency (24x365 basis). The validation of atmospheric motion vector (wind products), sea surface temperature, outgoing long wave radiations (OLR) vertical profile of temperature and humidity has been carried out for the period of July 2014 to October 2015 and the feedback is used for fine tuning of algorithm of these products.

The satellite based technique/tools for monitoring and forecasting of evolution of clouds cluster that leads to the severe weather has been developed and implemented operationally. The method is used to generate NOWCAST Satellite images for next three hours on half hourly basis.

Atmospheric CO_2 and CH_4 concentrations were monitored at Sinhagad (SNG) mountain observatory, located at 1.6 km altitude from mean sea level since November 2009, on weekly basis. Model simulations has shown Indian summer monsoon influences CO_2 observations over this region with seasonal variability of approximately 8 ppm, which gets more than double in the winter season. Apart from this, airborne observations have been performed over Maharashtra and adjacent Arabian Sea in July 2015. Laser based monitoring instrument was used to monitor horizontal and vertical profiles of CO_2, CH_4, CO, and H_2O concentration over the region. All the above mentioned data will be used to validate model simulations as well as to estimate CO_2 sources and sinks over Indian region. For determination of CO_2 flux at terrestrial ecosystems of north east India, two flux towers have been installed in two locations of North East India viz., Kaziranga National Park (KNP), Assam, and Selembong Forest, Darjeeling district, West Bengal. Eddy covariance system for flux measurements and other various sensors for quantifying radiation parameters have been installed during 2015.

Airborne Observations:

Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Aircraft observations have been carried out from Kolhapur as base in the triangular area between Kolhapur, Mahabaleshwar and Solapur in the month of July 2015. Research observations for 75 hours have been taken during the dry July month of 2015 over Maharashtra. These observations of cloud microphysics, aerosol, black carbon, chemistry and green house gases (GHG) are conducted with specific emphasis to understand the cloud characteristics in view of the planning for randomized seeding experiments for 2016-17. Several airborne observations have been made in collocation with High Altitude Cloud Physics Laboratory and DWR at Mahabaleswar including vertical profiling of clouds in the rain shadow area, aerosol and cloud observations as well as over the Arabian Sea. GHG and aerosol chemistry observations over these locations were done for the first time. With the completion of Phase-III in 2015, CAIPEEX project has resulted in 820 hours of airborne observations over the Indian region and is a major achievement.

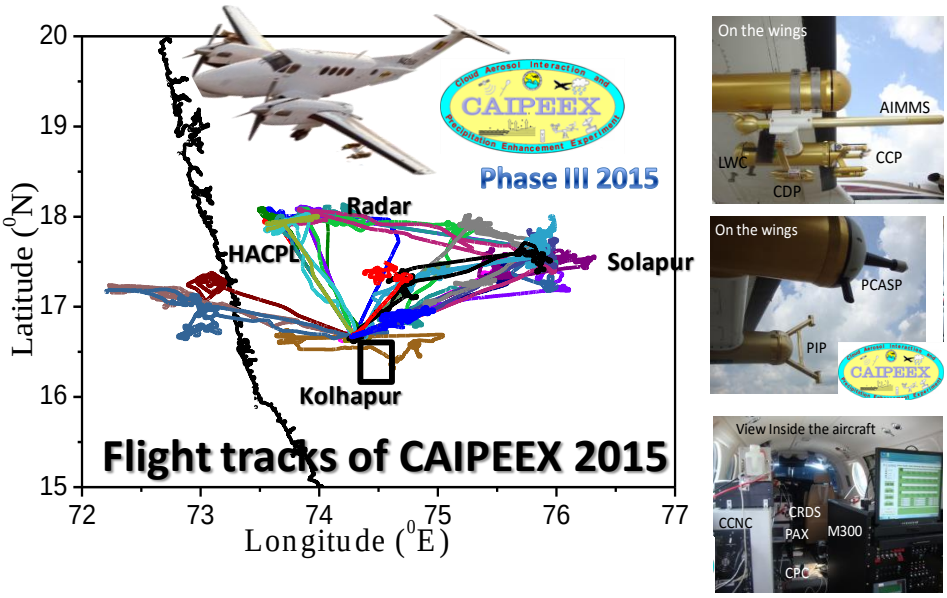

Fig. 2.6 Flight tracks of CAIPEEX 2015

For the first time, ice water content, ice number concentrations, particle size distributions from monsoon clouds and useful parameterization for deriving such parameters in numerical models, radars etc. are established from CAIPEEX airborne observations. Also, relationship between the surface CCN and the cloud base CCN, activation characteristics are established from CAIPEEX airborne observations. The prominent role of ice multiplication through Hallet Mossop process in monsoon clouds is revealed for the first time through observations and is validated with large eddy simulations. The important role of ice microphysics after the onset of north east monsoon is revealed and the link with aerosol effect is illustrated. Nocturnal initiation of storms with longer lifetime supported by moisture transport associated with the LLJ is revealed. New ideas in explaining droplet spectral broadening in downdrafts in cumulus is proposed from DNS studies in combination with CAIPEEX aircraft observations.

High-Altitude Cloud Physics Laboratory (HACPL) at Mahabaleshwar:

The HACPL is fully functional in its newly constructed building. Recently, time-of-flight (TOF) Aerosol chemical speciation monitor is installed, tested and put in operation at HACPL for aerosol chemical speciation measurements for characterizing the dominant chemical species in aerosol. Initial results show the dominance of organic compounds which can be source for secondary organic aerosols over this region. During the CAIPEEX aircraft campaign in July 2015, observations from Radiosonde, and Proton Transfer Reaction Mass Spectrometer (PTRMS) for Volatile Organic Compounds (VOC) measurements were also carried out.

Aerosol-CCN variability and their relationship were also studied for the first time at HACPL. The study reveals that diurnal variation in aerosol and CCN concentration shows relatively higher values during early morning hours in monsoon season but higher values during the evening hours in winter and pre-monsoon. Seasonal mean variation in aerosol and CCN (SS above 0.6%) has shown higher (less) in monsoon (winter) season. Despite of dominant sink processes such as cloud scavenging and

washout mechanisms in operation, higher concentrations of aerosol and CCN were over this high altitude site indicate local emissions and biogenic Volatile Organic Compounds (BVOC) emissions from wet forest as major sources.

Lightening Detection:
Lightning Location Network installed over Maharashtra to understand the characteristics of lightning occurring over this region has been strengthened with installation of three more sensors at Mahabaleshwar, Nanded and Phalghar. The performance of this network in detecting lightning is being assessed and is found to be performing well. The recent occurrence of large scale thunderstorms with hails in October 2015 has been captured with great accuracy by this network. Efforts are being made to develop a protocol for sharing the information about impending lightning strikes to the Government of Maharashtra.

Experimental Monsoon Prediction using the Monsoon Mission Coupled Ocean-Atmospheric Model (CFSv2):
Dynamical model based seasonal and extended range predictions of the monsoon for the year 2015 were prepared on real-time basis and shared it with the 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 experimental dynamical seasonal forecast generated by using the latest high-resolution (T382 spectral resolution) research version of the coupled model (CFSv2) indicated a deficient rainfall in 2015 South West monsoon season. The experimental forecast issued on 2nd June 2015 suggested that the monsoon rainfall during the 2015 monsoon season (June to September) averaged over the country as a whole is likely to be 86% ± 5% of long period model average (LPMA). The experimental five category probability forecasts for the 2015 monsoon season rainfall over the country as a whole using the experimental dynamical prediction system are 61% (deficient), 24% (below normal), 13% (normal), 2% (above normal) and 0% (excess).

The actual rainfall in the 2015 South West monsoon season averaged over the country as a whole was 86% of its long period average (LPA) value. Thus, the model forecast indicated accurately a deficient monsoon in 2015.

2.3 MONSOON 2015

Monsoon Onset:
Based on an indigenously developed statistical model, it was predicted on 15th May 2015 that monsoon will set in over Kerala on 30th May with a model error of ±4 days. However, the actual monsoon onset over Kerala took place on 5th June 2015.

Long Range Forecasts:

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 93% of LPA (below normal) with a model error of ± 5% of LPA. This forecast was updated to 88% ± 4% of LPA (deficient) in June. The actual season rainfall for the country as a whole was 86% of LPA, which is within the limits of second stage forecast issued in June. Considering the four broad geographical regions of India, the forecasts issued in June for the season rainfall over northwest India, Central India, northeast India and south Peninsula were 85%, 90%, 90% and 92% of the LPA respectively, all with model errors of ± 8%. The actual rainfalls over northwest India, central India, northeast India and south Peninsula were 83%, 84%, 92% and 85% of the LPA respectively. The actual season rainfall of northwest India is 2% of LPA less than the forecast and that of northeast India is 2% of LPA more than the forecast. However, the actual season rainfalls over central India and south Peninsula were less than the forecast by 6% and 7% of LPA respectively but well above the lower forecast limits. The forecast for the second half of the monsoon season (August –September) for the country as a whole was 84% with a model error of ±8% of LPA against the actual rainfall of 77% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole is also within the forecast limits.

The forecasts for the monthly rainfall over the country as a whole for the months of July and August issued in June were 92% and 90% respectively with a model error of ± 9%. The actual monthly rainfalls during July and August were 84% and 78% of LPA respectively, which are below the forecasts by 8% of LPA and 12% of LPA respectively. Thus whereas the actual July rainfall was within the forecast limit, the actual August rainfall was 3% of LPA below the lower forecast limit. The Table below gives the summary of the verification of the long range forecasts issued for the 2015 southwest monsoon.

Regions	Actual Rainfall (mm)	Normal Rainfall (mm)	% Departure from LPA
Country as a whole	760.6	887.5	-14%
Northwest India	510.6	615.0	-17%
Central India	815.5	975.5	-16%
South Peninsula	605.7	716.1	-15%
East & Northeast India	1317.5	1438.3	-8%

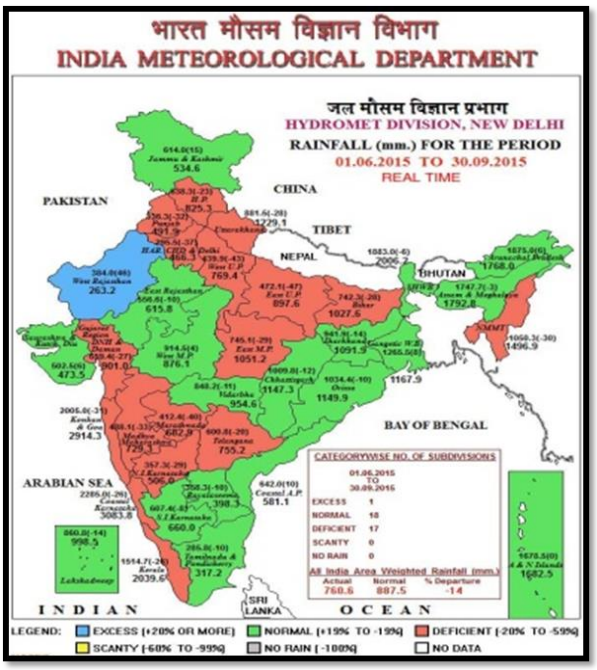

Fig. 2.7 Sub-divisionwise rainfall for the months June-September 2015 over the country

2.4 CYCLONE MONITORING AND PREDICTION

During the year 2015 there were four cyclones over the north Indian ocean including three over the Arabian Sea and one over the Bay of Bengal. Comparing with the long period average of 1891-2014, it was less than normal over Bay of Bengal and above normal over the Arabian Sea. However, considering the recent years 1990-2014, the activity over the North Indian Ocean was normal, as normally four cyclones have developed during 1990-2014, though it was excess over the Arabian Sea and subdued over the Bay of Bengal. These cyclones were:

- Cyclonic Storm, ASHOBAA over the Arabian Sea (07-12 June 2015)
- Cyclonic Storm, KOMEN over Bay of Bengal (26 July-02 August 2015)
- Extremely Severe Cyclonic Storm, CHAPALA over the Arabian Sea, (28 October-4 November 2015)
- Extremely Severe Cyclonic Storm, MEGH over the Arabian Sea (5-10 November, 2015)

Cyclone Forecast Verification:

During the year 2015, the annual average track forecast error was found to be 94 km, 151 km and 209 km, respectively for 24, 48 and 72 hrs against the long period average error of 107, 164 and 230 km based on data of 2010-2014. The 96 and 120 hr track forecast error were 283 and 356 km respectively. Also the track forecast skills compared to climatology and persistence forecast are 37%, 50% and 57% respectively for the 24, 48 and 72 hrs lead period which is lower than long period average of 2010-2014 by about 10%.

The skill compared to persistence forecast based on AE has been 30%, 57% and 66% respectively against the long period average (2010-14) of 40%, 55% and 68% respectively. The skill compared to persistence forecast based on RMSE has been 33%, 58% and 68% respectively against the long period average (2010-14) of 45%, 60% and 73% respectively.

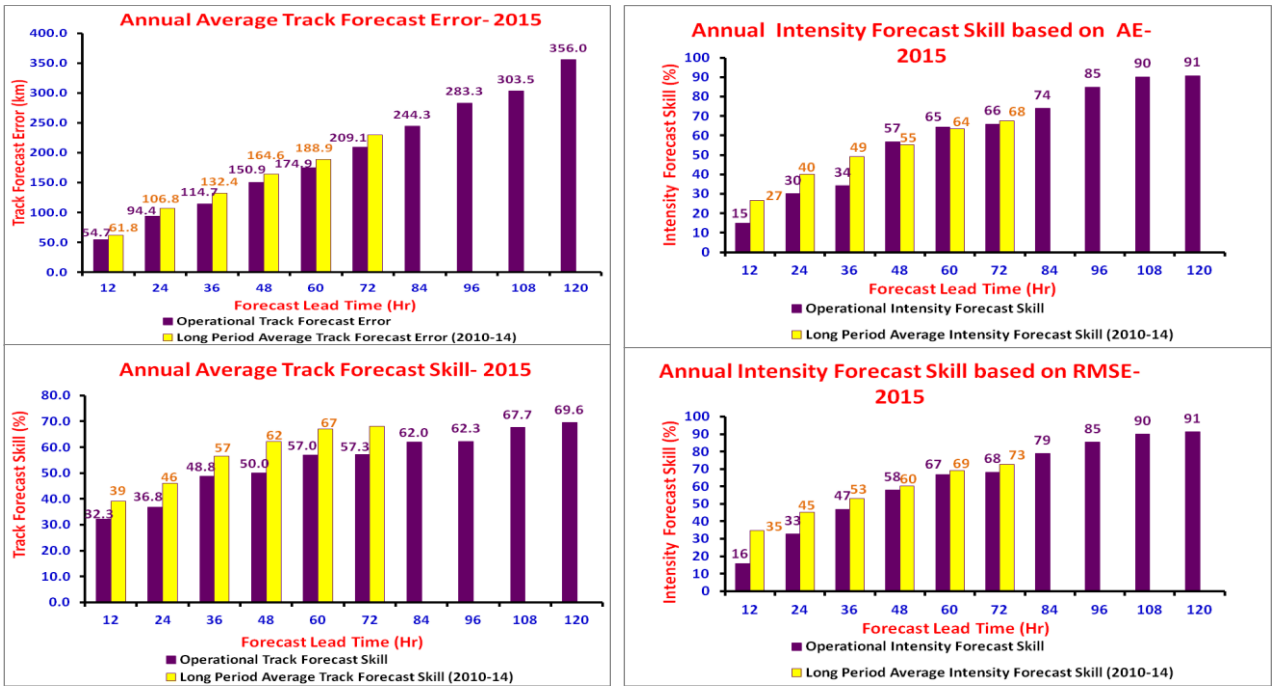

Fig. 2.8 Different skill parameters regarding cyclone prediction

During 2015, in general, the errors have been higher and skill less for landfall, track and intensity mainly due to the fact that out of total of four cyclones, three developed over the AS and errors are in general higher for the systems developing over AS than those over BoB. The annual average intensity forecast error based on AE has been 14, 20 and 19 kts respectively for 24, 48 and 72 hrs lead period of forecast against the long period average of 11, 16 and 18 kts. The annual average intensity forecast error based on RMSE has been 18, 28 and 28 kts respectively for 24, 48 and 72 hrs lead period of forecast against the long period average of 15, 20 and 22 kts. During the year 2015:

- Country report on tropical cyclone genesis, intensity, track, landfall process and warning communication was sent to WMO IWTX-2015.
- RSMC, New Delhi provided input for development of WMO's synergized standard operation procedure (SSOP) for multi hazard early warning system.
- SMS to registered general public were issued during cyclonic disturbances affecting India with effect from 2015. 10,726 SMS were disseminated during 2015.
- Synergized fishermen warnings.
- CAP feed for Google's Public alerts: ESSO-IMD is in the process of implementation of common alert protocol (CAP), for multi-hazard warning dissemination through multi-platform devices.

- ESSO-IMD started issue of coastal weather bulletin and sea area bulletin for coastal shipping and high sea shipping respectively through NAVTEX stations installed by Directorate General of Light house and Light Ships (DGLL) from 30th March 2015.

2.5 DISSEMINATION

In order to expand the dissemination of the weather forecasts to tourists, the information regarding the prevailing weather and the forecast of various cities, is also provided on toll free number 1800 180 1717 through Interactive Voice Response System (IVRS). ESSO-IMD has also developed a mobile App called “Indian Weather” by which initially, current weather and 4-days forecast for 220 cities is being provided. At present 80 additional cities have been added with Graphical User Interface (GUI) feature totally re-designed for better navigation. Presently ESSO-IMD issues thunderstorm forecast on the nowcast scale (3-6 hr validity) for 147 stations out of which 45 stations have been added to the App to provide thunderstorm forecast. ESSO-IMD introduced sector wise 7 days special forecast and warnings for Western Himalayan Region for Indian Army and application of forecast for generating advisory for heat wave for railways and highways has been taken up.

Special forecasts were issued for pilgrims of Char-Dham Yatra, Kailash-Mansarovar Yatra, Sri Amarnathji Yatra and Kumbh Mela. ESSO-IMD has recently started weather information for Mata Vaishno Devi Shrine comprising of (i) Yatra Route Weather Advisory, (ii) current observations, (iii) 6-hourly low level wind and temperature forecasts for helicopter operation and (iv) 3-day forecasts and warnings for Jammu Division.

There has been consistent improvement in forecast skill of heavy rainfall events. Percentage Correct (PC) for Heavy Rainfall Warnings during the monsoon 2015 was 80%. False Alarm Rate (FAR) and Missing Rate (MR) were 14% and 41%, respectively during the monsoon 2015, which were 40% and 48%, respectively for the monsoon seasons of 2002-14. Probabilities of Detection (PoD) and Critical Success Index (CSI) during monsoon 2015 were assessed at 59% and 41%, respectively which were up from 52 % and 38%, respectively observed for the monsoon seasons of 2002-14. The statistics are shown in figures below.

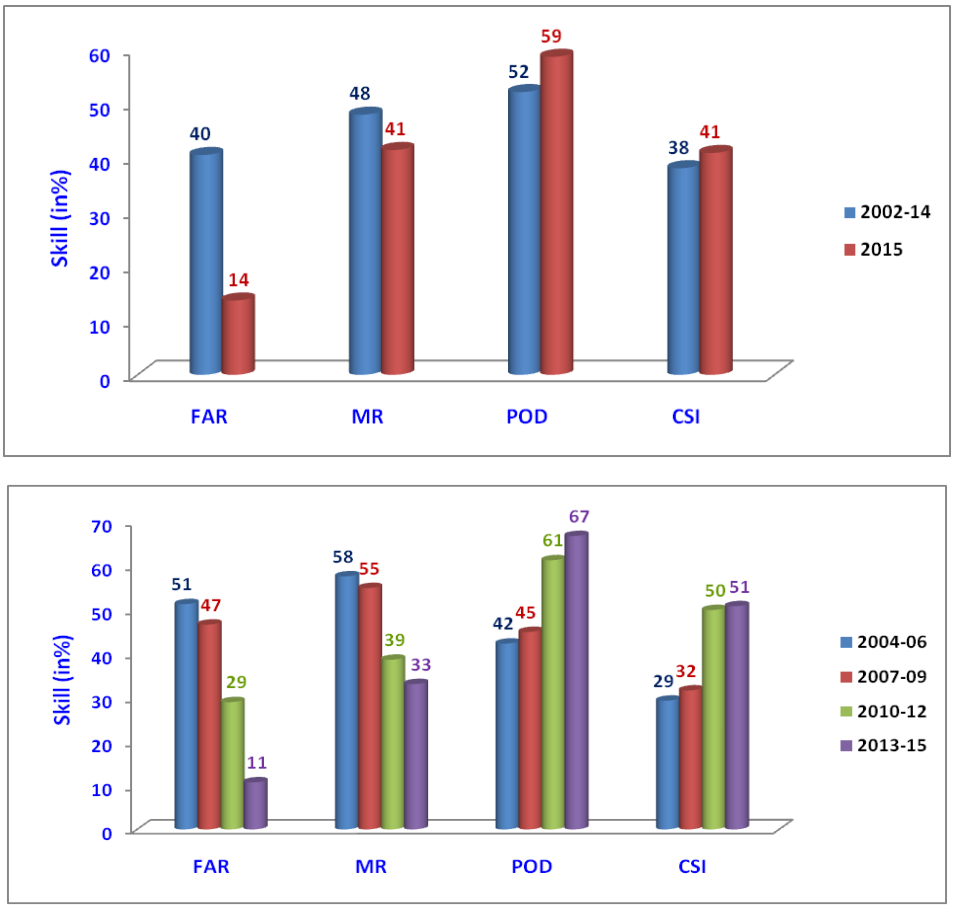

Fig. 2.9 Different skill parameters regarding monsoon prediction

Agro-Meteorological Advisory Services (AAS) under Gramin Krishi Mausam Seva: District level AAS bulletins are prepared and issued by Agro-meteorological Field Units (AMFUs) located in State Agricultural Universities, ICAR institutes, IITs etc. At present these bulletins are issued for 633 districts in the country.

Dissemination of advisories: Dissemination of AAS bulletins are made available to the farmers through different multi-channel system and are also being disseminated in both Regional and English languages through "Kisan SMS" and a portal (http://farmer.gov.in/advs/login.aspx). At present 11.50 million farmers are benefitted by this service. Weather forecast and advisories under alerts and warnings through SMS now enable farmers in planning farming operations effectively to minimize/control damage of crops under adverse weather conditions. Dissemination of weather based AAS bulletins to farmers under pilot mode through Reliance Foundation Information Services (RFIS) in collaboration with ESSO-IMD was also started during the year. Presently it is being disseminated in seven states covering 61 districts, 5400 villages and 45 crops and reaching to 42,000 farmers directly.

Research & Development Efforts:

- R & D projects on e-Agromet, experimental surface soil moisture estimation, Sowing Suitability of crops have been undertaken through different institutes.

- A new Initiative under Gramin Krishi Mausam Sewa, Forecasting Agricultural output using Space, Agrometeorology and Land based observations have been undertaken.

Environmental Meteorology Services:
ESSO-IMD continued to provide environmental meteorology services to the Ministry of Environment, Forests and Climate Change and carried out environmental impact assessment of more than 2000 thermal power, industrial, coal and mining projects in the country in 2015. Environmental monitoring of parameters of atmospheric environment was continued with addition of new networks of aethalometers (15) and nephalometers (12) in the country. Air quality monitoring for 10 stations in NCR Delhi under the system for air quality forecasting and research (SAFAR) was continued. The SAFAR has been operationalized jointly by ESSO-IITM and ESSO-IMD to monitor and forecast air quality in NCR Delhi, Pune and Mumbai.

Hydro-meteorological Services:
The Hydro-meteorological Division is providing the necessary technical and operational support to various Central/State Govt. organization and other agencies in the field of Hydromet design, flood forecasting, rainfall monitoring for water management and agricultural planning purposes etc. During 2015, design storm studies of twelve projects were completed. Total 119 sub-basins of different flood prone rivers in the country are covered for flood forecasting by the Central Water Commission during the 2015 flood season. The lead time support was also enhanced through estimation of Quantitative Precipitation Forecasts (QPFs) from 2 days to 3 days and outlook from 3 days to 4 days. The total of 19,793 QPFs were issued in 2015 for day-1, 18,298 for day-2 and 18,285 for day-3.

Winter Fog Field Campaign at New Delhi (December 2015-February2016):
ESSO-IMD and ESSO-IITM have jointly launched an observational fog campaign at the Indira Gandhi International Airport (IGIA) and at ICAR institute at Pusa during this winter season (2015-16), starting from 17th December 2015. The main objective of the proposed field campaign is to study the evolution characteristics and variability of fog events over Delhi and its associated dynamics and thermodynamics and associated microphysics. The observational campaign includes simultaneous measurements of surface meteorological conditions, radiation balance, turbulence, thermo-dynamical structure of the surface layer, droplet and aerosols microphysics, aerosol, fog water chemistry, vertical profile of winds, temperature and humidity to describe the complete environment in which fog develops. These measurements form the basis for understanding some of the key questions associated with fog formation and dispersion. These measurements and their associated processes will be used for simulation fog ultimately after conducting such field campaigns for atleast 3-5 years.

The campaign is being conducted with cooperation and support from Airport Authority of India, GMR and Indira Gandhi International Airport, New Delhi. In addition to ESSO-IITM and ESSO-IMD, the Indian Air force (IAF), ICAR and Indian Institute of Science Education and Research (IISER) Mohali are also participating in the observational

campaign. For modeling efforts, ESSO-IITM, ESSO-NCMRWF and IIT Delhi are involved.

Fig. 2.10 Different equipments and the instrumented tower installed at IGI Airport, New Delhi for the fog campaign

Chapter – 3

Ocean Services, Technology, Observations, Resources, Modeling and Science (O-STORMS)

The O-STORMS is one of the seven rationalized schemes which primarily encompasses three major components (i)Ocean observation networks for understanding coastal and oceanic processes to provide best possible services, (ii)Marine scientific surveys for exploration and exploitation, (iii)Development of technology for harnessing marine resources. The O-STORMS is primarily executed by the following centers of the Ministry – ESSO-INCOIS, ESSO-NIOT, ESSO-ICMAM and ESSO-CMLRE. The details are as under.

3.1 COASTAL AND OCEAN OBSERVATION SYSTEM, SCIENCE AND SERVICES

The primary mission of ocean information services of the Ministry is to provide the best possible ocean advisory services to cater to the needs of coastal regions of India and partner maritime countries in the Indian Ocean region, through national programs and international effort. A global arena of operational oceanographic services is being rendered through accurate and timely ocean information services and advisories to the public and targeted users using state-of-the art technologies and observation systems.

Ocean Information Advisory Services (O-IAS): The ocean information and advisory services being rendered to various stakeholders in India and countries of the Indian Ocean Region include (i)Tsunami early warnings, (ii)Ocean State Forecasts, (iii)Potential Fishing Zone Information, (iv)Ocean Data Dissemination, (v)Capacity Building. These services of immense economic benefit cater to the needs of over twelve sectors of both private and public enterprise, which have been contributing substantially to the GDP of the nation.

Indian Tsunami Early Warning Centre (ITEWC) had monitored 33 earthquakes of magnitude ≥ 6.5 during the period 1st January to 14th October 2015. None of these earthquakes had occurred in the Indian Ocean region. The performance of the ITEWC in monitoring the tsunamigenic earthquakes and issuing advisories as well as the accuracies of the service were well within the acceptable limits of the international standards.

In order to assess the effectiveness of the communication channels through which the Tsunami advisories are being provided, one Communications Test (COMMs) was conducted on 10th June 2015. During this exercise, ITEWC disseminated notification messages to 23 National Tsunami Warning Centre (NTWCs) and the other two Tsunami Service Providers (TSPs) [Australia and Indonesia] in the Indian Ocean and also received notification messages from other TSPs and ascertained that the communication network is working efficiently. In collaboration with Ministry of Home Affairs (MHA), a Tsunami Mock Drill was conducted on 26th September 2015 for the eastern coastal states (Andhra Pradesh, Odisha, Puducherry, Tamil Nadu and West Bengal) to improve awareness and preparedness of administrators and the general public.

Ocean State Forecast (OSF) Services:
ESSO-INCOIS continued to provide forecasts on the state-of-the oceans for a wide spectrum of users. The OSF services were particularly useful during the occurrence of the cyclone 'Ashoba' (8-10 June 2015). The search and rescue operations by the Indian Coast Guard for their missing flight during 11-18 June, 2015 off Karaikal, southeast coast of India, was assisted by ESSO-INCOIS by providing information on the most probable regions where the lost persons and objects could be found in the sea. ESSO-INCOIS used the "Search And Rescue" module developed in-house for this purpose. Several new products were launched related to ocean state forecast, which include Online Oil Spill Advisory (OOSA) and Experimental predictions of Kondal-kattu (high winds in the Palk Bay).

OSF services extended to Seychelles and Sri Lanka – The Ocean State Forecast service for neighbouring countries, Seychelles and Sri Lanka was inaugurated on 10th July 2015 by the Union Minister for Earth Sciences, Dr. Harsh Vardhan in New Delhi (Fig. 3.1). In the Integrated ocean information and forecast system, ESSO-INCOIS is now providing 3-day forecasts (available at 3-6 hour temporal resolution) on winds, waves, currents, temperature in map form for Seychelles and Sri Lanka. These forecasts are updated daily on operational basis. Location specific forecasts are also being delivered for selected locations [Seychelles: 18 locations and Sri Lanka: 22 locations].

Fig. 3.1 Ocean State Forecast system for Seychelles and Sri Lanka (in collaboration with RIMES), inaugurated on 10th July 2015

Potential Fishing Zone Advisories – The PFZ advisories and species specific advisories (Tuna) were rendered to the user community. An atlas was prepared using available PFZ data for all the months during the period 2002 to 2014 (Fig. 3.2). The atlas contains analyses based on the PFZ advisories for a given month. This atlas is a useful reference tool to understand the variation in the occurrence of PFZ over time and space. This also serves as a benchmark observation for future modelling efforts to understand the variability of the PFZ and generate gap-free products during cloudy days.

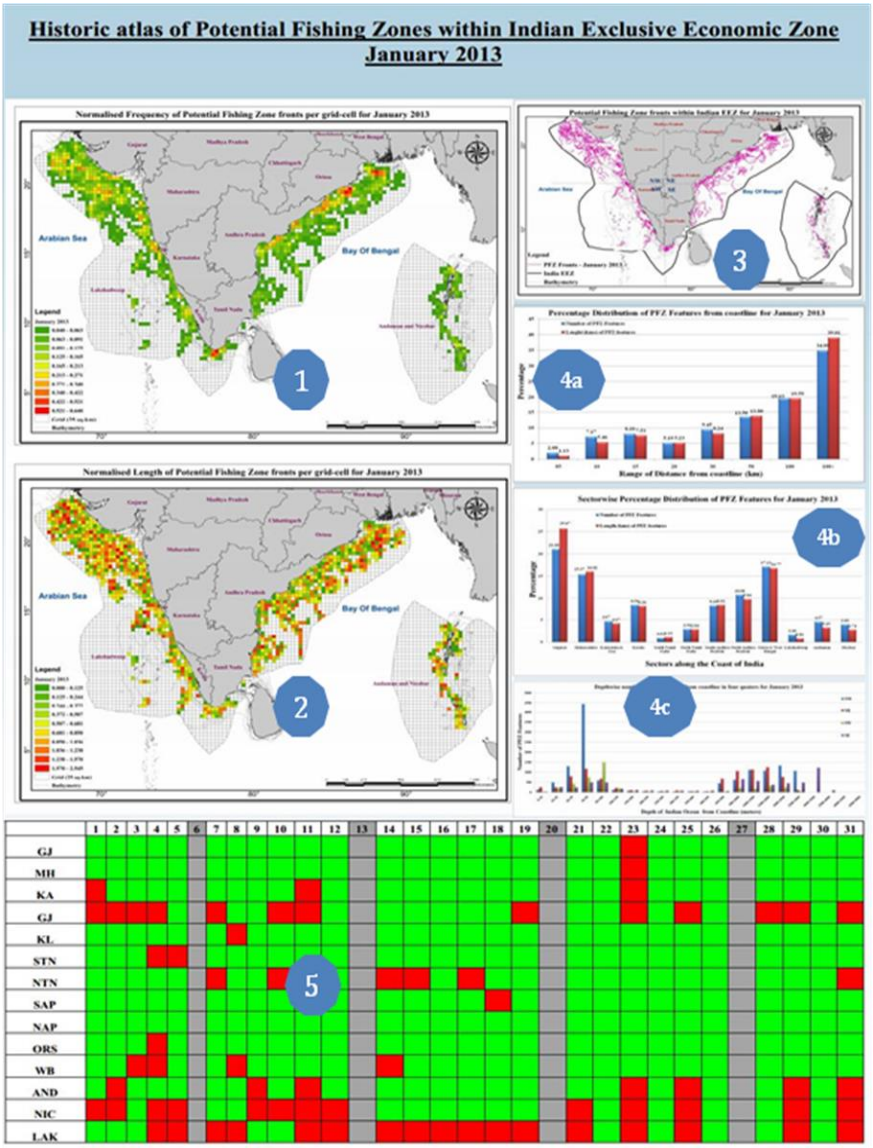

Fig. 3.2 A sample page from the PFZ Atlas. Numbers denote sections such as 1) spatial distribution of PFZ frequency, 2) spatial distribution of PFZ length, 3) monthly composite of PFZ, 4) monthly distribution of PFZs w.r.t. (a) distance from coast, (b) sector and (c) bathymetry, 5) date-wise availability of PFZ data for each sector during a month

Mariculture Site Suitability – A preliminary mapping (using Remote Sensing data) of suitable sites was prepared for mariculture (installing cages or rafts in sea, to grow marine flora or fauna), for all coastal states and in all the calender months.

NOAA-MoES Technical-cooperation – Fourth workshop under NOAA-MoES collaboration for developing predictive capabilities of fisheries and algal blooms was conducted at INCOIS during 23-26 September 2015. Researchers from NOAA, INCOIS and CMLRE primarily focused on Oil Sardine stock along southwest coast. Precipitation is found to be an important factor that drives sardine movement. Other major parameters could be SSHa, Chl-a and upwelling. Further statistical analysis, to explain sardine migration is underway. INCOIS is pursuing additional focus on Tuna, with the help of NOAA.

Oceanographic Data Services of ESSO-INCOIS – Being the central repository for oceanographic data in the country and the designated National Oceanographic Data Centre (NODC) by International Oceanographic Data Exchange Programme of Intergovernmental Oceanographic Commission, the archival and distribution of quality controlled oceanographic data were continued from several observational platforms. Notable additions of data in the past one year are the biogeochemical data obtained from CMLRE (FORV Sagar Sampada), XBT, XCTD and equatorial current meter mooring data from NIO and Physical, Chemical and Biological Oceanographic data received from ICMAM for the period 2002-2007. INCOIS data center had also obtained 50 physical records of historical cruises of FORV Sagar Sampada (Cruise No: 1 – 50) from CMLRE and CMFRI. Gridded datasets of temperature and salinity were prepared using the observations from Argo floats from 2004 and made available in the Live Access Server of ESSO-INCOIS.

Fifth User Interaction Workshop – Over 150 participants representing the users from various agencies attended the Fifth User Interaction Workshop which was held on 3rd March 2015. The user interaction workshop provided the users to interact directly with the scientists of ESSO and provide their valuable feedbacks and suggestions on our products.

Ocean Modeling and Data Assimiliation – ESSO-INCOIS continued to provide ocean analysis using the Global Ocean Data Assimilation System (GODAS). Both in-situ and remote sensing data are being assimilated using 3D-VAR technique to the GODAS system. Data assimilation scheme based on the Localized Ensemble Kalman Filter (LEnKF) is being developed for both Modular Ocean Model (MOM) as well as the Regional Ocean Modeling System (ROMS). Forecasts of wind-waves using very high resolution setup (~ 250 m) of SWAN model for the coast off Pondicherry was made available on experimental basis. Work is progressing in setting up SWAN and WAVEWATCH III with finite element mesh structure for more accurate predictions of wind waves in the coastal waters as well as the open ocean. In order to simulate the ecosystem processes in the Indian Ocean, a bio-geo-chemical module was integrated with ROMS model setup with spatial resolution of ~ 9.5 km x 9.5 km. Comparisons with the observations showed that the model is able to simulate the distribution of bio-geo-chemical parameters quite realistically.

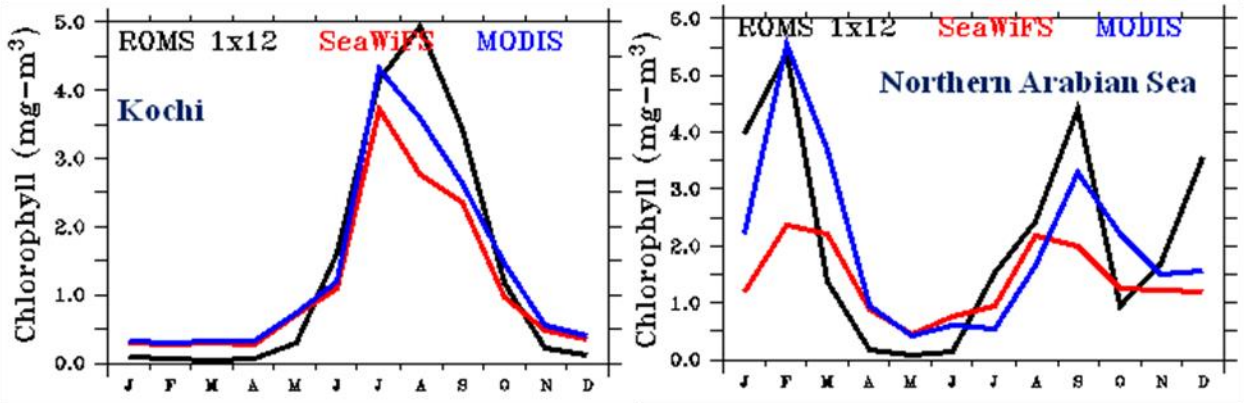

Fig. 3.3 Model simulated temporal variability of sea surface chlorophyll

ESSO-INCOIS is currently setting up a “High-resolution Operational Ocean Forecast and Reanalysis System (HOOFS)” to provide accurate operational ocean predictions at a very high resolution. The HOOFS setup comprises a series of very high resolution (~ 2.25 km x 2.25 km) numerical ocean model (Regional Ocean Modeling System, ROMS) setups covering the entire coastal waters of the country. The forecasting systems for the west coast of India and the south-eastern Arabian Sea were made operational in 2015.

Ocean Observation Systems (OOS):

The Ministry has a comprehensive ocean observations network to acquire real-time, time-series data on surface meteorological and upper oceanographic parameters from the seas around India including from the Indian Ocean Region. A wide range of ocean observation systems are deployed in different parts of the Indian Ocean for acquisition of specific ocean parameters on different spatial and temporal scales. These include moored buoys, drifters, current meters, wave rider buoys, argo floats, tide gauges, coastal radars and acoustic Doppler current profilers. The primary purpose of acquiring a suite of accurate measurements of ocean parameters is to cater research and a wide range of operational services including issue of early warnings. These observation systems are broadly classified into two categories viz. drifters and moored. The details of observations systems deployed, operated, maintained and supported by India and their current status are as under.

Name of Platform	Target	Commissioned till December, 2015	Data received during October, 2015	Parameters	Type of Platform
Argo Float	200	270	130*	Temperature and salinity profiles upto 2000 m	Drifting
Drifters	150	144	7*	Surface temperature, pressure, currents	Drifting
Moored Buoys	16	32	197	Upto 25 surface meteorological and upper oceanographic parameters including waves, winds, temperature, salinity, currents	Moored
Tide Gauges	36	25	19	Sea level data	Moored
High Frequency(HF) Radars	10	12	12	Surface currents and waves	Moored
Current Meter Array	10	11	5	Current profiles in the deep sea	Moored
Acoustic Doppler Current	20	21	16	Subsurface currents	Moored

Profiler (ADCP)					
Tsunami Buoys	7	7	6	Tsunami waves	Moored
Wave Rider Buoy	16	11	9	Surface waves	Moored

*The remaining floats/drifters have completed their life time and as such no data can be received from them.

Moored Buoy Network

Considering the importance of continuous measurement of data of high reliability and quality, which is of scientific relevance, optimal numbers of buoys are maintained at strategic locations in the Bay of Bengal and Arabian Sea. The components being executed by ESSO-NIOT under the programme of OOS are:

(i)Moored Data Buoys – Met Ocean & Tsunami, (ii)CAL VAL Phase II, (iii)Technology demonstration of new observational systems. The Moored Buoy Network performance is successful till date, providing valuable data despite many challenges faced. Four met ocean and coastal buoy systems were also deployed and maintained in locations such as Agatti, Andaman, Goa and Chennai using INSAT and GPRS communication for real time data transmission and data returned more than 97% and cost wise saved more than 96% of air time charges. The tsunami buoys are also deployed and maintained at identified locations near geographical fault lines. Presently these tsunameters are working at four locations and provides real time water level data which is being disseminated to Indian Early Tsunami Warning Centre at Hyderabad and the data is being shared with the global community with the support of NDBC USA. Till December 2015, 71 deployment/retrieval operations were done for which 17 cruises (comprising 304 ship-days and covering 26581 nm (nautical miles) with 2378 man-days) were undertaken. PRAKRUTI, (Indigenous OMNI buoy system) was designed and developed under “Make in India” program with HRIDAYA (Data Acquisition System) which is the heart of the PRAKRUTI. It has the facility to interface with all the buoy sensors, able to program the data collection, process, store and transmit in real time via satellite to data center.

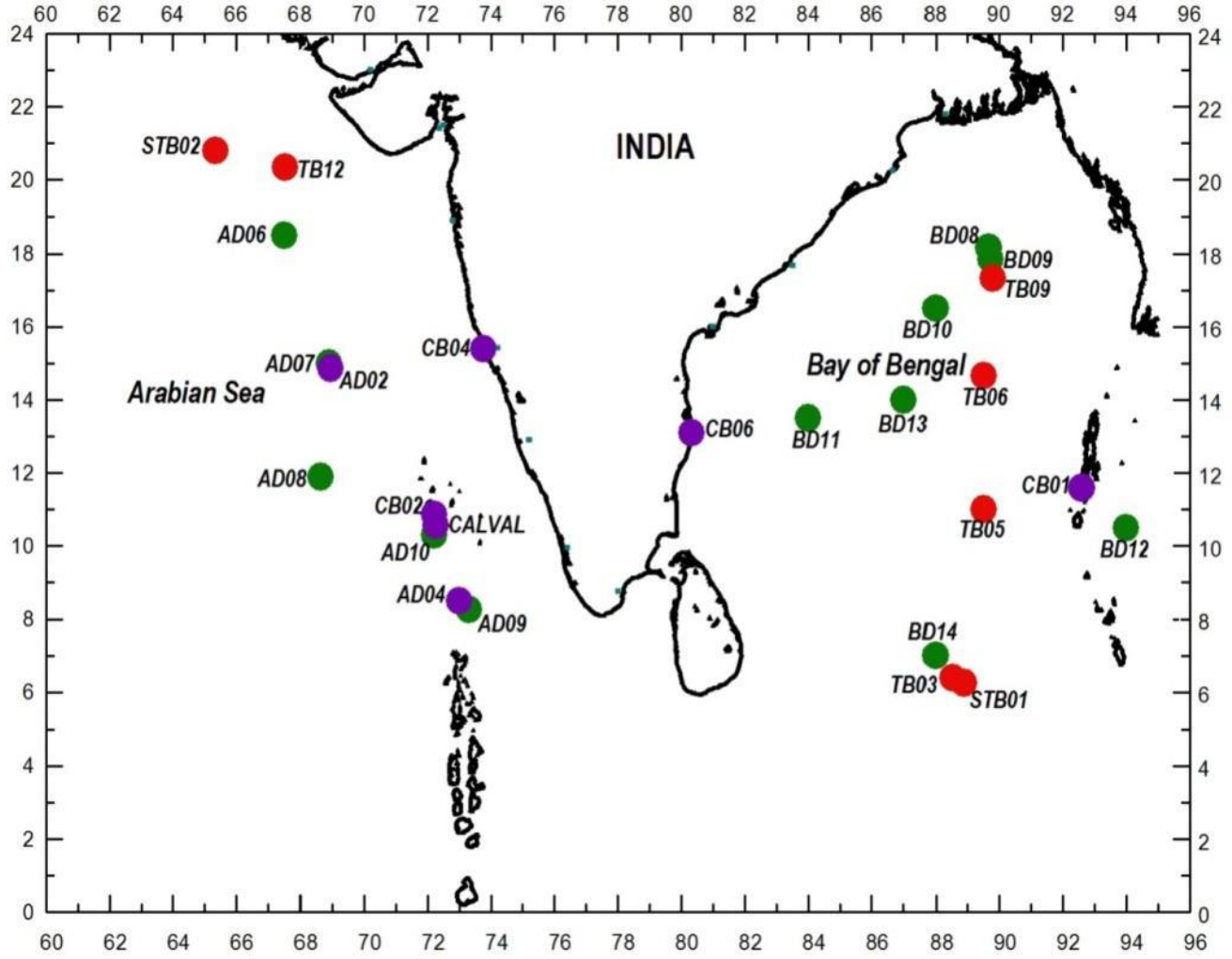

Fig. 3.4 Moored Buoy Network

CALVAL PHASE II – ESSO-NIOT in collaboration with SAC Ahmedabad established twin buoy CALVAL site off Lakshadweep. A pair of buoy systems, Met and Optical, consisting of fully automated hyper spectral radiometers, fluorometer and meteorological sensors, has been realized and deployed during the phase-I site at Kavaratti in Lakshadweep, Arabian Sea, for pre-programmed in-situ data collection and transmission via INSAT-3C satellite. A prototype autonomous ocean data collecting Robofish was developed and tested. The next phase development of the laboratory scale AquaBot prototype has been undertaken after the tests at sea, with caudal fin propulsion. Indigenously developed underwater Glider was tested successfully in the Acoustic Test Facility,NIOT. However activity is undertaken by imparting training to OOS staff under the Indo-US project. Development of ITBS - 'Sagar Boomi' will avoid the technology dependency and provides the capacity to upgrade, improve the tsunami buoy system with cost competitiveness. The development includes next generation buoy hull, Low Power Integrated Data Acquisition Module (LIDS) and Indigenized BPR and deployed in November 2015 as a trial basis.

Arctic Observation – IndARC Mooring – The first underwater moored observatory was deployed by India in the Polar Waters on 23rd July 2014 and successfully retrieved on 15th July 2015 by using on-board Research Vessel Lance (Norwegian Polar Institute). The mooring system worked for one year and all the sensors performed well during the period. The design, development and installation of this underwater moored observatory were successfully executed by ESSO-NIOT in collaboration with ESSO-NCAOR, Goa. This in-house design effort to withstand harsh polar weather is a milestone achievement for the country. One of the major constraints in such a study has been the difficulty in reaching the location during the harsh Arctic winter and obtaining near-surface data. On 20th June 2015, the redeployment of Arctic mooring was carried out.

Ocean Mixing and Monsoon (OMM) Programme:

As part of the Ocean Mixing and Monsoon (OMM) programme, the first intense observation cruise was organized onboard ORV Sagar Nidhi (#SN100) during 21st August to 15th September 2015 in the northern Bay of Bengal. The cruise objective was to collect near surface oceanographic and atmospheric data to understand fine scale ocean mixing in the upper ocean, as a part of the Air Sea Interaction Research Initiative and Ocean Mixing and Monsoon Experiment (ASIRI-OMM) project, a collaborative program between Earth System Science Organization (ESSO), India and USA. This program aims to improve predictive monsoon models through study of air-sea fluxes and upper ocean processes in Bay-of-Bengal and focus on the effects of Bay of Bengal freshwater flux on the Indian Ocean Monsoon. A total of 23 scientists (21 Indian scientists including research students from various Indian institutes and 2 US scientists from University of Washington) participated in this cruise. Many state-of-the art oceanographic instruments were deployed. Ship mounted Automatic Weather Stations (AWS), Radiometers and Inherent Optical Profiler (IOP), Seaglider and Lagrangian floats were used to collect data during the curise. More than 10000 underway CTD profilers and 500 line km of upper ocean ADCP current profiler data were collected. Both ships executed parallel operation in the Bay of Bengal. Glider, Lagrangian float, underway CTD, fast CTD, wire walkers, drifters and autonomous robotic boat and temperature and depth profiler were successfully deployed and operated during this cruise.

RAMA Program – As a part of RAMA program, two cruises were conducted in 2015. The first cruise was onboard ORV Sagar Kanya during 19th August to 15th September 2015 in the equatorial Indian Ocean which serviced six RAMA buoys. A cruise was conducted from 8th October to 8th November 2015 in the equatorial Indian Ocean which serviced 5 ATLAS and 5 ADCP mooring. At present 76% RAMA array sites has been occupied (35 buoy locations are occupied out of planned 46).

Indian Argo Program – India continued to contribute to the Global Argo program by deploying 20 Argo floats in 2015, thus making the total Indian contribution to 377 floats. Presently, there are 760 active argo floats in the Indian Ocean, out of which 126 are deployed by India.

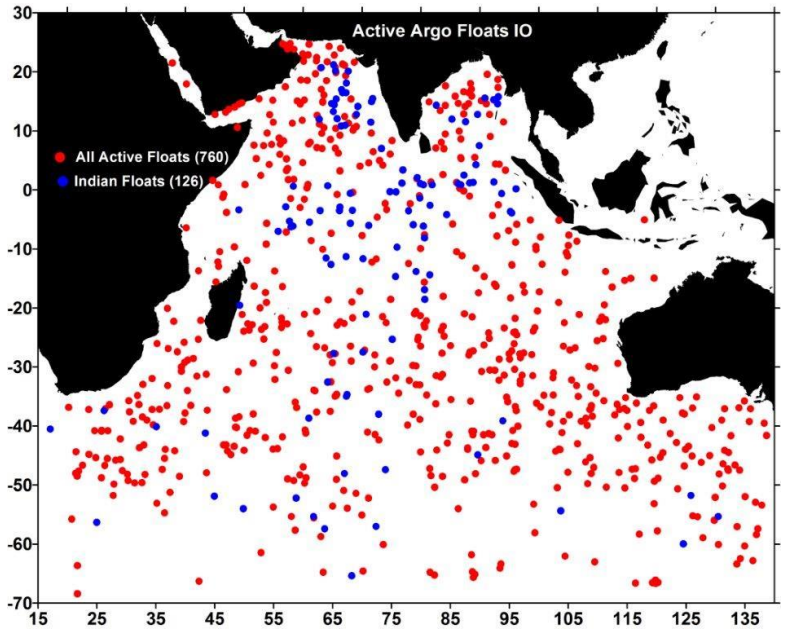

Fig. 3.5 Active Argo floats in Indian Ocean (in colors; blue dots indicate Indian Argo floats and red dots indicates Argo floats deployed by other countries)

Marine Automatic Weather Stations (MAWS) – In 2015, 11 Automatic Weather Stations (AWS) were installed onboard MV Swaraj Dweep, MV Nancowry, SCI Yamuna, SCI Kundan, MV Campbell Bay, SCI Mukta, MV Sentinel, MV Dering, MV Chowra, MV Kalighat and MGS Sagar. With the above installations ESSO-INCOIS now maintains a network of 30 AWS stations.

Wave Rider Buoys – ESSO-INCOIS maintained a network of 10 wave rider buoys around the Indian coastline. In 2015, 10 redeployments were carried out. A web interface was developed for the inventory management and record keeping pertaining to coastal observatories. ESSO-INCOIS signed an MoU with Regional Multi-hazards Early Warning System (RIMES) to establish an Integrated Ocean Information System for the Indian Ocean Rim Countries. It is planned to deploy wave rider buoys at coastal zones of Seychelles and Sri Lanka as part of the project in order to validate the forecast products and improve the ocean model.

Currents Observations and Simulations in the Indian EEZ (COSINE) – With the funding from the Ministry, CSIR-NIO has been maintaining 16 Acoustic Doppler Current Profilers (ADCPs) which record the vertical profile of currents in the coastal waters of India. The active moorings include one pair and three individual ADCPs off the west coast of India and four pairs and three individual ADCPs off the east coast of India.

ADCP current meter moorings in the equatorial Indian Ocean – In order to measure ocean currents, CSIR-NIO has been maintaining five active deep-sea current meter moorings in the equatorial Indian Ocean during 2015. A map showing current meter locations is provided in the figure below. Data from this network of ADCPs is extensively used for the validation of model simulations and understanding the variability in the Indian Ocean circulation. The observed data during 2010-2014 covered the negative phase of the Indian Ocean Dipole (IOD) in 2010 and positive phases of the IOD event in 2011 and 2012 and again negative phases of IOD in 2013 and 2014. The data is analyzed to examine whether the observed

currents show the impact of the IOD events.

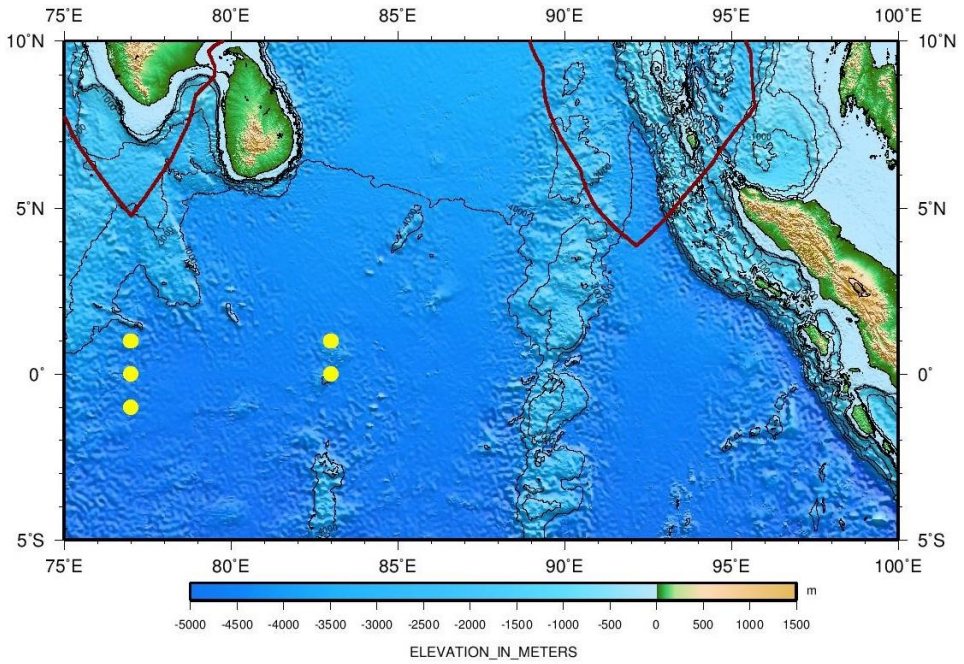

Fig. 3.6 Map showing locations of the equatorial current meter moorings as denoted by the yellow dots

Indian XBT Project – CSIR–National Institute of Oceanography (NIO) has been executing the Indian XBT project supported by the Ministry for the past 25 years. Under this project, near-surface temperature / salinity data are being collected by deploying XBTs / XCTDs using ships of opportunity (cargo ships). The main objective of this program is to understand and document the variability of upper ocean thermo-haline fields on different time scales. XBT / XCTD data are collected along selected shipping transects in the seas around India at fortnightly to monthly intervals. During May 2015, Silver Jubilee of the Indian XBT Project was celebrated at the CSIR-NIO and a CD containing 25 years of processed XBT / XCTD data was released during the function.

Ocean Modeling:

Early Warning for Storm Surges – A storm surge model based on ADCIRC has been successfully configured for the east coast of India for the prediction of storm surges that may occur during the landfall of cyclones. Triangular gridded meshes are developed for the entire east coast of India to compute cyclone induced surges and associated inland inundation. Model is tested with some past cyclones and the simulations are in good agreement with available observations. Experimental forecast of the storm surge and associated inundation were issued in real time during the severe cyclone PHAILIN that had a landfall near Gopalpur on 12th October 2013.

HYCOM – Hybrid Coordinate Model (HYCOM) has been equipped with a data assimilation scheme (based on multivariate linear statistical estimation using Best Linear Unbiased Estimate (BLUE)) to assimilate sea level anomalies and SST. The system takes boundary conditions from Global HYCOM and issues 5-day daily updated forecasts of oceanic

parameters. Cross-verification of the model free-run and forecast runs were carried out and it was found that there is no considerable deterioration of skill from forecast day 1 to 5.

High-resolution Regional Ocean Modeling System (ROMS) for coastal ocean forecasts – The first in the proposed series of very high resolution Regional Ocean Modeling System (ROMS) setups for the coastal waters of India has been set up for the northwestern coast of India (64.0^{o}E to 74.0^{o}E, 8.0^{o}N to 25.0^{o}N). Currently, this model set-up takes boundary condition from the basin-scale set up of ROMS with a horizontal resolution of 12.5 km.

Wave Modelling: The first in the series of high resolution wave forecast models for the Indian coasts, SWAN (*Simulating WAves Nearshore)* has been set up for the coast off Puducherry on the east coast of India. The boundary conditions for SWAN are taken from the global Wave Watch (WW3) run at ESSO-INCOIS.

Ocean Colour Research:
Time-Series Observations – The time-series stations established in Indian coastal waters, as a part of Ocean Colour Research programme are being continued with the addition of stations off Veraval, Chennai and Sundarbans.

Chlorophyll dynamics in near coastal waters of western Bay of Bengal using in-situ and long-term satellite data – The temporal distribution of Chla, TSM and $a_{CDOM}440$ showed one common peak during southwest monsoon season (August-October). Chla also showed a prominent peak during pre-southwest monsoon (March-April).

The Chla, retrieved from Moderate Resolution Imaging Spectroradiometer onboard the Aqua satellite (MODISA), Ocean Colour Monitor onboard Oceansat-2 (OCM-2) and Visible Infrared Imager Radiometer Suit (VIIRS) onboard Soumi National Polar-orbiting Partnership (NPP), showed overestimation in the nearshore waters (depth < 30m). The error in satellite estimation of Chla was in the range of 33 to 51% and the overestimation was predominantly due to the covariance of TSM with Chla. The Chla retrieved from MODISA using OC3M algorithm was better compared to other retrievals.

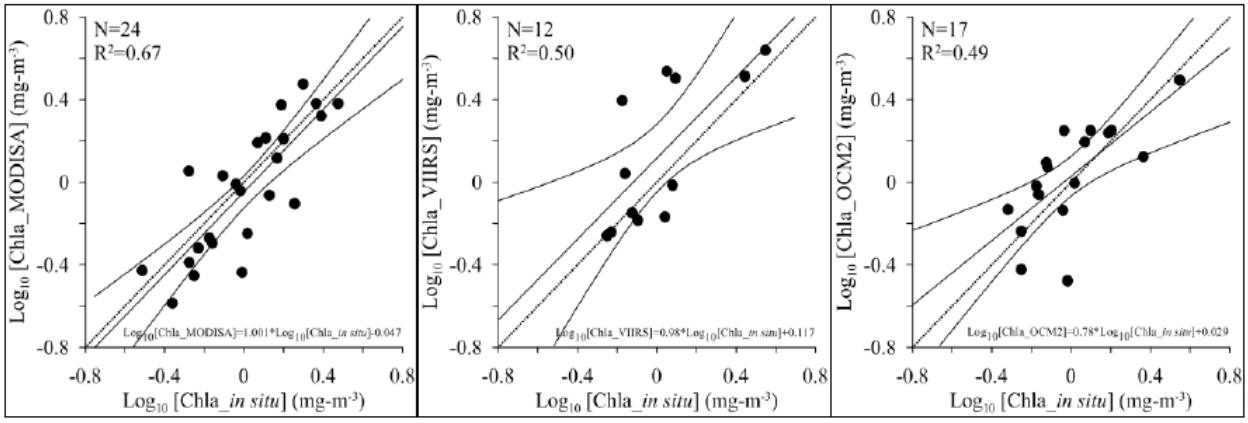

Fig. 3.7 Scatter plot showing the relation between in-situ measured Chla and that derived from (a) MODISA using OC3M algorithm, (b) VIIRS using OC3V algorithm and (c) OCM-2 using OC4-O2 algorithm. The dotted line indicates 1:1, solid straight line shows the regression and solid curved lined shows the 95% confidence limit

3.2 COASTAL RESEARCH

Hydrodynamics and sediment transport studies along South Maharashtra: The knowledge of near shore hydrodynamics and its interaction with beaches is very essential at local scale to understand the causes of coastal erosion and estimation of sediment transport in coastal regions. The 4-M approach i.e. measurement, monitoring, modeling and mapping is being implemented to understand the causes of coastal changes, estimation of sediment transport and prediction for shoreline position for effective coastal zone management along Rathnagiri and Vengurla beaches of south Maharashtra coast. Monthly monitoring of shoreline, beach profile and beach sediment characteristics at 10 selected stations was carried out to study the change in morphological and sediment textural distribution of foreshore beach during two annual cycles since May 2013.

Hydrodynamic, measurements were made during the pre-monsoon (February-March, 2015) by deploying various oceanographic equipments to setup a fine scale numerical model for nearshore hydrodynamics and quantify sediment transport rates. The surface gravity wave climate was implemented the Indian ocean to regional scale using WAVEWATCH-III model. The model was setup with available various other wind datasets i.e. ECMWF, NCMRWF, NCEP etc and sensitivity analysis was carried out to arrive at a suitable input datasets. These results were used to set up a local scale model (SWAN) for nearshore waters off Rathnagiri and Vengurla. The local models were schematized with 10 m spatial resolutions to capture wide range of nearshore and surf zone processes, which are very vital in estimation of sediment transport in coastal zone.

Monitoring and mapping the shoreline change along Indian coast: Regular monitoring of shoreline and its spatial and temporal trends are required to establish proper shoreline management plans. Shoreline changes for the entire east coast of India covering total distance of 2961 km starting from Kanyakumari to Sundarbans delta has been analyzed to find the long term and inter annual shoreline change rate. The study was carried out using geospatial techniques along with ground truth survey all along the east coast of India. The multi-resolution satellite data such as Landsat TM, Landsat ETM+, IRS-P5 (Cartosat-1), IRS-P6 (LISS-III) and (LISS-IV) of different dates was used for shoreline change rate.

In most cases, erosion is mainly due to anthropogenic activities such as construction of ports, breakwaters, groins etc. In some cases extreme events like cyclones, storm surges, river sediment/water discharge etc. cause shoreline erosion. The study is also considering such factors to study the long and short-term shoreline change patterns. Also in each year, shoreline position is monitored and updated on the maps. Currently annual updation of shoreline change maps using 2015 data is under progress.

State wise erosion-accretion pattern of east coast of India:

S. No.	State	Coastal Length (km)	Erosion (%)	Stable (%)	Accretion (%)
1	Tamil Nadu*	1014	43	31	26
2	Andhra Pradesh	974	28	18	54
3	Odisha	475	30	10	60
4	West Bengal**	498	67	10	23
Total		2961	39	20	41

*including Puducherry **including islands

Sea Water Quality Monitoring along Indian Coast: Monitoring the health of coastal sea is highly essential to assess the status of environmental quality and to alert government and public institutions for their implications relating to fisheries and other human related uses. ICMAM has been collecting data on 25 different parameters on physical, chemical and biological including microbiological characters of water and sediment samples, at 20 select locations around the coastline of the country.

Prediction of Water Quality along the Chennai coast –

Recently, there is a growing concern on the degradation of water quality due to discharge of untreated sewage in the coastal waters. In order to assess the level of pollution and develop a prediction system for Chennai coastal waters, water quality, sediment and biological parameters for 36 locations on a monthly basis are being monitored since January 2013. Water level, surface current, drifter data are extensively collected as a part of dispersion study and a water quality model was setup for Chennai coastal waters to carry out simulations for water quality state variables viz., temperature, salinity, oxygen and bacteria levels (pathogen) in response to biochemical, dispersion and transport processes. Low dissolved oxygen (~5 mg/l) and high concentrations of nutrients (phosphates and nitrates) were recorded in the coastal waters. Excess phosphorus triggers algal blooms of toxin producing species mostly during January and April and succession of phytoplankton species are reported. The current distributes and disperses the bloom within surf zone and contaminates the coastal environment and the public utility beaches. Initial carbon measurement indicates Chennai coastal waters are highly saturated with carbon dioxide and region acts as potential source to the atmosphere.

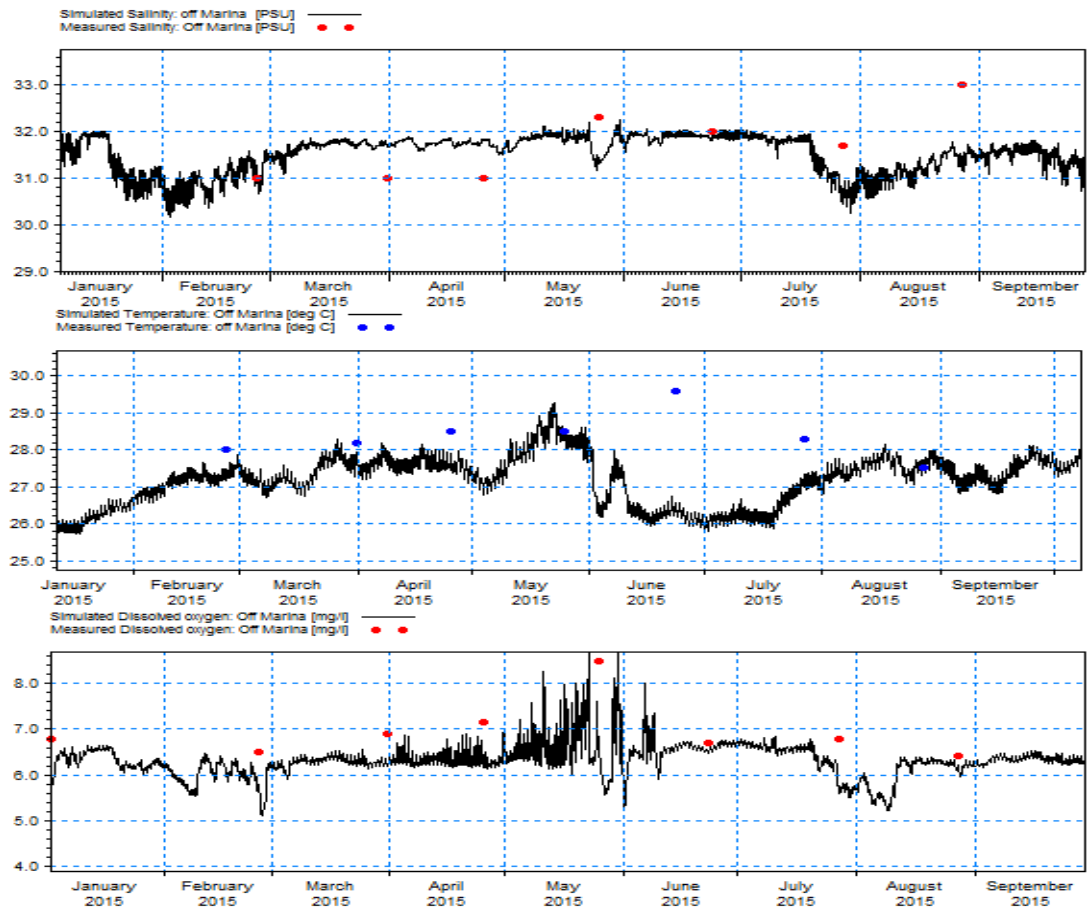

Fig. 3.8 Validation of salinity, sea surface temperature (^{0}C) and dissolved oxygen (mg/l) off Marina beach, Chennai coast

Ecotoxicology studies – Toxicity experiments to derive Seawater Quality Criteria (SWQC) for heavy metals like Nickel, Selenium, and pesticide Chlorpyrifos for the Ennore creek and adjacent coastal waters of Chennai have been initiated. Experiments for Nickel were completed and Selenium and Chlorpyrifos are under progress.

Bioaccumulation studies – Monitoring of heavy metals like Copper, Cadmium, hexavalent Chromium, Lead and Nickel in seawater, sediment and tissues of marine organisms such as Fish, Crab, Oyster and polycheates were sampled towards upstream of Ennore estuary at fortnightly intervals from November 2014 to October 2015.

Ecosystem Modeling: Towards developing an ecosystem model for the coastal waters of Cochin, five transects with 25 locations within the 50 m depth contour were examined for three seasons that includes post-monsoon (January 2015), pre-monsoon (April 2015) and monsoon (August 2015) for all the biogeochemical variables. The nutrient distributions showed distinct patterns in spatial distribution between the three contrasting seasons.

The pCO_2 distributions are in agreement with the results of primary productivity. For all the seasons, the surface pCO_2 distribution showed that the coastal waters of Cochin acts as a net source of CO_2 to the atmosphere.

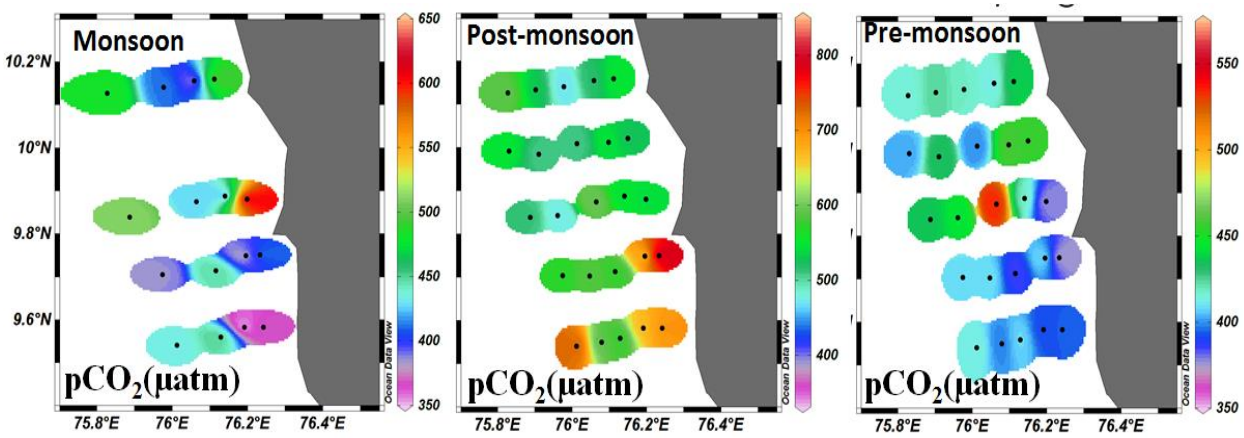

Fig. 3.9 Spatiotemporal variability of pCO_2 in coastal waters of Cochin

Capacity Building: As per its mandate, to develop capabilities in the coastal states and UTs through capacity building programmes, ESSO-ICMAM project directorate has been carrying out training programmes in the various aspects of coastal zone management. During this plan period about 21 programmes have been conducted till date. ESSO-ICMAM conducted a five days training course on "Coastal Processes and Shoreline Mapping" during 3rd August to 7th August 2015 at WALMI, Anand, Gujarat for the field engineers of Gujarat state government in which 46 engineers involved in coastal protection work and shoreline management work were imparted training.

3.3 MARINE LIVING RESOURCES

Marine Living Resources Programme (MLR) is a multi-institutional research program being implemented through the Centre for Marine Living Resources and Ecology, Kochi (ESSO-CMLRE). Under this program, studies are carried out on five major research themes viz., (1) Monitoring and Modelling of Marine Ecosystems (MMME), (2) Deep Sea and Distant Water fishery (DSDWF), (3) Integrated Taxonomic Information System (ITIS), (4) Southern Ocean MLR (SO-MLR), and (5) Technology development on MLR (MLR-TD).

Monitoring and Modelling of Marine Ecosystems (MMME): Time-series observation on O_2 saturations along the mid-shelf waters of Kochi revealed that there is not much difference in the values of O_2 saturations between now and the observations made five decades ago, except for marginally higher values during the peak upwelling period. The region between Mangalore and Rathnagiri in the north of Kochi have been reported to be sulphidic condition in its inner shelf region, whereas such conditions do not seem to occur off Kochi presumably due to the difference in the initial oxygen content of upwelling source water. This showed that there is no indication of an intensification of coastal hypoxia off Kochi due to human activities unlike many other coastal areas. However, the low oxygen sub-pycnocline waters over the shelf maintains the oxygen levels critically poised and just short of anoxia, underlining the vulnerability of the region to potential global change. In view of model results predicting the expansion of oxygen minimum zones in future, coastal hypoxia in SEAS is expected to add further stress on coastal biogeochemistry and fishery resources. Dissolved Oxygen changes over the south-eastern Arabian Sea shelf – comparison of 2012 with historical (1958-60) data is as shown below.

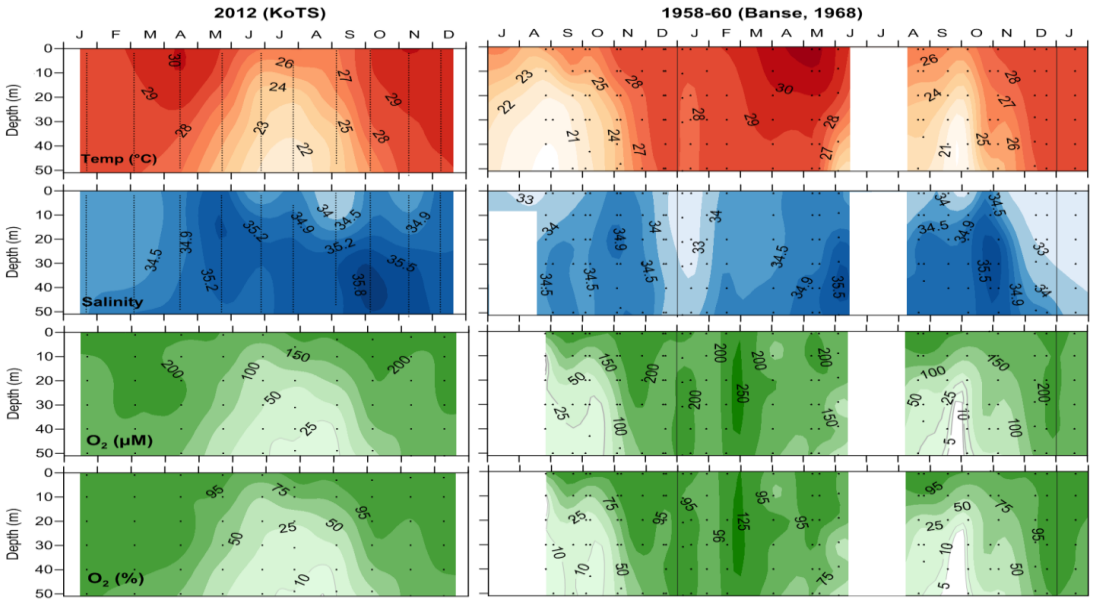

Fig. 3.10 Dissolved Oxygen changes over the south-eastern Arabian Sea shelf – comparison of 2012 with historical (1958-60) data

Observations during the summer monsoon (June-September) along the eastern Arabian Sea shelf where seasonal hypoxia occurs indicate that the oxygen levels close to the sea bottom were found to influence benthic faunal distribution. The sensitive groups such as crustaceans and echinoderms were very less in terms of abundance whereas the polychaetes group were predominant. Under the benthic biodiversity studies in the Andaman and Nicobar Islands, about 566 species were recorded which includes one new species namely *Armandia sampadae.* The study proved that this region is one of the hotspots so far as benthic biodiversity is concerned. A unique shallow water assemblage of an exclusively deep-water echinoderm, *Ophiomyces delata*, was observed in the Duncan Passage, Andaman Islands.

Plankton ecology in Arctic Fjords: ESSO-CMLRE initiated studies on phyto and zooplankton ecology in the Arctic Fjords – Kongsfjorden, using in-situ and satellite oceanographic techniques. Standing stock of zooplankton and its diversity are considered as reliable index to assess the productivity besides providing clue on long term changes of the region. Initial observations of the study showed that copepods, Pteropod, Amphipod, Chaetognath, Euphausiid, Decapod larvae and Cephalopod were observed to be the dominant zooplankton groups in this region. Dominance of Copepod *Calanus glacialis* was observed near the glacier stations and occasional swarming of Comb Jelly was noticed throughout the Fjord.

Deep-Sea and Distant Water Fishery (DSDWF): Surveys were undertaken to identify trawlable fishing grounds and to map the distribution and abundance of deep sea resources along the South Eastern Arabian Sea and the Andaman Sea. A total of 20 bottom trawl operations were carried out (12 in Andaman waters, 8 in SEAS), of which three grounds were identified as trawlable grounds in Andaman waters. A potential ground for deep sea lobster *Puerulus sewelli* was identified off Andamans (11.9°N, 92.3°E) with a maximum catch of 28kg/hr CPUE. The catch from Andaman sea were dominated by teleost fishes (89%) followed by crustaceans (8%) and elasmobranches and molluscs. Among the teleost fishes,

Psenopsis cyanea constitutes about 57.10% followed by *Bembrops caudimacula* (14.85%) and *Pterigotrygla hemisticta* (8.00%).

Studies on the distribution and abundance of tuna larvae near reef and offshore around Minicoy islands in Lakshadweep waters were studied. The larvae of oceanic tuna species of *Katsuwonus pelamis* (skipjack tuna), *Thunnus albacares* (yellowfin tuna) were recorded from the area. Studies indicated that the waters around the seamounts ecosystems are potential breeding ground for the oceanic tuna species.

Integrated Taxonomic Information system (ITIS): ESSO-CMLRE has been recognized as regional node of International Ocean Biogeographic Information System (IOBIS) of Intergovernmental Oceanographic Commission (IOC). As part of this, about 1.06 lakhs records of marine species occurrence from the northern Indian Ocean have been inventoried from primary (actual specimen's observation) and secondary (literature) sources and archived as database. A new species of pycnogonid namely *Ascorhynchus levissimus* was reported for the first time from the northern Indian Ocean. Besides that, an enigmatic sea pen namely *Gyrophyllum sp.* and a mushroom coral namely A*nthomastus grandiflorus* were reported off Nicobar waters. Under the Census of Marine Life (CoML) program which was initiated for resolving taxonomic ambiguities amongst cryptic species, about 800 deep sea samples were collected, taxonomically identified and tissues of them were stored in alcohol for sequencing and further to develop barcodes. Initially, barcodes were developed for *Hyalinoecia tubicola, Lysirude channeri, Bregmaceros nectabanus, Mitrella bicincta, Plesionika martia, Fissidentalium proforundum* and *Amphiophiura sordida*.

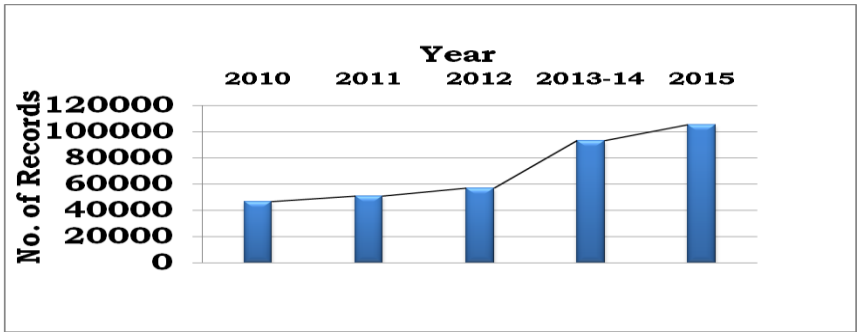

Fig. 3.11 Number of marine species occurrence records over the years under the IOBIS program

Technology Development on MLR (MLR-TD): Marine ornamental fishes were breed and reared upto marketable size in the hatchery set-up at Agatti, Lakshadweep which was established under MLR-TD programme. The hatchery has a capacity to produce around 800 - 1000 numbers of juveniles of different species of clowns in the size range 3-3.5 cm in a span of three months. The centre achieved success in the spawning of marine ornamental shrimps such as *Stenopus hispidus, Saron marmoratus* (Olivier, 1811) and host anemone of the clown fish, *Heteractis magnifica* (Quoy and Gaimard, 1833).

As part of the technology dissemination to islanders, a 10-day training workshop on "Marine ornamental fish breeding and rearing at Lakshadweep Islands" was held during the period from March 23rd to April 1st 2015. About 20 graduate students from Andorth College, Andorth Island attended the training. A training manual titled "Hatchery Technology of Marine

Ornamental Fishes – Breeding & 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.

Southern Ocean MLR (SO-MLR): Opportunistic visual survey were conducted by ESSO-CMLRE from the ice-free areas of Western Indian Sector of Southern Ocean onboard ORV Sagar Nidhi during the austral summer (January-February 2015) to determine the distribution, migration patterns and habitat preferences of cetaceans in the Southern Ocean. Long finned pilot whale *Globicepahala melas* were observed in groups with more than 90 individuals socializing with common bottlenose dolphins *Tursiops truncatus* .There was one sighting of Sperm whale *Physeter macrocephalus* comprising two animals. Three sightings (consisting of five individuals) of unidentified whales and one group of unidentified dolphins (two individuals) sighted in three different locations. Also, sea birds and Adelie penguins *Pygoscelis adeliae* of southern ocean were observed during the marine mammal observation.

Fig. 3.12 Sightings of whale, bottle neck dolphins and albatross in Southern Ocean

Biogeochemistry (SIBER): Both Arabian Sea Time Series (ASTS) and the Bay of Bengal Time Series (BoBTS) are located in the core of OMZ of the Arabian Sea and the Bay of Bengal respectively. In addition to the open ocean time series sites, observations are also being carried out at a coastal time series site CATS (Candolim time series) located off Goa.

Overall, the total flux collected in the middle and deep traps are higher compared to the shallow trap. During 2014-15 the deep trap at BoBTS collected material up to 433 mg/m^2/day during July-August. In the Arabian Sea also, the particle flux showed maximum during southwest monsoon followed by spring inter monsoon (SIM). During 2013-14, the deep trap collected more material (upto 357 mg/m^2/day) during August (SW monsoon) followed by in March (SIM). The higher flux especially in shallow traps during March may possibly be due to the sinking of trichodesmium bloom which occurs regularly during Feb-March in the Arabian Sea.

3.4 INTERNATIONAL STUDY OF MARINE BIOGEOCHEMICAL CYCLES OF TRACE ELEMENTS AND THEIR ISOTOPES: GEOTRACES (INDIA)

Trace elements regulate ocean processes, such as marine ecosystem dynamics and carbon cycling. Several other trace elements also play vital roles in cell physiology and in biochemical reactions. However the role of these trace elements in controlling the structure and the productivity of marine ecosystems is not well understood. GEOTRACES (India) programme was started to map the distribution of trace elements and isotopes in the Indian Ocean and to identify the factors influencing these distributions. A total of nine projects have

been sanctioned by the Ministry under GEOTRACES (India) programme. The important achievement during the period could be the expedition to the Southern Indian Ocean. The clean sampling enabled GEOTRACES and Hydrothermal combined cruise onboard ORV Sagar Kanya (SK-324 and 325) in the Indian Ocean (October - December 2015).

3.5 OCEAN TECHNOLOGY

The National Institute of Ocean Technology (NIOT), an autonomous Institute under the Ministry of Earth Sciences, undertakes various Ocean Technology programs aiming at developing reliable indigenous technology to address the issues associated with harvesting of non-living and living resources from Oceans, as well as protection of coast, construction of offshore structures etc.

Deep Sea Technology: Polar Remotely Operable Vehicle (PROVe) was mobilized to Indian Antarctic Base Station Maitri to participate in 34th Indian Scientific Expedition to Antarctica in summer 2015. PROVe was deployed at Priyadarshini Lake near Maitri station and was tested for its functionality by capturing of the underwater visuals of lake bed and algal mats. PROVe was deployed and qualified for its polar scientific usage at New Indian Barrier Ice Shelf at Antarctica during March 2015. The images of the ice shelf along with vertical profile of irradiance, salinity and temperature were collected after maneuvering the vehicle upto 62 m depth in ice shelf region.

Fig. 3.13 Polar Remotely Operable Vehicle (PROVe) in Antarctica

Autonomous Coring System (ACS): Deep water sea trial was conducted during April – May 2015 to qualify the Deep Sea Autonomous Coring System (ACS) landing at gas hydrates site with soft sediments of < 1 kPa. Hydraulically foldable foot with surface area of 20 m^2 was developed and integrated with ACS and successfully landed and drilled up to 24 m below sea floor at Krishna – Godavari basin gas hydrate site at 1057 m water depth. Drilling was done up to a maximum depth of 38 m in 18 hrs time period at Chennai offshore.

Integrated Mining System: Development of the Integrated Mining System (IMS) had been in an advanced stage of development, with module level tests of the deep water crawler and pumping platform's components being undertaken.

Concurrently, industry perspective of the proposed mining configuration was sought, as a consultancy-study project titled "Configuration and Handling Studies of Flexible Transport

Riser System" from experienced offshore consulting firms. The contract was concluded with M/s 2H Offshore Engineering (Malaysia), a leading offshore consultancy firm specializing in riser systems.

In-situ Deep Water Soil Tester: One of the most critical part of the IMS development has been the capability of the Mining Machine to effectively move and maneuver on the extremely soft soil of the sea bed at CIOB. Since the data on the soil strength at site, in as-it-is condition, was most critical for developing the locomotion system of the Mining Machine, an in-situ Soil Tester has been developed. The equipment can be deployed from a ship to a depth of up to 6000 m and can effectively measure the soil shear strength and bearing pressure up to 40 cm, apart from image profiling of the sampled location.

Fig. 3.14 In-situ soil tester

3.6 COASTAL ENGINEERING

Engineering Investigations and Model studies for the 'Kalpasar' Project were carried out to assess the effect of proposed dam under the Gulf of Khambhat development Project (Kalpasar) on flow pattern on the upstream and downstream areas of the dam. Model results of the post dam scenario shows significant increase in water level at dam corridor which gradually decreases towards south. Based on the numerical model (hydrodynamic, wave and storm) results, the proposed dam design height has been determined and provided to Kalpasar Department.

Demonstration of shore protection measures through beach erosion and artificial replenishment studies for Rama Krishna beach, Visakhapatnam was done with a detailed hydrodynamic, wave and sediment transport model study. Comparison of numerical model

results with available field data indicates a reasonable agreement on hydrodynamic parameters. Various mitigation schemes have been tried out in the simulation study. Based on the considerations of effectiveness, cost, durability and ease of installation, a 'perched beach' concept has been finalized.

At Puducherry beach, offshore retaining structures of various configurations were studied in order to increase the life of the nourished Puducherry beach and also to minimize the effect of erosion on the north side. Design of beach profiles for nourishment was done based on site specific conditions along Puducherry coast which indicated an immediate requirement of 1.0 million m^3 of sand for nourishment. A specialized consultant was engaged to assist in design and execution of offshore reef.

Wave Structure Interaction Studies are being conducted on intake structure at Agatti Island, where wave and tidal measurements have been recorded since March 2012 till date by bottom mounted directional wave recorders which measure both incident and reflected waves. An extensive array of pressure transducers is fixed on the intake structure to measure the incident wave pressure. The total pressure acting on the intake structure has been estimated for the pre-monsoon and monsoon seasons for design of structure. 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. Numerical code (Open FOAM) has been used to estimate the wave force on the intake structure. Probabilistic analysis was carried out for occurrence of maximum wave heights (H_{max}) during North-East and South-West Monsoon for each year from 2012 to 2015. The shape and mean of probability distribution function during North-East Monsoon is relatively same with significant change in scale factor. But, during South-West Monsoon the shape and scale of probability distribution function is relatively same with significant increase in mean over each year, indicating the increase in intensity of wave climate and need for long-term field measurements/studies.

3.7 OCEAN ENERGY

Ocean Current Turbines: Horizontal axis configuration of 0.8 m diameter cross flow turbine was fabricated and tested with sets of three straight blades and three helical blades. The turbines were successfully tested in a gravity driven seawater channel of a thermal power station. Blades were also designed for a scaled up turbine using computational fluid dynamics principles for performing at low current speeds.

Floating Type Wave Energy Device: Backward Bent Ducted Buoy (BBDB) – A 196 mm diameter unidirectional impulse turbine with characteristics matching the backward bent ducted buoy (BBDB) was fabricated using rapid prototyping technique. Laboratory tests indicated that the light weight turbine rotor greatly improved the dynamic performance of the turbine. The BBDB fitted with this new turbine when tested in open sea off the Chennai coast generated electricity with higher efficiency as compared to the smaller turbine used in the earlier sea trial.

3.8 MARINE BIOTECHNOLOGY

Biodiesel was produced from *C. vulgaris* oil by base-catalysed transesterification

reaction. The chemical characteristics of the biodiesel and diesel engine performance of biodiesel were compared to diesel and it was found that the emission parameters of biodiesel were comparatively lower than diesel. Biodiesel (B-10) powered diesel car test run was successfully carried out from Nellore to Chennai during the foundation stone laying ceremony of ESSO-NIOT, Nellore. Solar powered electroflocculation technique for harvesting microalgae from 1 tonne culture medium was optimized and patented (German Patent No. 20 2015 104 046). Chlorella growth factor extracted from wet biomass of marine micro algae *Chorella vulgaris* was found to contain significant number of pharmacologically vital proteins and possess anti proliferative effect against cancer cell lines.

Toluene degrading *Nesiotobacter sp.* isolated from 2000 m depth marine sediment from Bay of Bengal was cultured in a high pressure-low temperature fermentor at 10 bar pressure. The rate of toluene biodegradation increased as the pressure increased and maximum degradation was recorded at 10 bar pressure. The new halotolerant strain (NIOT.Ch.34) of species *Streptomyces fenghuangensis* possessing antibacterial and anticancer activity was isolated from deep-sea sediment (2000 m water depth). Chemical characterization revealed the presence of biologically active derivatives, like pyrrolo[1,2-a]pyrazine, 2,5-piperazinedione, vinylbital and unusual amino acids forming 24.5, 4.3, 3.9 and 2.1% part, respectively. Biodiversity and antagonistic properties of cultivable actinobacteria from the deep sea sediments of Barren Island was investigated and 84 isolates exhibited good antibacterial activity against the type strains. Recombinant glutaminase-free L-asparaginase producing marine actinomycetes *Nocardiopsis alba* was developed and L-asparaginase production has been optimized.

Open Sea Cage Culture of cobia initiated at Olaikuda with the technical support of ESSO-NIOT using their own financial resources has successfully harvested cobia fishes viz., 7.0, 1.38 and 2.2 tonnes during May to November 2015. The geospatial analysis of Indian seas carried out revealed a vast Indian sea space to the tune of 13.67% (2,76,123 km^2) of Indian EEZ, which is technically suitable for taking up offshore farming in the country between 6 to 100 m depth zone.

Fig. 3.15 Community based cage farming harvest at Olaikuda

3.9 MARINE SENSORS, ELECTRONICS AND OCEAN ACOUSTICS

The in-house developed Buried Object Scanning Sonar (BOSS) system was further improved to enhance the Signal to Noise Ratio (SNR) while preserving boundaries of detected target images generated by the BOSS system. An improvement of 12.8 dB Peak Signal to Noise Ratio (PSNR) was estimated. The BOSS system was also enhanced with a 31 channel planar hydrophone array compared to the earlier 16 channel linear arrays. Tests were conducted in Acoustic Test Facility (ATF) followed by Royapuram harbour sea trials, off Chennai to demonstrate the enhanced system performance in real time while towed at 1-2 knots. The buried metal plate (1 x 0.9 x 0.005 m) at a depth of ~30cm below the sea bed was successfully detected by BOSS system. During these trials, presence of a second layer in some of the harbour areas was also detected by the system indicating the capability of the BOSS system as an Acoustic Sub-Bottom Profiler as well. Development of four nested element cymbal hydrophone arrays was also accomplished and tested during this trial.

Trial production of the in-house developed Autonomous Underwater Profiling Drifter (AUDP) by Indian industry has been completed. Two AUPDs deployed in Arabian Sea delivered profile data. Three prototype drifter buoys with INSAT communication deployed in Bay of Bengal functioned upto 189, 69 and 36 days, respectively. A prototype Deep Ocean Pressure Recorder was deployed in Bay of Bengal at 3452 m depth during December 2015. Design and development of Orthogonal Frequency-Division Multiplexing (OFDM) based Acoustic Modem was completed.

An inertial type three element vector sensor array for ocean acoustics detection for a frequency range of 10 Hz to 6 kHz was designed and developed in collaboration with M/s Keltron Electro Ceramics, Kerala. The vector sensor array was tested at Acoustic Test Facility (ATF) and at Underwater Acoustic Research Facility (UARF), Idukki for a maximum range of 400 m from the acoustic source. Direction of Arrival (DOA) of acoustic signal was estimated using conventional beam forming method. The estimated direction from the beam former output compared well with the known source direction along the azimuth.

An ambient noise system which consists of a hydrophone Cetacean C55 make and data acquisition module for Arctic measurements was made and tested. It was tested in Environmental Chamber in order to qualify for polar measurements and deployed successfully in the Arctic region as part of IndArc Mooring.

The National Accreditation Board for Testing and Calibration Laboratories (NABL) granted renewal of accreditation to Acoustic Test Facility (ATF) for the extended scope from 100 Hz to 500 kHz including accreditation of vibrating water column based low frequency calibration system with the validity upto 2017.

3.10 OCEAN SURVEY AND MINERAL RESOURCES

This major programme to carry out topographic survey of the Entire Exclusive Economic Zone (EEZ) of India, which is around 2.2 million km^2, by utilizing the state-of-the-art technologies of swath bathymetric multibeam echosounders (MBES) is being carried out through ESSO-NCAOR, ESSO-NIOT and CSIR-NIO. Geological Survey of India is also carrying out surveys in collaboration with ESSO-NCAOR. The details of area covered so far

and status of surveys are indicated in figure below (Fig. 3.16).

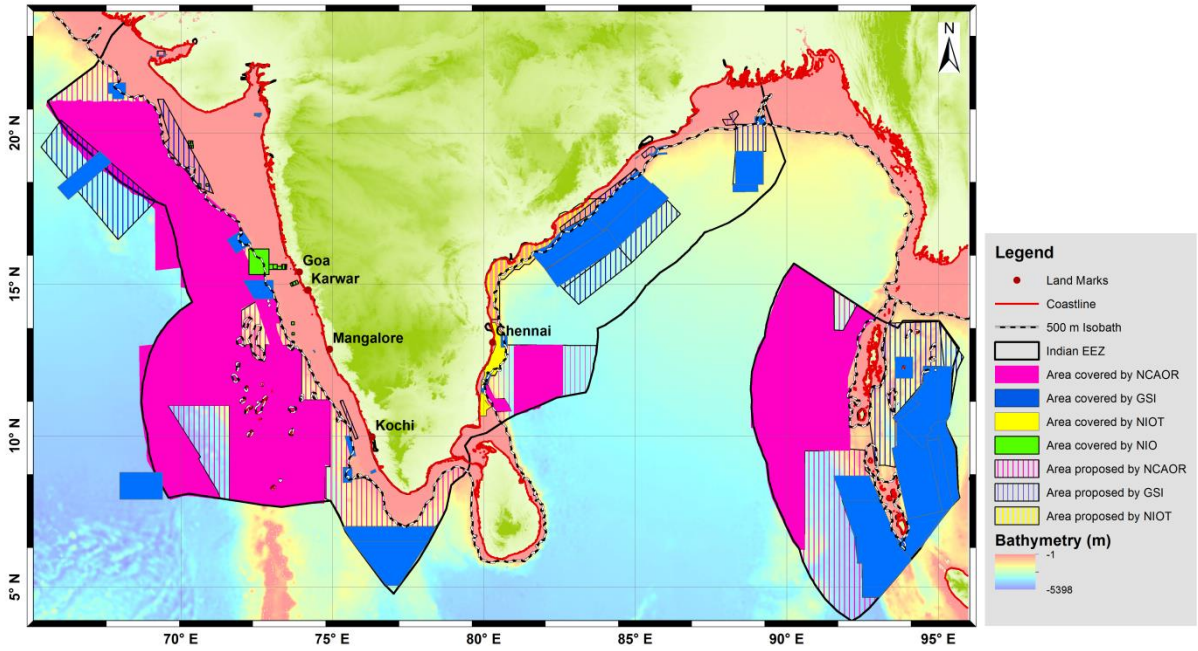

Fig. 3.16 Areas *covered so far and priority areas*

During 2015, four cruises were undertaken (three cruises in the western offshore and one cruise in the eastern offshore region) onboard ORV Sagar Kanya and RV-MGS Sagar. Mapping and identification of major geo-morphological features such as submarine landslides, seamounts, abyssal hills, channel level etc. were also undertaken. The acquired MBES datasets were processed and the horizontal and vertical uncertainty of multibeam data was calculated at 95% confidence level.

Delineation of India's Continental Shelf: The first partial submission towards the extended Continental Shelf claims of India as per the provisions of United Nations Convention on Law of the Sea (UNCLOS) was made by India in 2009. In order to explore additional possible submissions for the Indian ECS claims in future, acquisition of new multi-channel seismic (MCS) data was carried out in Bay of Bengal as well as Western Andamans.

Polymetallic Nodules (PMN): The Polymetallic Nodules programme is oriented towards exploration and development of technologies for eventual extraction of nodules lying on the seabed at 4000 to 6000 m water depth from the Central Indian Ocean Basin (CIOB) allocated to India by UN. India is presently having an area of 75,000 km^2.

During the year, the main aim was to arrive at areas that are not mineable within the First Generation Mine Site (FGM). It has been emphasized that with the present technology areas having slope angle more than 8° are not feasible for the mining system. The slope angle analyses over the FGM area also led to marking of areas more than 8°. A map has been made based on the available high resolution multibeam data. The un-mineable areas have been identified within the FGM.

Environmental Impact Assessment (EIA) studies for nodule mining in Central Indian Ocean Basin (CIOB) were carried out for evaluation of environmental data for prediction of potential impact of mining on marine ecosystem and for providing inputs for mining of polymetallic nodules. The main aim is to collect the baseline environmental data in Test Mining Site (TMS) and Test Reference Site (TRS) in the CIOB with the objectives of study of benthic environmental conditions and water column properties. A cruise on board RV Sindhu Sadhana (SSD-13) was undertaken for the purpose.

The nodules associated with fauna were used for microbiological and benthic biological studies. The environmental baseline data collection is completed in the Test Mine Site (TMS) in a block of ~12.5 km x ~12.5 km identified within the FGM. In addition, for a real time comparison, baseline data collection is completed in the Test Reference Site (TRS). The laboratory analysis of geochemical, biological, sedimentological and geotechnical parameters is underway onshore.

Technology Development – Extractive Metallurgy – Reduction roasting-melting studies for sea nodules were carried out to work on the objective of recovering four metals, Cu, Ni, Co and Mn from sea nodules. A number of campaigns of reduction roasting were carried out at 4 kg scale followed by melting of the reduced mass, metal-slag separation and their analysis. In addition to this, downstream processing of the liquors containing Cu, Ni, Co and Fe was studied where iron was removed successfully through precipitation as well as solvent extraction route. Following separation of iron from the liquor, bulk sulphides of Cu, Ni and Co were prepared. Electrochemical splitting of ammonium sulphate solution was carried out in a three compartment electrolytic membrane cell for the generation of ammonia and sulphuric acid solutions. The efforts were put for the generation of maximum possible concentration of ammonia i.e. 40 g/L and desirable concentration of sulphuric acid solution required for dissolution of bulk sulphides i.e. 10 g/L. Electrowashing of residues such as kaolin, fly ash and Mn residue were carried out under similar conditions and fly ash was found to give the best cake formation among all of them.

Studies on Hydrothermal Sulphides: A comprehensive geoscientific exploration programme on hydrothermal mineralization in parts of Central Indian Ridge (CIR) and South West Indian ridges (SWIR) was initiated.

CTD operations were carried out in few selected locations in order to study signatures of hydrothermal plumes existing in the region. Few CTD casts show temperature and salinity anomalies near bottom depths with weak signals of turbidity anomalies.

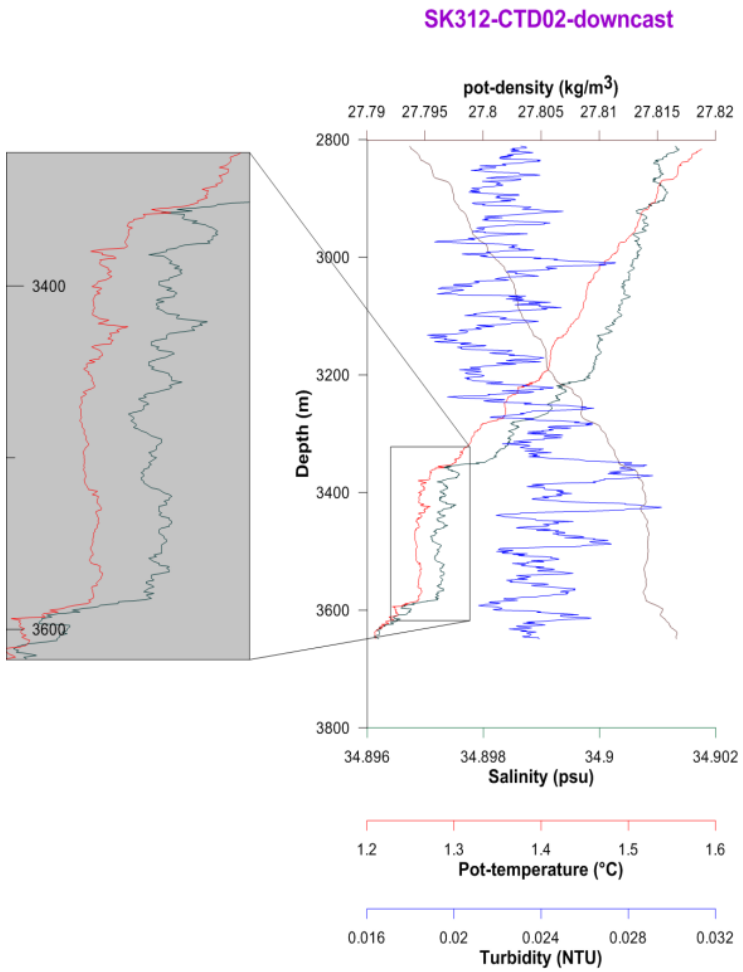

Fig. 3.17 Temperature and salinity anomaly found in SWIR

Petrographic studies of Rocks and Sulphides: Petrographic and Scanning Electron Microscopy – Energy Dispersive Spectroscopy (SEM-EDS) studies of representative rocks were carried out in order to study various alteration processes and micro-structures within the rocks to understand the seafloor hydrothermal processes. SEM-EDS studies of rocks show the presence of Sulphur, Nickel and Cr-spinel along the mineralized veinlets. SO_3 abundance ranges from 0.59 to 1.18 compd%, NiO varies from 2.43 to 24.60 compd%, Cr_2O_3 from 10.44 to 11.06 compd% and Al_2O_3 around 8.94 compd%. EDS probe were carried out on different layers of the chimney fragment. It shows the presence of Sulphur, Copper and Iron. Sulphur abundance ranges from 1.87 to 19.64 compd%, Iron varies from 63.00 to 91.00 compd% and Copper from 1.24 to 2.45 compd%. Traces of Cobalt were also identified. Hydrothermal circulation has caused deuteric alteration of host minerals to great extents and is responsible for the remobilization and transportation of valuable metals flow through vein channels.

Morphological Studies of Sediments: Sediments collected from few dredging stations were studied with the help of SEM-EDS. It shows the presence of Sulphur, Zinc, Lead and Copper at various percentages. The presence of these elements in the sediments indicates the possibility of hydrothermal activities in few locations in and around the cluster E and CD.

Geochemical Studies of Rocks and Sulphides: Whole rock geochemical analysis were carried out on selected rock samples and sulphides in order to understand the metal

enrichment, geochemical behaviour and alteration processes prevailing in the region. Geochemical characteristics of the altered MORB from the region will provide better understanding about the alteration processes and chemical exchange of fluxes during Mid Oceanic Ridge (MOR) hydrothermal activity. Geochemical analyses were carried out in the chimney samples to know the concentrations of various metals. Initial data shows enrichment of Cobalt, Copper and Zinc in these samples. Data also shows enrichment of Gold and Palladium in these samples. Geochemical analyses of ultramafic rocks were carried out in order to understand the influence of hydrothermal activity in the region. The plot of La/Lu_N by Eu_N/Eu^* in these rocks shows influence of hydrothermal activity in the SWIR and CIR region.

Geochemical Studies of Fe-Mn Crusts: Studies were carried out to know the source and origin of Fe-Mn oxides present in the region. Geochemistry of Fe-Mn crusts shows a wide range in major and trace elements concentrations. Integration of the results of the analysis of data/ samples from the region provided significant clues about many possible and probable locations of hydrothermal activity and mineralization. Further analysis is in progress to identify exact locations of hydrothermal mineralization.

Chapter – 4

Polar and Cryosphere Research (PACER)

Variability in polar environment has a large global impact. The changes in ice cover, snow variability etc. have a perceptible influence on global water cycle. Also the climate anomalies generated in the polar regions may influence the low latitudes by modification of ocean and atmospheric dynamics. The ice beneath the surface holds important clues to the past climate and its variability. All these factors are crucial for future environment planning and prediction. This section, in a nutshell, illustrates the activities carried out by the National Centre for Antarctic and Ocean Research (ESSO-NCAOR) in various polar science disciplines.

4.1 SCIENTIFIC STUDIES IN ANTARCTICA

Cryosphere and Climate:

Moisture source and sea ice variability in coastal Antarctica during the last century – High resolution records of deuterium excess (d-excess), methane sulphonic acid (MSA) and ss-Na^+ flux in an ice core from coastal Antarctica revealed that synchronous changes in moisture source and sea ice variability in coastal Antarctica during the last century is controlled by the El Nino Southern Oscillation (ENSO) and Southern Annular Mode (SAM) interactions. Cluster of backward wind trajectories shows that air parcels were mainly originated from the Weddell Sea with additional sources from the Ross Sea and the Bellingshausen-Amundsen Sea regions. Among them, ss-Na^+ flux record shows significant positive relationship with winter SIE in the Weddell Sea. Wavelet analysis of SAM index and SOI shows the highest common power in 4–8 year band during 1940–1960 and 1990-2000 overlapping with the period of higher SIE. This indicates SAM-ENSO tele-connection influencing SIE on annual to decadal time scale. The study supports the role of SAM and its tele-connection to ENSO in controlling moisture transport as well as SIE in oceanic regions surrounding Antarctica.

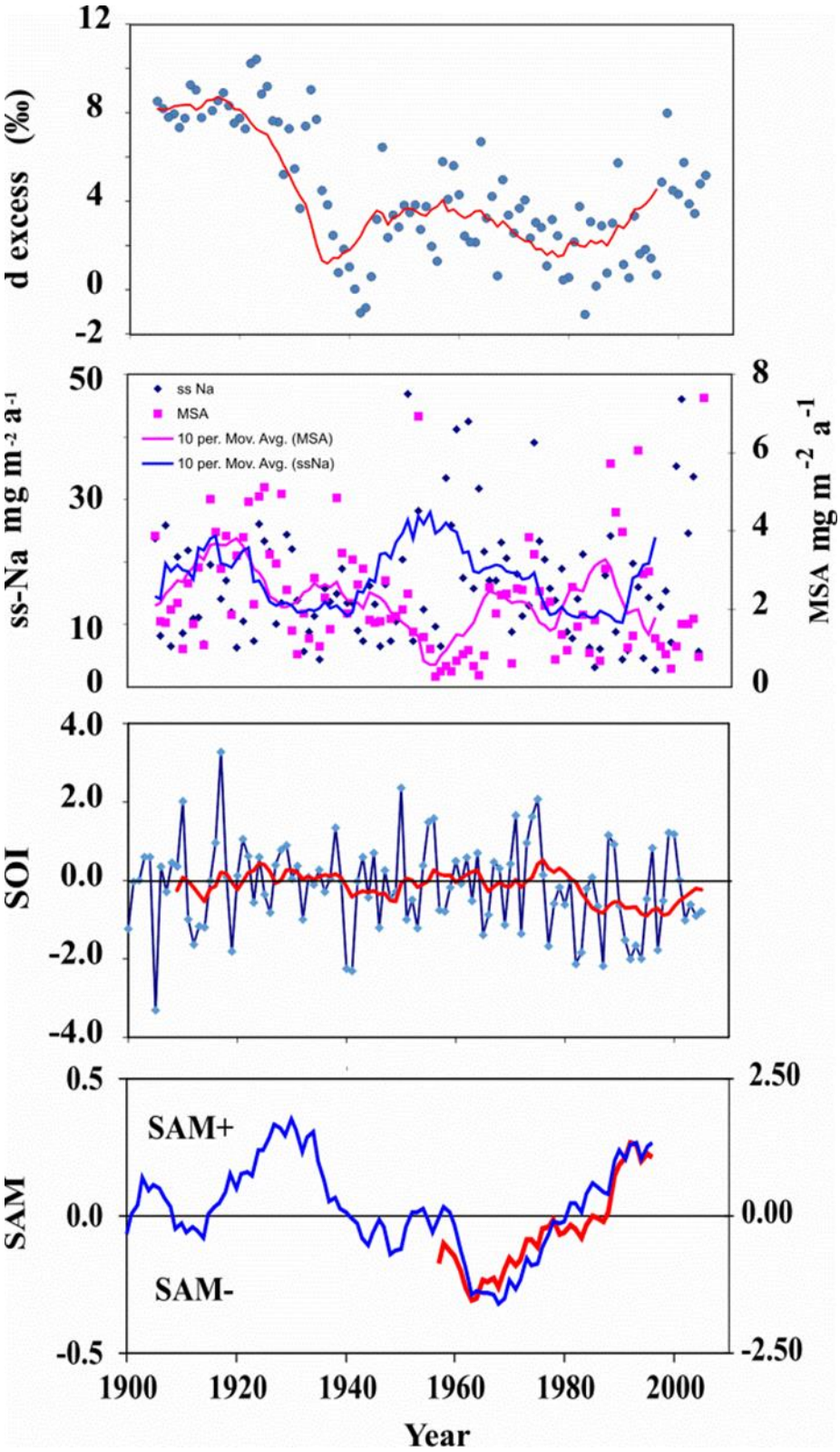

Fig. 4.1 Antarctic ice core record of sea ice and moisture variability

Improved cryospheric lake detection using high-resolution satellite data – Antarctic coastal oases are essential sources of spatially distributed fresh water bodies. Semiautomatic approach was devised for extracting water body features based on a novel set of normalized difference water index (NDWI) by incorporating high-resolution WorldView-2 (WV-2), panchromatic (PAN) and multispectral image (MSI) data. An extensive quantitative evaluation was carried out to test the newly designed NDWI approach for extracting water bodies on Larsemann Hills, eastern Antarctica. The results suggest that

the modified NDWI approach render intermediate performance with bias error varying from ~1 to ~34 m^2 (least amount of misclassified pixels).

Synergetic merging of Cartosat-1 and RAMP to generate improved Digital Elevation Model of Schirmacher oasis, eastern Antarctica – An enhanced digital elevation model (eDEM) of the Schirmacher oasis region, eastern Antarctica, has been generated synergistically by using Cartosat-1 stereo pair-derived photogrammetric DEM (CartoDEM) based point elevation dataset and multi-temporal Radarsat Antarctic mapping project version 2 (RAMPv2) DEM based point elevation dataset. The newly constructed eDEM achieves a vertical accuracy of about seven times better than RAMPv2 DEM and 1.5 times better than CartoDEM.

Role of the Southern Hemisphere Polar Cell on Antarctic Sea Ice Variability – The study explores modes of variability in the Southern Polar Cell and their relationship with known global climate modes and Antarctic sea ice. It is found that Polar Cell is barotropic in nature and 500 hPa geo-potential height (Z500) field can satisfactorily represent variability in the Polar Cell. A new climate mode called Polar Coastal Index (PCI) has been defined, which describes more than 15% and close to 30% variability of circumpolar trough and ABS low, respectively. These results indicate that ENSO driven Polar Cell variability plays crucial role in influencing Antarctic sea ice as it interacts with other climate modes and leads the combined impact at the inter-annual time scale.

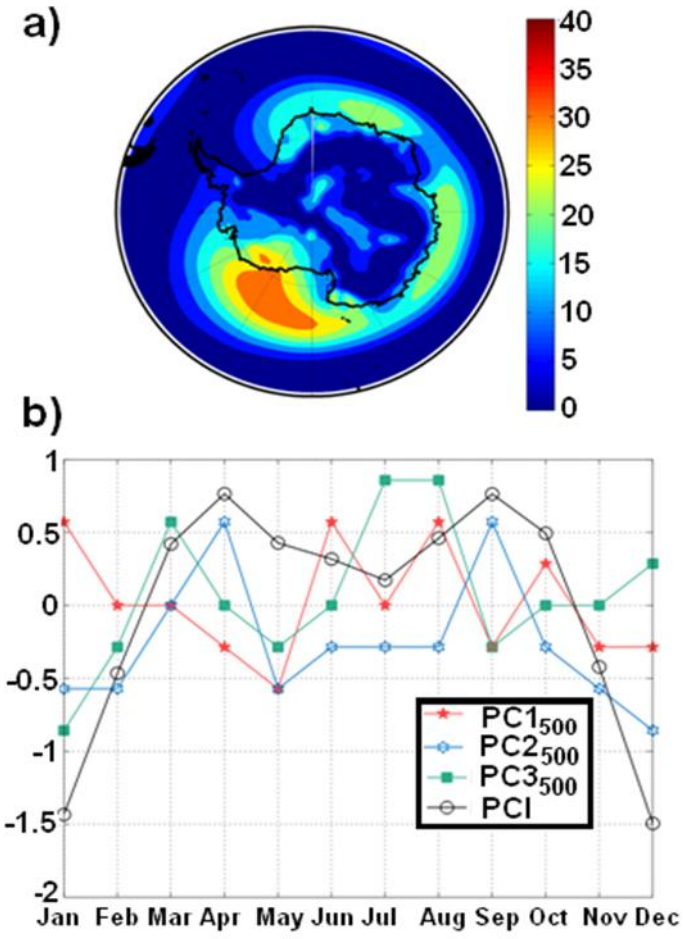

Fig. 4.2 (a) Spatial distribution of mean sea level pressure field variance (in %) explained by Polar Coastal Index (PCI) (b) Seasonal variations of first three leading modes and PC1

4.2 ATMOSPHERİC SCİENCES

Remote influences on low-level jet in the Arabian Sea: The low level jet (LLJ), a strong south-westerly low of air with in the lower troposphere during summer, over the Arabian Sea plays a vital role during summer by transporting moisture from ocean around the peninsula and bringing monsoon rains. The inter-annual variability of LLJ during various seasons reveals that maximum variability in the strength of LLJ is during May – July, with an increasing trend in its strength. The influence of remote factors influencing LLJ is studied. The regression of global sea surface temperature anomalies on to an LLJ index shows strong positive co-variability in the northwest Pacific. A band of positive co-variability in the south Indian Ocean is also seen. The co variability in the south Indian Ocean reflects the influence of Southern Annular mode on the LLJ.

High latitude response of Indo – Pacific SST variability: The high latitude response of three climate modes in the Indo – Pacific, the ENSO, ENSO-Modoki and the Indian Ocean dipole were studied. In the case of ENSO and ENSO-Modoki, the pacific events, the southern high latitude was characterised by a high pressure anomaly with northward (cool)/ southward (warm) flow along its eastern/western margins. This is a part of two wave trains originating in the Pacific (the Pacific South American Pattern) and in the eastern Indian Ocean (the east Indian Ocean wave train). However, in case of ENSO-Modoki, the high pressure cell was closer to the Ross sea than it was in the case of ENSO. In the case of the Indian Ocean dipole, the effect was not extending in to the western hemisphere, the response in the high latitude was characterised by a low pressure anomaly with southward (warm)/ northward (cool) air flow along its eastern/ western margins near the Ross sea. While the Pacific wave train was absent, another wave train starting from Africa (equatorial African wave train) was present. Figure below shows these differences in wave train response to ENSO, ENSO-Modoki and the Indian Ocean dipole. The purple coloured circles in Figure (a) denote response to ENSO-Modoki and black coloured circles denote response to ENSO. Solid/broken circles signify high/ low pressure anomalies. Figure (b) represents wave train response to Indian Ocean dipole after removing ENSO effects using partial regression. Blue/ red ovals indicate regions of warming/cooling associated with the southward/northward circulation anomalies generated.

Tropopause folds observed in Antarctica by MARA: The upper troposphere-lower stratosphere observations from Movable Atmospheric Radar for Antarctica (MARA), installed at the Indian station Maitri, Antarctica, allowed to investigate the dynamical aspects of atmosphere associated with events like stratosphere-troposphere exchange through Tropopause fold (TF). MARA encountered many such TF events during the last one year of operation.

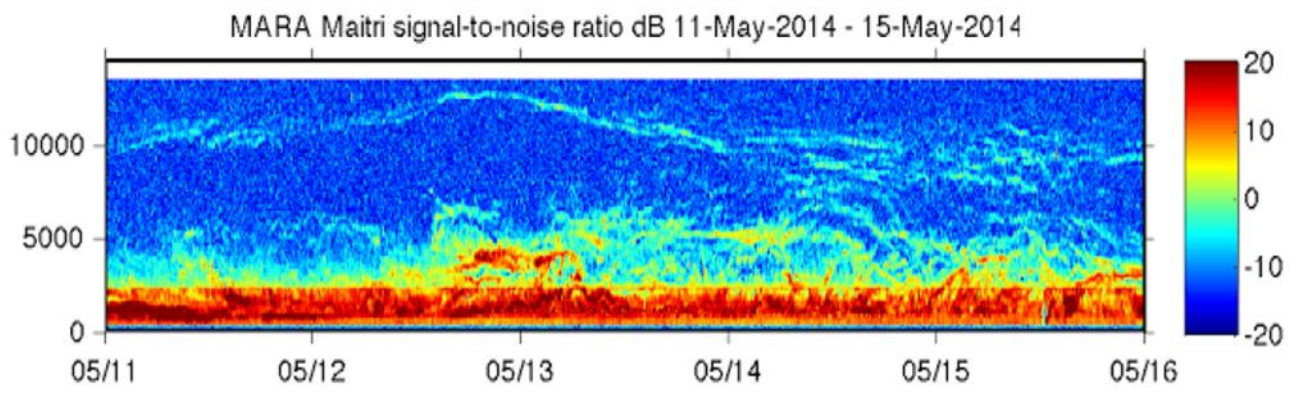

Fig. 4.3 Signal-to-noise ratio from upper troposphere-lower stratosphere experiments during 11th May to 15th May, 2014 – the base of the high SNR indicates the tropopause

Fig. 4.3 indicates a drop in tropopause height from above 10 kms till 13th to merely 6-8 kms after 14th May. These folding events largely occur due to convective mixing along a frontal passage, whose signatures can be found in the vertical and horizontal wind products obtained from MARA.

The TF observed by MARA are also compared with the model simulation using the Weather Research and Forecasting (WRF) model to provide scope for improvement of WRF models in Antarctica region. Typically, 1.5 PVU contour is considered as the height of tropopause in the polar region. The potential vorticity, zonal and vertical wind derived from the WRF output fairly follows the pattern detected by both MARA.

4.3 PAST CLIMATE AND OCEANIC VARIABILITY

Past Indian Summer Monsoon Precipitation reconstruction and its relation with Solar Activity since mid-Holocene: In the south-eastern Arabian Sea, along the southwest coast of India, significant changes in salinity occur due to orographic precipitation and subsequent runoff related to Indian summer monsoon (ISM) precipitation. To quantify the salinity changes due to ISM precipitation, a sediment core was collected offshore Mangalore from the middle of the OMZ from a water depth of 589 m. The core spans a period of 154 to 4772 yr BP (years Before Present) with an average sedimentation rate of 8.96 cm/Kyr while the average resolution is ~112 years/cm. The stable oxygen isotope ratio (δ18Oc) of the planktonic foraminifera Globigerinoidesruber were analysed while the past SST variations were determined using an independent parameter - Mg/Ca - in the same species. The salinity varies from a maximum of 35.5 (arid) to a minimum of 32.4 (wet). The long-term trend determined through linear regression shows that the salinity has been increasing since mid-Holocene implying increasing aridity. The SST varied from a maximum of 29.9°C to a minimum of 27.5°C. This large SST variability is due to its coastal location that is affected by moderate upwelling, which is also seen in the present day climatological data. This implies that SST needs to be taken in to account while inferring past precipitation variability using δ18Oc of foraminifera from the southwest coast of India. We identify periods of aridity during the Little Ice Age (and a few centuries prior to it) and at 1300 yr BP, 2000 yr BP and 4600 yr BP. These periods of aridity are also found in terrestrial records like speleothems and lacustrine records from central India indicating their regional significance. Comparison with a new record of the total solar irradiance (TSI), shows that the ISM precipitation declined in phase with the TSI during the recent periods of major TSI minima but it lagged the TSI beyond 1300 yr BP by a couple of hundred years.

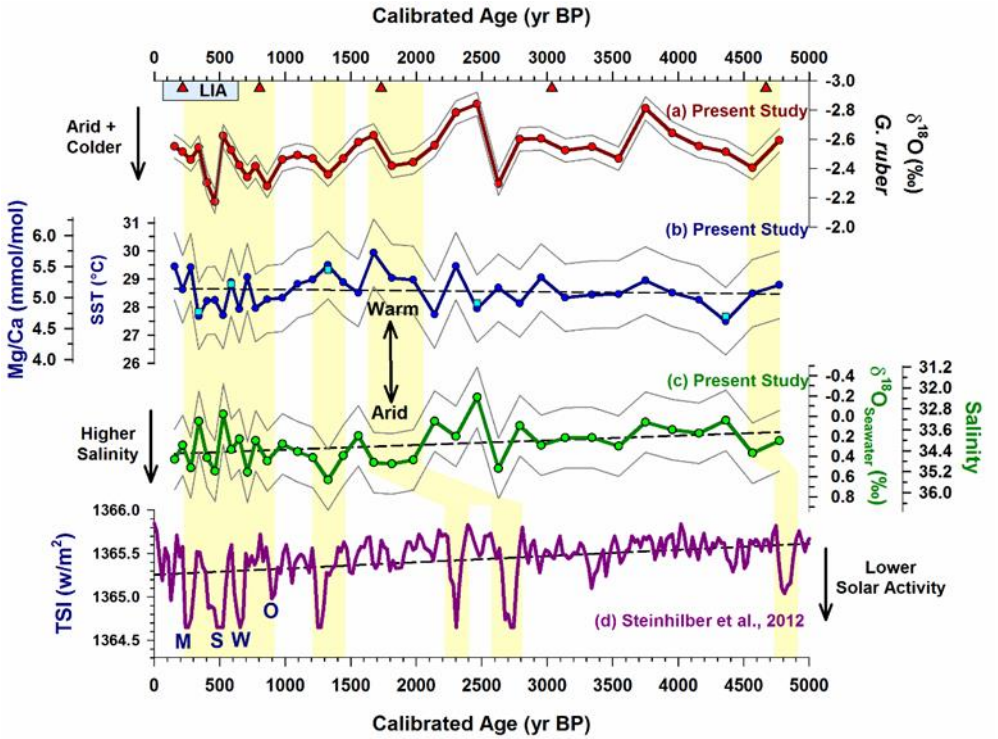

Fig. 4.4 SST and salinity variability of the south eastern Arabian Sea since mid-Holocene. Bands depict the periods of higher salinity/reduced Indian Summer Monsoon precipitation. Dashed lines depict the long-term trend determined through linear regression (least square method). The capital alphabets depict the Maunder, Spörer, Oort, and Wolf minima. Dark grey lines in panel 'a' show the precision of the oxygen isotope measurement of G. ruber while those in panels 'b' and 'c' show the calibration uncertainty in the SST and the oxygen isotope of seawater reconstruction. LIA: Little Ice Age.

Response of Long Lake sediment to Antarctic Climate, a perspective gained from sedimentary organic geochemistry and particle size analysis: A 50 cm long sediment core retrieved from Long Lake, a periglacial lake of Schirmacher Oasis from Dronning Maud Land was measured for elemental (C%, N% and C/N), isotopic ($\delta^{13}C$, $\delta^{15}N$) and particle size (sand-silt-clay percent) variation. The radiocarbon dated core spanning the last 48 calka BP indicates that the productivity has been autochthonous for majority of the down-core. The isotopic signals vary marginally for the entire glacial period (48 to 8 calka BP) suggesting an intense cold period. The gradual increase in C/N ratio, sand content and $\delta^{13}C$ and decrease in $\delta^{15}N$ beginning at ~6 calka BP suggest that the Long Lake experienced longer ice-free conditions owing to sustained warmer Holocene conditions suggesting that the ice-cover over the Long Lake persisted well through early-Holocene. The sand and silt percent shows inverse correlation typically reflecting the warmer and colder conditions. The Holocene is characterized by higher sand content owing to melting of ice due to warmer conditions. The Long Lakes' response to Antarctica climate is reflected in its response to the ice-cover conditions which regulates the productivity and sedimentation in the lake system.

Late Quaternary study on climate variability in Indian Sector of Southern Ocean: A recent paleoclimatic study using the Southern Ocean (SO) diatom records suggest a glacial shift in the Antarctica winter sea-ice limit and Polar Front respectively up to the modern day Polar Frontal Zone of Indian sector of the Southern Ocean. This study has revealed that glacial periods north of the Polar Front were characterised by high diatom productivity and larger *Fragilariopsiskerguelensis* (pennate diatom) and

Thalassiosiralentiginosa (centric diatom) sizes. The larger and highly silicified diatoms such as *F. kerguelensis* and *T. lentiginosa* may have effectively contributed in transporting biogenic silica and organic carbon to the sea bed for the last 42 ka BP.

Oxygen isotope distribution at shallow to intermediate depths across different fronts of the Southern Ocean – signatures of a warm-core eddy: Southern Ocean, an important component of the earth's climate system, is changing in response to the anthropogenic climate change. To understand better the dynamics of the Southern Ocean, oxygen isotopic variability and its relation to salinity is documented especially at intermediate depths (up to 1000 m) across different fronts, at six stations in the Southern Ocean. Signatures of a warm-core eddy shown in Figure below extended from 40 to 44 °S and 56 to 59.5 °E. It consisted of Subtropical Surface Water (STSW). Other water masses identified were the Antarctica Surface Water (AASW), Antarctic Intermediate Water (AAIW), and Upper Circumpolar Deep Water (UCDW) based on the salinity, temperature and oxygen isotopic ratios. The slope of the oxygen isotope-salinity relationship indicates that the water in the warm-core eddy was derived from a region dominated by evaporation/precipitation while the water surrounding the eddy came from a region dominated by melting/freezing.

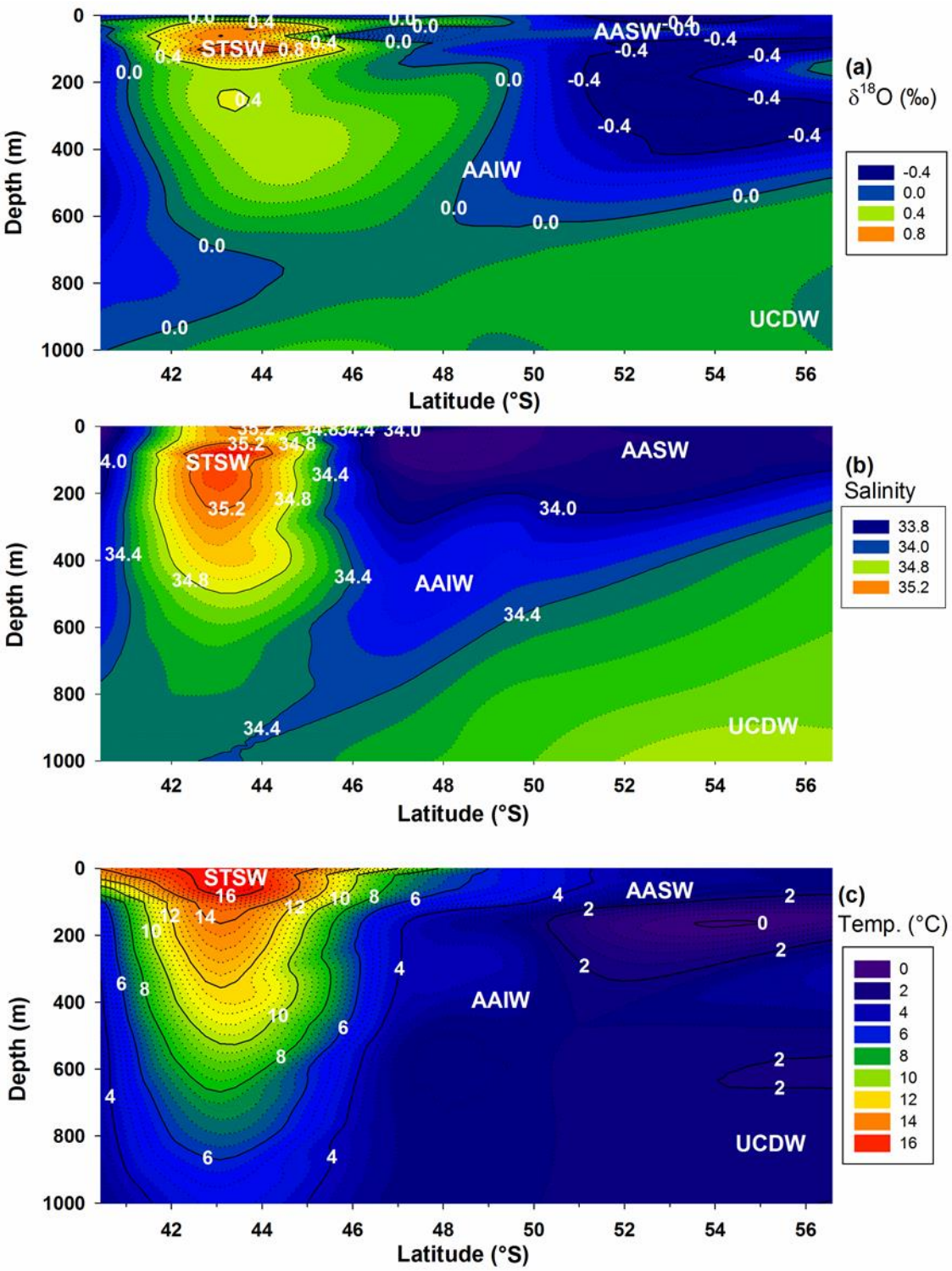

Fig. 4.5 A warm-core eddy characterized by higher temperature, salinity and oxygen isotope values than the surrounding water is clearly evident. STSW, AASW, AAIW and UCDW refer to the Subtropical Surface Water, Antarctic Surface Water, Antarctic Intermediate Water and Upper Circumpolar Deep Water, respectively

4.4 OPERATIONS, MANAGEMENT AND RESEARCH SUPPORT FOR THE ANTARCTICA EXPEDITIONS

XXXIV Indian Scientific Expedition to Antarctica: The XXXIV (34th) Indian Scientific Expedition to Antarctica was flagged off from Goa in multiple batches with the first batch departing on 1st November 2014. A total of 124 expedition members (scientists and logistics) from 23 different organizations travelled in and out of Antarctica.

Some of the major projects implemented by the Indian Scientists at Maitri and Bharati during the summer through winter months of 2014-15 comprise (by the agencies indicated against each) as under.

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

Environmental Monitoring of the Maitri Station Premises: The environmental conditions around the Maitri station were monitored. The measurements made were (a)Aerosol, (b)NO_x, and (c)Black carbon, to monitor the air quality. In addition to that, water quality was also monitored in various lakes around Maitri.

Antarctica Treaty Consultative Meeting and Committee for Environmental Protection: During the XXXVIII Antarctica Treaty Consultative Meeting (ATCM) and XVIII Committee for Environmental Protection (CEP) meetings held in Sofia, Bulgaria, a Working Paper on *Management Plan for Antarctica Specially Protected Area (ASPA) No. 163: Dakshin Gangotri Glacier, Dronning Maud Land* and a Background Paper on *Follow-up to the Recommendations of the Inspection Teams to Maitri Station* were presented.

XXXV Indian Scientific Expedition to Antarctica: The XXXV expedition members were sent in different batches, commencing November 2015. The studies would cover (i)Atmospheric Science and Meteorology, (ii)Biology and Environmental Science, (iii)Human Physiology Medicine, (iv)Earth Science and Glaciology, (v)Students Participation Scheme.

4.5 SCIENTIFIC STUDIES IN ARCTIC

Long-term monitoring of Kongs fjorden for climate studies: The Conductivity Temperature Density (CTD) measurements in Kongs fjorden during 2014 showed higher summer temperature in 2014 compared to summers of 2011, 2012 and 2013. The volume of Atlantic water (AW) was also observed more.

Retrieval and Redeployment of IndARC: The 'IndARC' multi-sensor oceanographic subsurface mooring which was deployed by India in cooperation with Norwegian Polar Institute (NPI) in the transition zone of Kongs fjorden in July 2014 was retrieved in July 2015. The first set of hourly temperature, salinity, dissolved oxygen and current data covering all the seasons was successfully collected from Kongs fjorden in the Svalbard region of Norwegian.

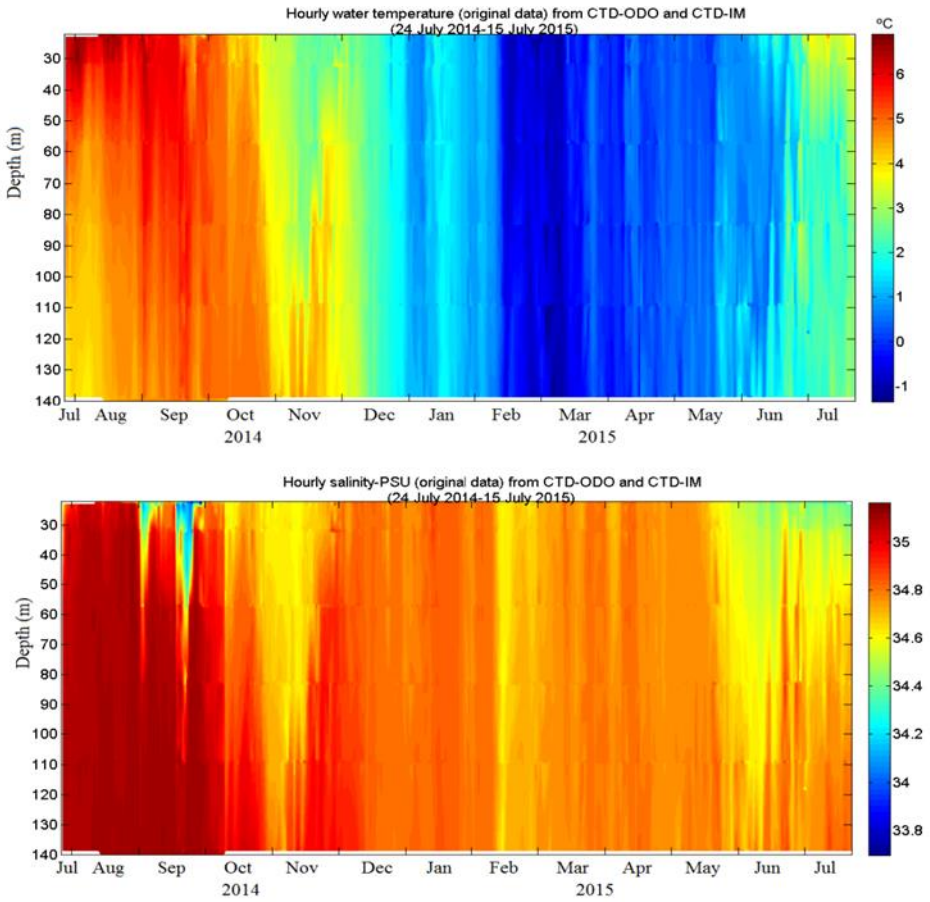

Fig. 4.6 Temperature (°C) and Salinity (psu) measured at Kongs fjorden using CT sensors from IndARC-I during 24th July 2014 to 15th July 2015

The mooring (IndARC-2) was redeployed on 19th July 2015 with additional sensors added to measure fluorescence (24 m), photosynthetically active radiation (35 m), nitrate (37 m) and ambient noise measurement system and transducers (30 m).

Clouds and Precipitation in NyÅlesund during Summer 2015: A team of two members visited the Indian Arctic station Himadri during August to carry out the study using a microwave rain radar. Very low clouds have been noticed in August with occasional precipitation. During this time, atmospheric circulation was characterised by a high pressure system in western Europe and a low pressure circulation in the mid latitude Atlantic. This drove warm moist air from the warmer southern region into the Arctic. The low level clouds could be due to the interaction of this warm southerly flow with the local SST gradient that displayed fronts off the NyAlesund coast. Cold SST (~2°C) was noticed along the coast and warm waters offshore (~11°C). This SST gradient could be a result of changes in the warm west Spitzbergen current that flows offshore and the intrusion of east Spitzbergen current along the coast.

Operations, Management and Research Support for the Arctic Expeditions: During the year 2015, the Indian station “Himadri” was manned for 152 days and a total of 25 scientists visited Ny-Ålesund under 38 different projects. Taking into consideration the ongoing long term programs and the collaborative studies planned to be initiated between India and Norway, the call for proposals for the year was restricted to the following focus areas:

a) Atmospheric Science with special reference to study of aerosols and precipitation measurements over the Arctic
b) Biogeochemical studies in the Kongs fjorden

c) Glacier-Mass balance studies and snow-air flux measurements

4.6 HIMALAYAN CRYOSPHERE STUDIES

Cryosphere components play an important role in modulating earth's climate system and acts as an indicator and integrator of climate variability and change. The main objective of the study is to carry out an integrated study on glaciology, biogeochemical processes and ice core records to understand the role and response of cryosphere within the climate system in polar regions and their global linkages. Towards this, major studies were undertaken in Himalayas. Six major glaciers (*Samudra Tapu, Bara Shigri, Sutri Dhaka, Batal, Gepang Gath, and Kunzum)* of Chandra Basin in Lahaul Spiti region with different characteristics and dynamics are being studied for their long-term mass balance, energy balance, and hydrological balance characteristics. A team of researchers had camped at the Sutri Dhaka base camp during June-October 2015. Two AWS systems have been established at Sutri Dhaka – one at the base camp (4200 m altitude) and the other one at the glacier near the equilibrium line altitude (ELA) for measurement of energy balance components.

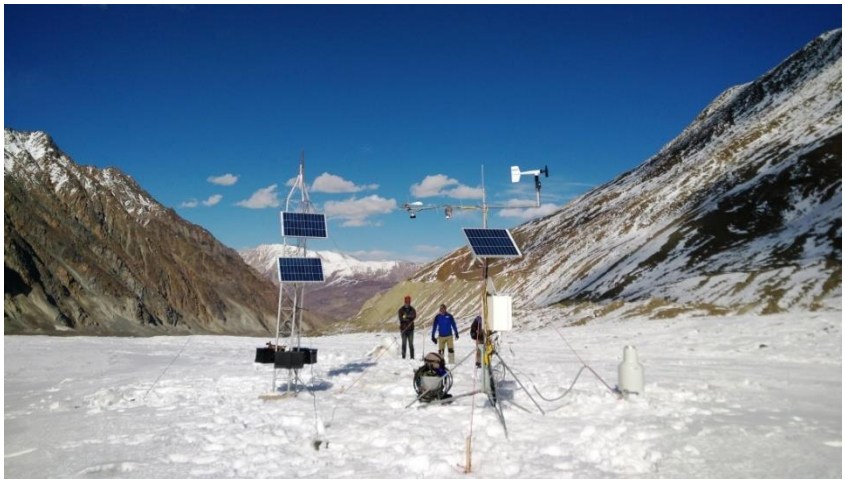

Fig. 4.7 Automatic Weather Station installed over Sutri Dhaka Glacier

A Field Station with facilities for accommodation and labs at Sutri Dhaka is under establishment. A Flow Tracker system has been installed in the Sutri Dhaka for hydrological studies. Annual and seasonal mass balance of the six glaciers has been studied.

Microbial diversity of Himalayan glacier cryoconites: Extreme low temperatures and oligotrophic environment makes survival of life difficult at the glaciers. In spite of these harsh conditions life does exist there. The diversity of bacterial and fungal life at the Himalayan glaciers, and the features they attribute in terms of physiological and biochemical characters were studied. Field sampling was performed at Chhota Sigri glacier. Cryoconites and pit profile sediment samples were processed for bacterial isolation on different isolation media, and incubated at four different temperatures (1, 4, 15 and 22 °C). The emerging colonies were isolated, purified and their colony characteristics studied. Bacterial cultures from Arctic sediment core samples were also studied. All the cultures were subjected to physiological and biochemical tests such as effect of temperature, pH and salinity on the growth of the isolates. The isolates were also tested for carbohydrate utilization ability and antibiotic susceptibility against 45 antibiotics using the disc method. The ability of these isolates to produce enzymes such as catalase, protease, amylase, lipase urease and cellulase was studied.

4.7 STUDIES ON HYDRODYNAMICS AND BIOGEOCHEMISTRY OF SOUTHERN OCEAN

The 8th expedition to the Indian sector of Southern Ocean was carried out from 9th January 2015 from Chennai onboard ORV Sagar Nidhi. The expedition team consisted of 16 scientists, representing 8 different research institutions and universities of India, 31 staff comprising of captain, officers, crew members and engineers. During the expedition 33 surface sampling stations and 9 multidisciplinary stations were monitored.

Distribution of copepod community structure in frontal systems of the Indian sector of Southern Ocean during SOE-7: Zooplankton play a major role in all of the Southern Ocean ecosystems, functioning as grazers, predators and scavengers and ultimately providing the link between primary producers and the upper trophic levels represented by predators including squid, fish, seabirds, seals and whales. To examine regionally specific physical, chemical and biological mechanisms that mediate the observed relationship in the abundance and distribution patterns of zooplankton communities in different fronts during the austral summer, Mesozooplankton samples were collected by horizontal towing of Bongo net (200 µm mesh). Zooplankton biomass varied between 1.34-60 mgC m^{-3} with highest biomass at PF2, followed by PF1, SAF and STF (average 30.32, 15.08, 11.6 and 3 mgC m^{-3}), respectively. The zooplankton density varied between 270-14893 (4836 ± 5418 N m^{-3}) with maximum average density at PF (7361 N m^{-3}) and comparatively less in tropical region (2312 N m^{-3}) indicating that availability of abundant preferential food material such as larger diatoms at PF might be the cause of enhancement of the zooplankton density.

Chapter – 5

Seismology and Geoscience Research (SAGE)

5.1 SEISMOLOGY

Observational Seismology, Earthquake Monitoring and Services:
The national network of the seismological observations has been functioning smoothly and during the period January-November, 2015, a total of 2280 earthquake events were detected and auto-located. These include 1547 events of magnitude 5.0 and above. Information pertaining to significant events was provided to all concerned State and Central Government agencies dealing with relief and rescue operations in the region, media and also posted on the website. A software module for issue of bulk SMS messages is also functional for disseminating a)initial earthquake hypocentral parameters (as SMS Level-1) to selected designated authorities upon auto-location of an earthquake event by Real Time Seismic Monitoring Network (RTSMN) system, and b)issue of final earthquake hypocentral parameters (as SMS Level-2) to a large number of users simultaneously in least possible time.

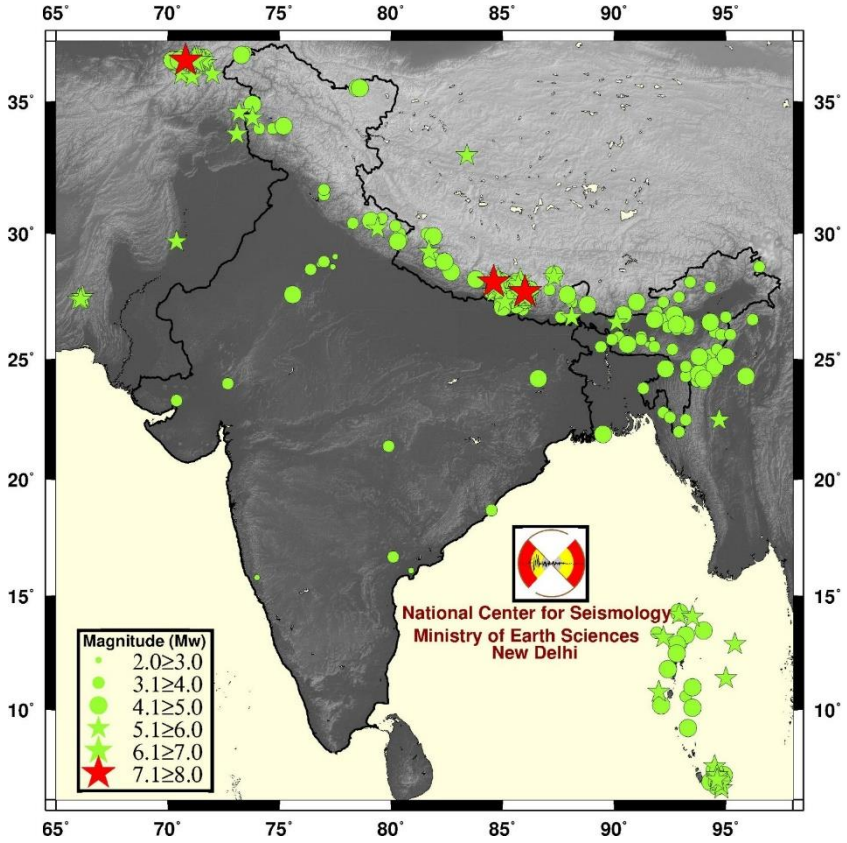

Fig. 5.1 Earthquakes in Indian subcontinent in January-November, 2015

During the period of report a large earthquake (M 7.9) occurred on 25th April 2015 at 11:41 hrs (IST) in Nepal (about 80 Km NW of Kathmandu), which was severely felt in the epicentral and adjoining areas and caused large scale damage in the epicentral region and Kathmandu. More than 8000 people lost their lives and about 20000 were injured in Nepal. This event was also felt in all northern, eastern and some parts of central India and caused some damage in adjoining UP and Bihar. The main shock

was followed by a number of aftershocks including, two major aftershocks of M 6.6 and 6.9 on 25th and 26th April 2015, respectively. Another major earthquake of M 7.3 occurred on 12th May 2015 at 12:35 hrs (IST) in Nepal (about 60 Km East of Kathmandu). This earthquake also caused loss of life and property in Nepal and adjoining UP and Bihar in India.

On 26th October 2015 at 14:40 hrs IST, a major earthquake of M 7.5 occurred in Afghanistan about 260 Km North-Northeast of Kabul. The event was severely felt in all northern states of India, including, Delhi and NCR. It is noteworthy that this event is the largest earthquake of the Hindukush region that has occurred in past fifty years.

Upgradation of Seismological Network and Generation of Intensity Map:
Detection and precise location of earthquakes is not only useful to undertake studies related to seismogenesis and seimotectonic, but is equally important to plan mitigation and management strategies. To achieve the objective, a project was launched to upgrade 44 existing seismological observatories in the country and also for establishing 34 new seismological observatories. As on 14th December 2015, a total of 23 seismological observatories have been upgraded and one new observatory has been set up under the project. These observatories have been integrated with operational centre through VSAT communication facility.

A new webpage has been developed for preparing online intensity map for felt earthquakes, similar to the one developed by USGS as “Did You Feel It (DYFI).” This page provides epicentral map, intensity map (simulated) and DYFI maps based on the felt report along with basic parameters. The URL of the page is http://125.21.185.24/eq_info/eq.html. DYFI maps along with other maps of Nepal earthquake of 25th April 2015 (M 7.9) and its largest aftershock of 12th May 2015 (M 7.3) were generated and uploaded on the webpage. Simulated intensity and DYFI maps were useful in disseminating information on Intensity and related hazard to affected people during the Nepal earthquakes and also helped rendering relief and rescue through government authorities during the period. Fig. below depicts the simulated intensity map for Nepal earthquake of 25th April 2015 (M 7.9).

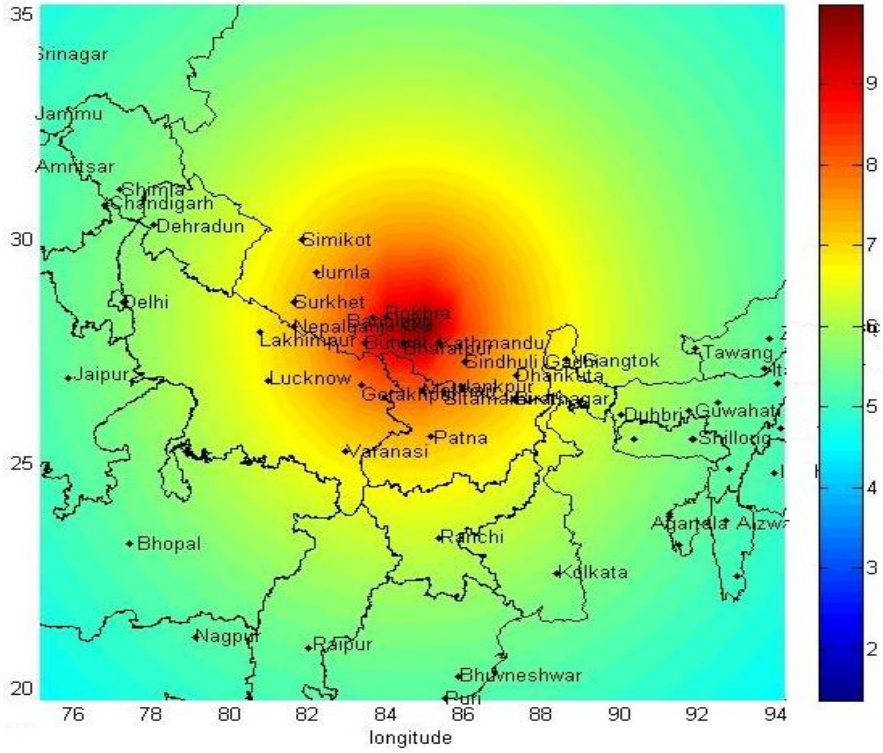

Fig. 5.2 Simulated Intensity map for Nepal earthquake of 25th April 2015 (M7.9)

As per the existing practice, the earthquake bulletins were prepared on monthly basis and archived. Also, seismological data and earthquake related information was supplied to various user agencies dealing with relief and rehabilitation measures, earthquake disaster mitigation and management related matters, seismic zoning, etc. Earthquake data was also supplied to various scientific, academic and R&D institutions for research purposes.

Seismic Hazard Microzonation of NCT Delhi on 1: 10,000 scale:

The seismic zoning map was prepared and published by BIS (Bureau of Indian Standards), classifying the whole country into four major groups Zone-V (High intensity) to Zone-II (Low intensity). These zones encompass wider area for which specific design spectra is commonly used, despite geological and geo-morphological variability within the respective zones. This variability may arouse different micro zones of equal hazard level within the macro zones and therefore for better assessment of the area/site, a micro-level seismic zoning map is desirable. Seismic hazard microzonation study has been carried out for the National Capital of Territory (NCT), Delhi on 1:10,000 scale and a report on the study was prepared and its abridged version has been uploaded on the web page.

This report provides information on Peak Ground Acceleration (PGA), Spectral Accelerations for different periods, Liquefaction Potential at different depths, Predominant Frequency, Amplification Factor, Average Shear Wave Velocity at 30 m depth, Geology and Geomorphology and GIS based Hazard microzones etc. The report has also been provided to NCRPB (National Capital Region Planning Board) for their document “Vision 2020” under Disaster Mitigation for better planning and development. The product hazard index map of seismic microzonation of NCT Delhi has also been provided to Delhi police, required for identifying suitable site in order to construct a building for disaster control purpose.

Seismic Hazard Microzonation of 30 targeted cities:
Seismic microzonation study for selected 30 cities, falling in seismic zone V, IV and III and State Capitals has been initiated by ESSO-NCS. In this direction, base toposheets on available scale (1:25K, 1:50K etc.) of targeted cites have been procured from Survey of India (SoI). Also, a MoU has been established with Geological Survey of India (GSI) for participation in the project. In order to generate base maps of targeted cities and also to identify suitable sites in the respective cities for geotechnical and geoscientific studies, geological and geomorphological maps on available scale have been procured from GSI.

Development of Earthquake Early Warning (EEW) System:
Under a project, supported by Ministry, Indian Institute of Technology (IIT), Roorkee is working on a pilot project for development of Earthquake Early Warning (EEW) System. For this pilot project, it has been planned to install 100 P-alert sensors in a small area of 70x60 km in central Himalayas. These sensors are expected to detect the initial ground motion radiating from an earthquake rupture, which would estimate the resulting ground shaking expected later in time either at same location or some other locations. The warning lead time may range from a few seconds to a little more than a minute and will primarily be a function of the distance from the epicenter. A successful EEW system may provide a lead time of about 60-70 seconds to Delhi, in case of a large earthquake in the Himalayas.

Scientific Deep Drilling in Koyna Intra-plate Seismic Zone, Western India:
A major project entitled “Scientific Deep Drilling in Koyna Intra-plate Seismic Zone of Maharashtra” has recently been launched by Ministry of Earth Sciences. The project is aimed at setting up of borehole observatories at depth for directly measuring the in-situ physical properties of the rocks, pore-fluid pressure, hydrological parameters, temperature and other parameters of an intra-plate, active fault zone in the near field of earthquakes - before, during and after their occurrence. This initiative will be leading to a better understanding of the mechanics of faulting, physics of reservoir triggered earthquakes and preparing a predictive model.

Based on the results of preparatory studies carried out during 2014-15, the main phase activities have been started. The first phase included drilling of nine exploratory boreholes up to ~1500 m depth in the vicinity of the Koyna seismic zone, borehole seismic monitoring, land/airborne geophysical surveys including magnetotellurics, airborne gravity gradiometry as well as magnetics, and LiDAR. The ongoing main phase involves drilling of two pilot boreholes, each to a depth of 3000 m and located in the vicinity of Koyna seismic zone, for measurements of physical and mechanical parameters – both in-situ as well as through laboratory testing of borehole samples and long-term monitoring.

A Research Laboratory called Borehole Geophysics Research Laboratory (BGRL) is being set up at Karad in order to start the activities.

Seismological and Other Studies around Shallow Boreholes:
Six exploratory boreholes located at Rasati, Kundi, Nayari, Ukhalu, Panchgani and Phansavle and instrumented with seismometers, at depths of few hundred metres in the granite-gneiss basement underlying the Deccan Traps have recorded earthquake events during the last eleven months. The precise epicentral location of

these recorded earthquakes has helped in refining location of sites for drilling pilot and main boreholes.

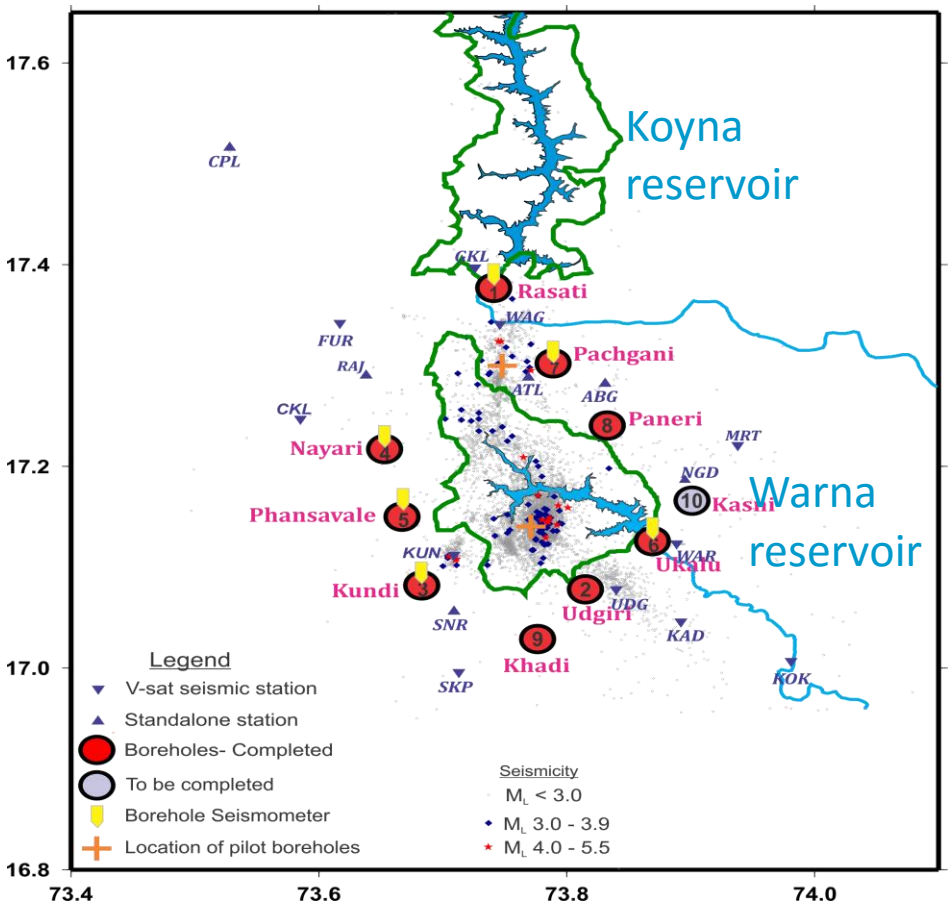

Fig. 5.3 Map of Koyna-Warna region showing the locations of proposed 3 km deep pilot boreholes (bold crosses), distribution of seismicity and exploratory borehole sites

5.2 GEOLOGICAL RESEARCH

Geophysical Studies at Koyna-Warna Region:
Laboratory studies on core samples underlying the Deccan flood basalt at number of sites in the Koyna-Warna region have been undertaken. The core samples offer unique opportunities to study the deformation mechanisms in an active seismic zone. In all cases studied so far, the flood basalt pile is underlain directly by granitic basement rock. No infra-Trappean sediments have been observed between these two major rock types.

To encourage wide participation, the Ministry has also sanctioned a number of projects to national research institutes, universities and other organizations to carry out specific studies on core samples related to geology, geochemistry, petrography, geochronology, palaeo-magnetism, hydrogeology, palaeo-environment, and geomicrobiology.

Rock physical and mechanical properties of basement granite-gneiss core samples from the Koyna region were measured utilizing the facility at CSIR-Central Institute

for Mining and Fuel Research, Dhanbad. The important parameters determined from the mechanical tests are: (i)uniaxial compressive strength (UCS), (ii)Young's modulus, (iii)Poisson's ratio, (iv)rock strength under triaxial condition, (v)cohesive strength of intact rock mass, and (vi)the angle of internal friction. Before carrying out UCS and tri-axial tests, ultrasonic velocity measurements were conducted using ultrasonic pulse transmission method. Both V_P and V_S were measured in the laboratory at room temperature.

Setting up of a facility for Geochronology:

A new initiative has been taken up to set up a Geochronology Facility at Inter-University Accelerator Centre (IUAC), New Delhi to cater to the need of geoscientists of the country. The facility will serve to provide high end experimental capabilities that are currently nonexistent in the country and add others facilities to complement existing facilities in India. This facility will have two major machines viz. Accelerator Mass Spectrometry (AMS) and the High Resolution Secondary Ionization Mass Spectrometry (HR-SIMS) which would be capable of dating geologically youngest and the old formations/rocks/sediments in the earth history and would provide an improved and quantitative understanding of the evolution of the Indian lithosphere and the regolith. Also, this facility will take up contemporary cutting-edge research in isotope geochemistry and geochronology pertaining to earth, atmospheric, oceanic and planetary sciences at international level.

Exploring the Indian Ocean Geoid Low:

The Indian Ocean Geoid Low (IOGL) is world's largest geoid low, centered around south of Sri-Lanka and covers a large part of the northern and central Indian Ocean. To investigate possible causes behind the origin of largest geoid low on earth, a major project titled "Exploring the Origin of the Largest Geoid Low on the Earth" has been initiated by NCAOR, Goa. In this direction, 2D multi-channel seismic (MCS) data have been acquired in Indian Ocean. A total of more than 3000 line km multi-channel seismic data was acquired using 8 km long streamer onboard chartered vessel RV Geo Hindsagar during 2015. In addition, wide angle seismic refraction data along 420 km long profile south of Sri Lanka using 12 four component Ocean Bottom seismometers (OBS) have been procured. The OBS data are aimed to provide deeper structural information about this region and would also help plan further passive OBS deployments in long term mode. The datasets are being analyzed to characterize the upper crustal structures in the study area which may have regional manifestation of geoid low.

Indian Activities towards deep sea drilling through IODP:

International Ocean Discovery Program (IODP) is an international marine research endeavour that explores earth's structure and history recorded in oceanic sediments and rocks and monitors sub-sea floor environments. India is an associate member to this consortium, which confers a unique opportunity to Indian scientists to get directly involved in the cutting edge research in the field of geosciences. During the period from 1st April 2014 to 31st March 2015, five Indian Scientists participated in IODP expeditions in the Bay of Bengal. Two expeditions IODP-353 and 354 (The Monsoon and Bengal Fan respectively) were focussed in unravelling history of Indian Monsoon over long period by analysing deep sea climatic records.

The scientific drilling helps in accomplishing within a regional seismic stratigraphic framework, allowing a robust estimation of sediment budget along with quantitative

estimates for weathering fluxes. Drilling through the fan base and into the underlying basement will permit additional constraints to be placed on the nature of crust in the Laxmi Basin (eastern Arabian Sea). This is highly significant for understanding problems of global interest such as paleogeographic reconstructions along conjugate margins in the Arabian Sea and models of continental breakup on rifted volcanic margins.

IODP Expedition 355:

Year 2015 has mainly been dedicated to the IODP Expedition-355 “Arabian Sea Monsoon”, which was carried out onboard DV JOIDES Resolution from 31st March to 31st May 2015. The Expedition was launched from Colombo, Sri Lanka and after completion, it ended at Mumbai, India. Following were the main objectives of ‘Expedition 355’:

1. Test whether Greater Himalayan exhumation is correlated with proposed monsoon intensification after 23 Ma
2. Determine if the monsoon strengthened or weakened at 8 Ma
3. Constrain the timing of the Himalayas and Tibetan plateau uplift by dating the initiation of fan sedimentation
4. Decipher the nature of the basement in the Laxmi Basin (eastern Arabian Sea) to constrain the early rifting process and its relation to the emplacement of the Deccan Flood Basalts along the western continental margin of India.

A total of 30 scientists from the world over, including 11 from India, participated in the expedition. Dr. D. Pandey, Scientist, ESSO-NCAOR was the Co-Chief of the expedition.

During the expedition two sites were drilled in the Laxmi Basin (eastern Arabian Sea). Site U1456, lies within the Laxmi Basin and was cored until the Miocene. However, Site U1457 penetrated to igneous basement in the transition zone between the Laxmi Basin and the Laxmi Ridge. In total ~1700 m of sediment and sedimentary rock, as well as 16 m of igneous basement was drilled. All the recovered cores were analyzed.

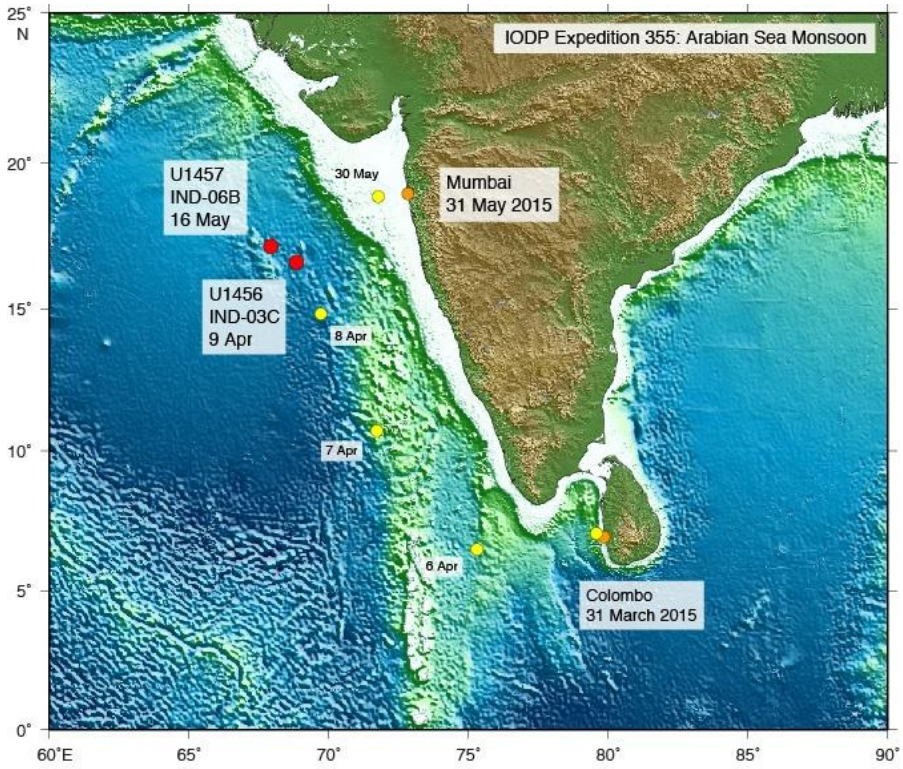

Fig. 5.4 Location Map of the Drilling

Deep crustal studies of the Indian continental margins and its interior – An onshore - offshore perspective:

The Southern Western Indian Margin (SWIM) is tectonically significant for geo-scientific studies as it embodies a zone of continental rifting and an interface between continental and oceanic crust. The onshore tectonic elements of SWIM are surrounded by the Precambrian Dharwarian trends and several shear zones within the southern granulitic terrain. Its offshore tectonic features include Kerala-Konkan Basin, Laccadive ridge, Laccadive depression, Prathap and Comorin ridge. There are several important tectonic features throughout this region that require the necessity of detailed geophysical investigation. To study the onshore-offshore crustal structures 2D multichannel seismic data have been acquired onboard Geo – Hindsagar during September 2015. The available ocean bottom seismometer (OBS) data is also being used to generate accurate velocity model using ray tracing method.

Landslide study in Western Ghats:

Evaluation of landforms having close relation to regions of active tectonics provides basic data for long-term prediction of natural hazards especially landslides. Considering the recurrence of landslides, earthquakes, eco-sensitive nature of terrain and increasing human interference, surveys were carried out in the Mahabaleswar and adjoining high relief region to document the recent occurrence of landslides and to elucidate the broad causative terrain factors relevant to the region. Over sixty landslide affected locations have been identified in the study area. Most of the failed surfaces are the steep slopes of road cuttings with little vegetation cover. The traverse from Mahabaleswar to a)Poladpur, b)Satara, c)Tapola and d)Wai reveals the presence of many failures.

Palaeo Fluids in the Petroliferous basins of Western Offshore – India:
Raman spectral analysis on oil inclusions from RV-1 well have been carried out to identify hydrocarbon species in HCFIs using the laser Raman micro spectrometer (LRMS). Peaks correspond to cyclohexane (863, 2660, 2938 cm^{-1}), benzene and its derivatives (309, 464, 703, 999, 1310, 1018, 1168, 1485, 1580 cm^{-1}), methane/methylene (2905, 2924, 2848, 2945 cm^{-1}), carbonyl group (1064, 1650 cm^{-1}), paraffin (1232, 2560 cm^{-1}), perchlorate ion (645 cm^{-1}), propane (940, 2740 cm^{-1}), acetylene (1662 cm^{-1}) and i-butane (800 cm^{-1}) along with the presence of CO_2 at 1410, 2350 cm^{-1}.

Palaeoclimate Studies of the Coastal lands of South Kerala:
The sediment archives retrieved from the subsurface coastal deposits of the uplifted block of South Kerala Sedimentary Basin between Achankovil and Thenmala Shear zones provided the geomorphic signatures attributed to sea level oscillations, climate variability and neotectonic activities during the Late Quaternary. The analysis carried out at ESOO-NCESS on the sediment archives and the preserved proxies contained in them along with geochronological data indicate that the inland wetlands in coastal plains between Achankovil and Thenmala shear zones are essentially the broadened remnants of the upper drainages of their pre-existed coastal plain rivers of post-Neogene age but certainly prior to late Pleistocene.

Modeling of Atmospheric Pollution and Networking:
Monitoring of eight atmospheric parameters continued at NCESS, Thiruvananthapuram and data is analyzed and archived on daily basis. Continuous measurements of nine air pollutant parameters (CO, CO_2, NO_x, PM2.5, PM10, O_3, BC, Methane, TNMHC) and seven meteorological parameters (AT, RH, RF, SR, WS, WD, BP) have been made Diurnal variation of PM_{10} and $PM_{2.5}$ during the period show similar pattern of variation. Both the particulate matter concentration gradually increase just an hour after sunrise in the morning. It is also observed that the PM_{10} attains sharp peak at 11.00 hrs while the PM2.5 attains at 08.00 hrs. The results of daily (24 hrs) average concentrations of PM_{10} and $PM_{2.5}$, and O_3, were compared with the available national ambient air quality standards (2009). It is found that the concentrations of these pollutants did not exceed the available standards.

Coastal Flooding:
A comprehensive program to study the coastal flooding due to swell waves (Kallakadal) along the SW coast was initiated. The term Kallakadal was first proposed by ESSO-NCESS and was accepted by UNESCO in 2012 for describing such freak events of coastal flooding. Though this type of coastal flooding is common along the low lying sectors of the Kerala coast particularly during the post-monsoon and pre-monsoon periods (i.e. from October – May) there has been a significant increase in the number of such events. The intensity of such an event (due to the arrival of long period waves from the Southern Indian Ocean with peak wave periods more than 15s) on a low lying coastal area can be severe when it coincides with the spring tide (highest high tide). The presence of coastal current moving towards south due to the influence of wind leads to severe flooding. This year, Kallakadal was first reported during the last week of January. The latest one occurred during August 2015. The oceanographic instruments were deployed at three locations to understand the flooding event. The deployment period was judiciously decided in such a way that it covers the Perigien Spring Tide event on 28th September 2015. It

is expected that the collected hydrodynamic data would give valuable information on the influence of Perigien Spring Tide on the Kerala coast.

Assessment of Submarine Groundwater Discharge (SGD) between Koyilandi and Kadalundi in Northern Kerala:

The significance of understanding SGD in the Indian context involves estimation of maximum pumping possibilities and defining the limit of seawater intrusion in the fresh-seawater interference zone. Such studies help in assessing the optimum exploitation levels of coastal fresh groundwater, locating feasible waste disposal sites in coastal zone and estimating seaward pollution transport levels.

Methodology adopted for the study includes direct measurements using seepage meters and piezometers, modeling, natural tracers using 222Rn, 226Ra, salinity, temperature, isotopes, and conventional hydrochemical methods.

Satellite images and resistivity surveys were conducted in the study area and it was inferred that the sediment thickness in the area is more than 35 m and the depth of water table is around 2 m. Inspection of open wells in the coastal zone under consideration indicated that the area releases fresh groundwater to sea during a considerable period of the year.

Chapter – 6

Research, Education, Training and Outreach (REACHOUT)

6.1 CAPACITY BUILDING AND HUMAN RESOURCE DEVELOPMENT

To gain scientific understanding of the individual components of the earth system (the atmosphere, ocean, geosphere, biosphere and cryosphere) as well as to study the interactions between them along with their response to the natural and human induced changes, several programmes are undertaken by the various units of ESSO. These programs are interdisciplinary in nature and specialized manpower in the field of earth system science is thus an important and integral part for the success of such programs in achieving the objectives through quantifiable deliverables. 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 at ESSO-IITM, ESSO-INCOIS and ESSO-IMD respectively with an aim to develop adequate training modules with focus on operational and service-delivery oriented responsibilities. While the advanced training school in Earth Science and Climate Change at ESSO-IITM was established during the mid-term stage of the XI plan, the training centers on oceanography and meteorology have been established at ESSO-INCOIS and ESSO-IMD during the XII plan.

In addition to the in house training schools, 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. 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, initiating 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.

Center for Advanced Training in Earth Systems Sciences and Climate (CAT ESSC):
The Centre for Advanced Training in Earth System Sciences and Climate (CAT-ESSC) was established in 2011 with the main aim of generating a pool of trained scientists for the country to take up existing problems and develop necessary skill to address the challenges in Weather, Climate Modelling and Predictions and to make world class state-of-the-art weather and climate forecasts. Therefore, the programme envisages specialized training programs in earth system sciences and climate science including modeling aspects targeting scientists in MoES institutions and students from different academic institutions. On successful completion of the induction training program, trainees are placed in any one of the institutions of MoES as Scientists in suitable grades based on their qualifications. Three batches of trainees have already been imparted the eighteen month induction training and have subsequently been placed in the various units of MoES. The International student hostel to be jointly shared by MoES-IMD and MoES-IITM for the activities of the

two training schools is under construction which will be completed by the end of this financial year.

Training in Operational Meteorology:
The Training School in Operational Meteorology approved in 2013-14 is being 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. An international student hostel to be jointly shared by ESSO-IMD and ESSO-IITM for the activities of the two training schools is being constructed and will be completed by the end of this financial year. Renovation of existing training hostel has been completed. Training of 61 new Met-II trainees is going on in two batches at the institute. Two short term tailor made advanced refresher training courses (Operational Climate Services and Tropical Cyclone) have been organized. A short term International training course on Aviation Meteorology for Meteorological Personnel from Bhutan and Oman has also been conducted. Three regular training courses namely (i) Advanced Meteorological Training course (ii) Forecasters Training Course (iii) Intermediate training course are also being conducted during 2015-16.

International Training Centre for Operational Oceanography:
The International Training Centre 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. An e-classroom, which is equipped with the state-of-the-art facilities was setup during 2015-16 for conducting training programmes. During 2015-16, the Centre conducted four short courses and training programmes.

ITCOOcean conducted an international training course on "Indian Ocean Dynamics: From the Large-scale Circulation to Small-scale Eddies and Fronts" during November 16-27, 2015 with Prof. Julian McCreary Jr., IPRC, Hawaii as the lead faculty was conducted. A total of 48 students/scientists attended the course.

Fig. 6.1 Lecture sessions in the e-classroom at ITCOOcean

ESSO-INCOIS has initiated the process for designation of ITCOocean as UNESCO Category-II institute. ITCOocean will act as one of the Regional Training Centre of Ocean Teacher Global Academy of IODE/IOC.

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. Pending decision about the identified country from African Union, no progress could be made towards establishment of an end-to-end system. However ESSO-NCMRWF is regularly generating the medium range forecast products over the African region. The same is uploaded on ESSO-NCMRWF webpage.

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 National Center for Medium Range Weather Forecasting (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 disseminated through NCMRWF website.

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, Ministry supports research projects in academic and research institutes in the various areas of earth system science namely (i) Atmospheric Science including Climate Science; (ii) Geoscience; (iii) Ocean Science and Resources; (iv) Hydrology and Cryosphere; (v) Earth System Technology.

Focused Research Projects – The following research projects in focused research areas were funded in 2015-16:
Atmospheric Science
- Study of Atmospheric Aerosols over NCR using Chemical Transport Model by Indian Institute of Technology, Delhi.
- Spatial Modeling of land use dynamics and its impact on fluxes and ecosytem services in Eastern Ghats, India in present and future climate scenario by University of Hyderabad.
- Analysis and Projections of extreme weather events over Western Himalayas by University of Kashmir.

Cryosphere and Hydrology
- Delineating physico-chemical dynamics of discharging groundwater to sea in coastal areas of the Bay of Bengal by IIT, Kharagpur.
- Modeling of soil moisture in a changing climate using the potential of probabilistic hydro-meteorological approach by IIT, Kharagpur.
- Establishing the reference condition on the Ganga River with Corona archival imagery by IIT, Kanpur.
- Seasonal Hydrologic Predictions based on Regional Forecasts of Monsoon Rainfall with CWRF and Statistical Downscaling by IIT, Bombay.
- Near-Real-Time Urban Flood Forecasting System by IIT Bombay.

- Assessment of Environmental Flows for Himalayan Rivers by 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 by IIT Kanpur.
- Resistance characteristics of alluvial channel with mobile bed vegetation by IIT Guwahati.

Geoscience

- Phosphorus fractionation in surface sediments – An Implication in Restoration and Conservation of Govind Ballabah Pant Sagar, Singrauli, M.P. by Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad, Jharkhand.
- Delineation of groundwater potential zone and identification of artificial recharge sites in Ramanagaram Taluk, Karnataka by Ghousia College of Engineering, Ramanagara, Karnataka.
- Evaluating Structural Control on Gold Mineralization in Gadag Region (Karnataka) – A Study Based on Fabric Quantification and Kinematic Analysis by 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 by National Geophysical Research Institute, Hyderabad.
- Characterization and genesis of gas hydrate zone in Krishna-Godavari Basin, Bay of Bengal using benthic foraminiferal and geochemical studies by Indian School of Mines, Dhanbad, Jharkhand.
- Rare Earth Metal abundances in certain Pan-African granitoids of Karbi Hills, Assam – their prospect examination by 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, Hyderabad.
- Migmatization, melting, leucogranite generation, and exhumation of the higher Himalayan crystallines (HHC), Sikkim Himalaya by Department of Earth Sciences, Indian Institute of Technology, Roorkee.
- Luminescence Chronology of Paleoflood and aeolian dunes deposit in Kaveri Basin – Implication to Holocene climate reconstruction to be implemented by Department of Earth Sciences, Indian Institute of Science Education and Research, Kolkata.

Ocean Science

- Establishment of Coastal Ocean Observatory at the Innovation Centre for Climate Change (IC3) and Capacity Building of School of Earth, Ocean and Climate Sciences by IIT Bhubneshwar.
- Biogeochemical Process and Paleoceanographic Studies of the Eastern Indian Ocean by National Institute of Oceanography, Goa.
- Shallow Water Benthic Communities and Food-web Dynamics – A case for Kakinada Bay and Coastal Andhra Pradesh by Andhra University.
- The Role of Crustose Coralline Algae (CCA) and Algivorous Fish Assemblage Structure in Natural Revival of Damaged Reef Ecosystems in Selected Reefs of Andaman Group of Islands.

- Effects of Human Intervention on the Fragile Ecosystem of Gulf of Cambay and Gujarat Coast by M.S.University, Baroda.
- Seasonal dynamics of enteropathogenic bacteria in Gulf of Khambat, Gujarat – Role of coastal population by CMCRI Bhavnagar, Gujarat.

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 project proposal. The Technology Research Board funded/approved the following projects.
- Solar Multi-effects Desalination System by Dr. Mani, IIT, Chennai at a total cost of Rs. 95 lakhs.
- Development of Ka Band Polarimetric Doppler radar for cloud profiling by Society for Applied Microwave Electronics Engineering and Research (SAMEER), IIT Campus, Powai, Mumbai.

Human Resource Development – Ministry supported two year M.Sc. course in Ocean and Atmospheric Sciences in University of Hyderabad and Human Resource Development through Sponsorship of five M.Tech. and five PhD students in various fields of Earth Sciences at IIT Delhi.
About 25 scientists participated in the International Union of Geodesy and Geophysics (IUGG) General Assembly at Prague during 22nd June - 2nd July 2015 alongwith a four member delegation from India. India also participated but unsuccessfully in the bidding process to host the next General Assembly of IUGG.
A training program at national level was organised on Active Fault Mapping at IIT, Kanpur during October 3-11 2015. About 25 participants attended this program. As a part of the training program, participants were taken to field surveys for mapping on ground as well as to provide exposure on trench related activities.

Human Resources Development:
Two students Mr. Vikram Goel and Mr. Ankit Pramanick joined Norwegian Polar Institute under Ph.D. Followship programme in Glaciology. Mr. Vikram Goel is working on the project “Current Status and Past Changes of ice rises in Dronning Maud Land, Antarctica. Mr. Ankit Pramanick is working on the project “energy balance modeling and melt water routing in a glaciated Svalbard fjord system”.

Prof. S.K.Tandon, MoES D.N.Wadia Chair at IIT Kanpur (IITK) contributed to the strengthening of Earth Science activities at IIT Kanpur particularly those related to Earth Surface Processes and the Anthroposcene and continued research activity on the geomorphology of large river system in terms of exploring their connectivity structure.

Laser Diamond Anvil Cell - IISER Kolkata – During 2012, Ministry had approved the establishment of the Laser Diamond Cell (LHDAC) at IISER Kolkata as a national facility. The proposal aimed to develop a Laser Diamond Anvil Cell to 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. An expert committee constituted by the Ministry visited the institute and examined in detail the various components of LHDAC. The committee expressed satisfaction that LHDAC facility is in

operation and providing for experimental studies of minerals and materials upto 3700 °K and 150 GPa. The committee advised that attempts be made to provide for higher temperature upto 5000 °K and emphasized that research programmes must be designed to address the problems that would help to understand the deep earth environment and synthesis of critical exotic materials with appropriate collaboration with other institutions in the country (for example Raja Ramanna Centre at Indore for synchrotron facility). The committee suggested additional equipment for making the system viable.

Economic Benefits and Cost estimates of the products generated by ESSO:

National Council for Applied Economic Research (NCAER), Delhi carried out a study to estimate cost estimates of the products generated by ESSO-NCMRWF (all models outputs) and ESSO-INCOIS (PFZ, Data Services, OSF etc.). The objective of the study is to estimate the Direct and Indirect Value of Weather Services by estimating the stage-wise cost incurred in producing the user-wise customized forecasts and by analyzing the economic values/costs and financial costs of the output including the cost of resources used. The study has been divided into two parts. The first part estimates the potential economic benefits of ESSO-NCMRWF dynamic weather forecasts provided to ESSO-IMD for the farming community and ESSO-INCOIS ocean state forecasts for Potential Fishing Zones advisories to marine fishing communities and its “No Tsunami Threat” advisories. To do this, NCAER used unit level analysis of agricultural households using data from the National Sample Survey, customized surveys of farming and fishing communities and interviewed strategic users of these forecasts. A limited survey of farmers and fishermen/boatmen was carried out by NCAER in partnership with Reliance Foundation. The second major part of this NCAER Report develops costing and pricing approaches and templates for the development of ESSO-NCMRWF and ESSO-INCOIS products and services.

Economic benefits of the Agro Advisory Service (AAS) and Potential Fishing Zones (PFZ) and Ocean state Forecast (OSF) as per NCAER Report is as follows:

- 95% of the farmers feel reliability of weather forecast has improved over the past 2-4 years which is mainly attributed to the NWP model output of ESSO-NCMRWF given 3-10 days in advance to ESSO-IMD.
- About 57% farmers felt that there is improvement in the timeliness of the weather forecasts.
- ESSO-NCMRWF has made an investment of Rs. 540 crores on knowledge networks, and the forecast generated has resulted in a net economic benefit of Rs. 3.3 trillion (330,000 crores) on the four principal crops namely wheat, paddy, sugarcane and cotton. Similarly top 14 principal crops can realise economic benefit at Rs. 60,000 crores annually and top 20 principal crops can realise Rs. 67,000 crores annually by using ESSO-NCMRWF-IMD weather prediction information.
- 10% of the total energy consumed is renewable. By using NCMRWF wind forecast for wind energy and cloud cover forecast for solar energy a net saving of Rs. 4,400 crores per year can be achieved which will also result in reduction in carbon footprint.
- The overall gain in PFZ is estimated as the cumulative of economic, environmental and ecological benefits. If the PFZ-OSF is operationalised uniformly across the country to all coastal areas, the marine fisheries GDP can increase to 7.8% per annum from the current 3.9%. The gross investments made by ESSO-INCOIS for PFZ and OSF is Rs. 32 crores

and the economic benefit due to this can be upto Rs. 23,800 crores over a 25 year useful life.

- Environmental benefits as a result of savings in diesel consumption due to identification of PFZ reduces carbon dioxide emissions which when computed in terms of carbon credits would work out to be Rs. 36,200 crores annually.
- The investment for the Tsunami Early Warning System is Rs. 133 crores, and the net economic benefits due to issue of a “No Tsunami Threat” advisory issued by ESSO-INCOIS in 23 cases since 2007 is around Rs. 80,500 crores.
- The cumulative economic benefits of OSF advisories provided to Indian Navy, Indian Coast Guard and ONGC exceeds Rs. 3.7 trillion over a gross investment made by ESSO-INCOIS of Rs. 6.47 crores in 2015.

Earth System Science and Technology Cells (ESTC):

Through establishment of ESTC in various Universities across the country, ESSO aims to encourage and develop theme based network projects with participation of different researchers from various universities, colleges and academic institutions to work together for specific theme with a lead university acting as ESTC. This not only encourages capacity building of young researchers engaged in the network projects, but also imbibes the spirit of joint participation of the academic fraternity through a common project with specific objectives and well defined deliverables. This restructuring of the ESTC has been effectively established since one year. The present structure enables for effective integration of individual projects at the proposal stage itself with a well defined deliverable which is more substantial compared to individual project deliverable processed earlier. Overall monitoring and periodic review of the progress of the ESTC projects towards their implementation will be done by a scientific steering committee (SSC) of respective discipline of Earth Sciences.

Two ESTCs have been established, one on “Marine Coastal Ecology of West Coast of India” and the other on “Satellite Meteorology”, as per following details.

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/Institutes. The network project comprise of twelve sub projects in the fields pertaining to marine bio-diversity and marine pollution. Two of the sites (so called polluted and pristine) apart from other sites along coastal Gujarat have been selected commonly for holistic ecological study. First year's observations and findings have been encouraging. Themes of projects and summary of observations were shared to stake holders in a workshop on “Marine Ecology of Gujarat Coast” at the Department of Life Sciences, Maharaja Krishnakumarsinhji Bhavnagar, held in October, 2015. All PIs of ESTC projects on Marine Biodiversity and Marine Pollution and other stake holders scientists, policy makers of state government (Gujarat Pollution Control Board, Alang, District Magistrate etc.) and others participated in the workshop for mutual sharing of knowledge and issues towards filing the gaps for proper benefits of research and plantings.

ESTC has been established for network projects on “Satellite Meteorology” for Atmospheric Sciences, at SRM University Katanklathur, Chennai (SRMU). The main objectives of establishment of ESTC on “Satellite Meteorology” are (a)Studies of Atmospheric Boundary

layer using space-borne and ground based techniques, (b)Studies on Tropospheric Warming and Stratospheric Cooling using GPSRO. It aims for network projects for R&D in Satellite Meteorology through network projects, initially focusing only on deriving atmospheric parameters of lower atmosphere using GPS radio occultation techniques. Scientists from ESSO-NCMRWF and ESSO-IITM are involved with the project so that it is ensured that the data collection, analysis and their assimilation into models is done appropriately and the mechanism of data collection be monitored.

6.2 AWARENESS AND OUTREACH PROGRAMME

The objective of the programme is to propagate and bring awareness about the activities of the Ministry among the public, student and user communities. This is ensured through participation in National and International exhibitions, sponsoring seminars, symposia, workshop in the area relevant to the programmes of the Ministry with a view to develop scientific temperament among masses and providing platform to academicians, scientists, students, researches etc., for fruitful interactions. The “Earth Day” is celebrated with the participation of School, College and University students. Ministry also supports the National and International Earth Science Olympiads.

Exhibitions:

During the year, the Ministry participated in 24 International and National Exhibitions. The details are follows.

International Exhibitions –

a. “India International Trade Fair-2015”, 14-27 November 2015 at Pragati Maidan, New Delhi.

b. “India International Science Festival-2015” from 04-08 December 2015 at IIT, Delhi.

c. “Indian Science Congress-2016” from 3-7 January 2016 at Mysore, Karnataka.

Fig. 6.2 Ministry’s pavilion during India International Science Festival-2015 at IIT, New Delhi

Fig. 6.3 Ministry’s pavilion during Indian Science Congress-2015

National exhibitions –

a. "6th Krishi Fair" (A National Level Agriculture Exhibition) from 25-29 May 2015 at Sardhabali Near Sri Gundicha Temple, Puri, Odisha.

b. Ministry of Earth Sciences Foundation Day 2015 on 27th July 2015 at Vigyan Bhawan, New Delhi.

c. "Infra Educa 2015", from 30-31 May 2015 at Patna, Bihar.

d. "Infra Educa 2015", from 27-28 June 2015 at Solan, Himachal Pradesh.

e. "7th AgriTech India 2015, 7th India Foodex 2015 along with India Food Park Expo-2015, 6th Grain Tech India 2015, 5th DairyTech India 2015 and Floor Tech India 2015" from 21-23 August 2015 at BIEC, Bangalore.

f. "INMEX SMM India 2015" from 23-25 September, 2015 at Bombay Exhibition Centre, Mumbai.

g. "11th Government Achievements and Schemes Expo-2015" from 29-31 July 2015 at Pragati Maidan, New Delhi.

h. "19th National Science Exhibition 2015" from 09-13 September 2015 at Netaji Maidan, Baranagar, Kolkata.

i. "Perfect Health Mela-2015" from 04-08 November 2015 at Talkatora Indoor Stadium, New Delhi.

j. "Indian National Exhibition-cum-Fair-2015" from 22-26 August, 2015 at Pa Baishnabghata, KMDA Ground, E.M. Bypass, Kolkata.

k. "Swasraya Bharat-2015" from 15-21 October 2015 at Calicut, Kerala.

l. "Banaras International Trade Fair-2015" from 16-23 August 2015 at Benai Bagh, Varanasi.

m. "4th Science Expo-2015" from 28-30 September 2015 at Daman.

n. "Uttarakhand Srajan 2015 – A National Expo-Seminar" from 15-18 October 2015 at Gairsain, Dist. Chamoli, Uttarakhand.

o. "36th IGC during ENGM 2015" from 27-29 October 2015 at IIT, Delhi.

Rural Exhibitions –

a. "KAUSALARTE VIGYANAM" – A Science, Technology and Innovation Exhibition cum Fair from 28-30 April 2015 at Jaikhini, Arajiline, Uttar Pradesh.

b. "North East Development Summit-2015 and Agro and Rural Expo" from 26-27 May 2015 at Veterinary College, Khanapara, Guwahati, Assam.

c. "Scientific Literacy Festival – A Science and Technology Literacy Workshop cum Exhibition" from 25-27 August 2015 at Khagaria, Bihar.

Earth Day Celebration 2015:

"Earth Day" has been celebrated across the country on 22nd April 2015 and the event was organized at 41 centers across the country including schools, college and universities. The theme was "Clean Earth Green Earth". 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 4000 children participated and prizes at National level were distributed on Ministry's foundation day.

Fig. 6.4 Earth Day Celebration-2015

Ozone Day Celebration 2015:

"Ozone Day" has been celebrated across the country on September 16th 2015 and the event was organized at 12 locations across the country in a similar manner. About 1500 children participated in this event.

Fig. 6.5 Ozone Day Celebration-2015

Participation in International Earth Science Olympiad:

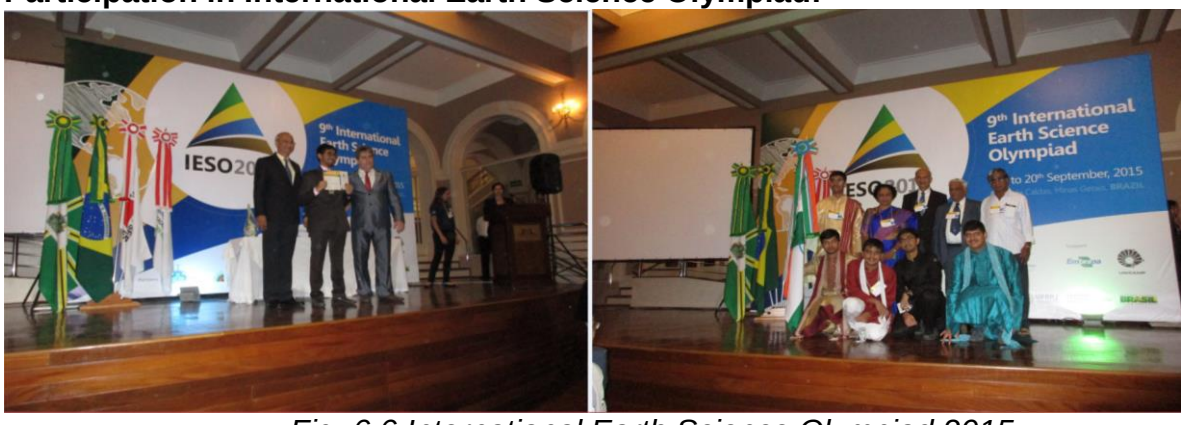

Fig. 6.6 International Earth Science Olympiad 2015

9th International Earth Science Olympiad 2015 was held at Sau-Paulo, Brazil during September 2015. Children from 28 Countries participated in the event with 90 students. Indian team won one Gold and three bronze medals.

Exhibition on Wheels:

The Ministry participated in exhibition with help of Mobile Exhibition Vehicle to display Ministry's activities on Earth, Atmosphere and Ocean Sciences and Technologies including earth processes for create awareness amongst students and general public in rural areas including School, College, Universities at Villages, Mandals, Talukas, District Headquarters, Cities etc. an 'Exhibition on Wheels', which was re-launched in 2014 and covered 20 places in the State of Kerala, 34 places in the State of Tamil Nadu and 26 places in the State of Andhra Pradesh.

Fig. 6.7 Exhibition on Wheels

Support to Seminar, Symposia, Conference, and Workshop etc.:

120 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 where the Ministry supported include climate change and impact on health, weather modification technology and disaster management, coastal dynamics, aquaculture, environmental pollution and its effects on agriculture and human health, marine ecosystem, disaster management, agro meteorological services, space technology and applications, geological science, snow and avalanches processes, mathematical modeling and simulation, fish development etc.

Chapter – 7

Airborne Platforms for in-situ Observations – Ocean Research Vessels (APOORV)

7.1 OCEAN RESEARCH VESSELS

The Ministry has five research vessels viz. Oceanographic Research Vessel (ORV) Sagar Kanya, Fishery and Oceanographic Research Vessel (FORV) Sagar Sampada, Technology Demonstration Vessel (TDV) Sagar Nidhi, Buoy Tender Vessel (BTV) Sagar Manjusha and Coastal Research Vessel (CRV) Sagar Purvi. In brief, summary of utilization of these vessels is given below:

Table - Utilization of Vessels in 2015 (April 2015 – December 2015)

Name of Vessel	Days at sea/ Utilization	Maintenance/Inspection/ Scientific Logistics/ Cruise Preparation (Days)	Number of Cruises
ORV Sagar Kanya	149	116	6
FORV Sagar Sampada	205	70	13
TDV Sagar Nidhi	154	90	8
BTV Sagar Manjusha	154	90	16
CRV Sagar Purvi	80	164	9

Oceanographic Research Vessel (ORV) Sagar Kanya – During the year 2015, the vessel was deployed for several national missions including Topographic Surveys in Exclusive Economic Zone (EEZ) of India, Hydrothermal - Geotraces Programme, Ocean Observations System (OOS) buoy and mooring operations etc.

Fishery Oceanographic Research Vessel (FORV) Sagar Sampada – FORV Sagar Sampada undertook thirteen cruises in Northern and Southern Arabian Sea, South Eastern Arabian Sea and Bay of Bengal including a cruise to Central Indian Ocean thus achieving 80% vessel utilization. These cruises were conducted mainly for Assessment of Pelagic and Demersal Fishery and Integrated Taxonomic Information System, Gelatinous zooplankton studies. Cephalopod and Myctophid resources, Hydroacoustic, CoML, IndOBIS, Microbial, Physical, Chemical and Biological Oceanography 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 buoys, OOS-NIOT Buoy deployment and retrieval of tsunami buoy, Ocean Mixing and Monsoon Cruise for multi-disciplinary studies and Ocean Data Buoy Operations for Ocean Observations in Bay of Bengal, RAMA Buoy Operation at Indian Ocean and Arabian Sea and Tropical Indian Ocean (TIO) Cruise Programme. Vessel Sagar Nidhi carried out Search and Rescue Operation for Missing Aircraft of the Indian Coast Guard.

Buoy Tender Vessel (BTV) Sagar Manjusha – Buoy Tender Vessel (BTV) Sagar Manjusha was utilized for implementing various projects/missions viz. CTD casting, Water, Grab and core sampling at Bay of Bengal and the Arabian Sea Ocean Observations System, for successful deployment and retrieval of Drifter Buoy, Met ocean buoy operations for Ocean Observations in the Arabian Sea and the Bay of Bengal, Wave Rider Buoy Deployment for weather prediction at Arabian Sea, 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 Vessel (CRV) Sagar Purvi – CRV Sagar Purvi is 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 ESSO-NIOT for Geo Scientific sampling in Arabian Sea and by National Centre for Sustainable Coastal Management (NCSCM) for water and sediment sampling to analyse the natural radioactive and biological parameters in the Arabian Sea and the Indian Ocean. It was also used by Pondicherry and Madras universities for CTD casting, Water, Grab and core sampling at Bay of Bengal.

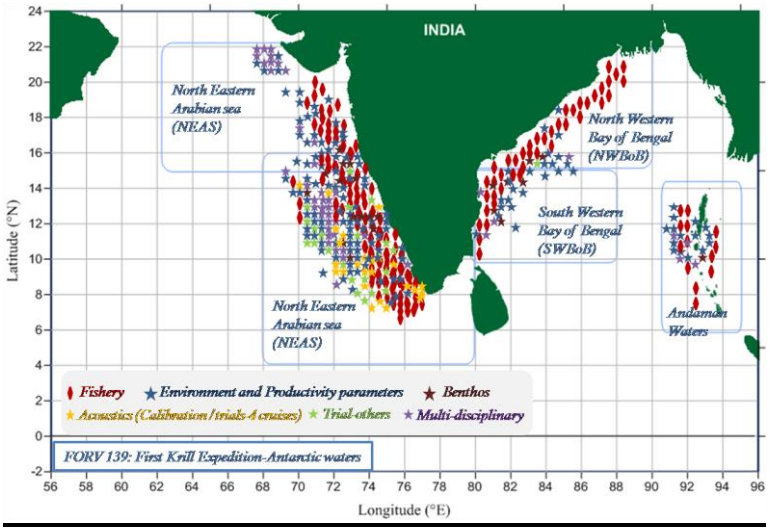

Fig. 7.1 Pictorial representation of vessel utilisation

ESSO-CMLRE as a part of the MLR activities is undertaking multidisciplinary studies on this aspect, and conducted a cruise onboard FORV Sagar Sampada to the central western Indian Ocean (Kochi-Mauritius-Kochi) during September 2015. CSIR-NIO and ICAR-CIFT also joined with ESSO-CMLRE for the studies on Myctophid resources, the associated environmental settings and development of harvest and post harvest technologies between latitude 8°N to 17°S and longitudes 57°E to 73°E.

Study Area Lantern fishes or the Myctophids are known to be abundant in the Arabian Sea and Central Indian Ocean, and the environmental settings favoring its occurrence and the biogeochemical impact of these short lived fishery (life span only 1-2 years) is least explored.

Mid water trawling – Total fishing effort of 27.35 hrs through 23 operations and the Catch Per Unit Effort (CPUE) was 12.74 kg/hr. The Deep Scattering Layer (DSL) focused sampling resulted in catch comprised of juveniles, egg and larval stages of fin fishes, shell fishes, crustaceans, cephalopods and gastropods. 90 species of fishes and 22 species of myctophids were encountered during the survey. Identified seven species of Myctophids and genus Benthosema, Diaphus, Myctophum, Hygophum, Electrona, Bolinichthys, Lampanyctus, Symbolophorus.

Acquisition of two New Vessels:

A national tender was floated on 13th December, 2014 for purchase of two new coastal research vessels. Queries raised by the shipyards were discussed in PMCC meeting and clarifications were uploaded on ESSO-NIOT website as per recommendation from PMCC. Bid evaluation is under progress.

Chapter – 8

INTERNATIONAL COOPERATION

Research and development is an international endeavour which forms an integral part of the activities of ESSO, which is mandated to provide the nation with best possible informed services through skilful weather forecast, climate information, ocean state, earthquakes, tsunamis and other phenomena related to earth systems. ESSO regularly engages with scientists overseas for strengthening 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.

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, development of an ocean wave modeling and assimilation system for the Indian Ocean Region to enhance the capability to generate a skillful global wave model system especially for monsoon conditions etc. The Implementing Agreement (IA) on Technical Cooperation for the study of Dynamical Seasonal Prediction of Indian Summer Monsoon Rainfall under which a "Monsoon Desk" was established at NCEP, is extended for another five years with the existing terms of reference.

Cooperation with UK Met Office (UKMO): The MoU with UKMO was signed in 2008 for exchange of technical knowhow, 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. The Cabinet approved the signing of the Consortium Agreement on Met Office's Unified Model (UM) Earth System Modeling Software between ESSO, UKMO, Korea Meteorological Administration (KMA), Commonwealth of Australia through its Bureau of Meteorology and Commonwealth Scientific Industrial and Research Organisation (CSIRO). The agreement will enable a mechanism to decide on joint programs for development of UM for Seamless Prediction of Weather and Climate.

Cooperation with NERC (Natural Environmental Regional Council): 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 Hydrological Cycle with special emphasis on South Asia. Five joint projects awarded are showing good progress. Monsoon research is another initiative undertaken under the MoES-NERC MoU where there is commitment of about three million euro from UK side with matching funding from MoES. An intense observational campaign will be organized in 2016 that will include NERC aircraft observations.

As part of the existing umbrella agreement between ESSO and NERC, UK on Technical Cooperation on Earth Sciences signed in March 2013, a Scoping Workshop on Atmospheric Pollution and its Impact was organized during 11-13 May 2015 in New Delhi to facilitate networking, discussion and enable researchers to share ideas on key research questions in the area of atmospheric pollution and human health which will contribute in improving air quality in Delhi. Following this, an Implementation Agreement (IA) on Atmospheric Pollution and Human Health in an Indian Megacity was signed between ESSO and DBT from India and NERC and MRC from UK. An Announcement of Opportunity for inviting initial proposals from Indian and UK scientists was published in September 2015. Around 18 proposals have been received which will be peer-reviewed.

Cooperation with Belmont Forum Countries: An MoU was signed between MoES and 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 (CRA) namely Coastal Vulnerability, Food Security and Biodiversity. Under the CRA on Climate Services and Inter-regional linkages, 18 proposals have been shortlisted. Final recommendation for funding of the proposals shortlisted will be made by January 2016 and recommended proposals are likely to be funded by April 2016. Under the Coastal Vulnerability. a set of four projects have been funded, which are progressing well towards achieving the targets. The performance of the projects was reviewed by a monitoring committee in November 2015.

Cooperation with UNESCO/IOC: Following the agreement signed in 2013, on activities related to capacity building through International Training Centre for Operational Oceanography (ITCOocean), two international and one national training course were conducted and 90 trainees including eight foreigners were trained in various aspects of operational oceanography. ITCOocean will also act as one of the Regional Training Centres of Ocean Teacher Global Academy of IODE/IOC. The mandatory two training courses would be jointly organized with IODE during December 2015-April 2016. During December 2015, the IIOE-2 has been launched officially by India.

BIMSTEC Center for Weather and Climate: Following the signing of MoA in March 2014, Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) Center for Weather and Climate has been established at ESSO-NCMRWF. Weather forecasts are prepared in real-time for the BIMSTEC countries and are uploaded in ESSO-NCMRWF website.

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 Science 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. Some preliminary work

under the said MoU has been initiated. The proposal related to development of Wind Profiler System is currently under consideration between ESSO-IITM and National Center for Atmospheric Research (NCAR), USA.

Cooperation with Research Council of Norway (RCN): An MoU was signed on 14th October 2014 during the state visit of Honourable 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 Science. Following two workshops on Geo-hazards and polar research in India in 2013, joint call inviting proposals 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, three proposals in Geohazards and five proposals in Climate Systems in Polar Regions are recommended for funding.

Cooperation with World Climate Research Program (WCRP), Geneva: An agreement has been signed on 9th February 2015 between ESSO-IITM and WCRP, Geneva on hosting International CLIVAR Monsoon Project Office (ICMPO) at ESSO-IITM. The ICMPO will be responsible to (i) implement CLIVAR Research Opportunities such as intra-seasonal, seasonal and inter-annual variability and predictability of monsoon systems, in close cooperation with relevant WCRP activities; (ii) development of a CLIVAR "Research Opportunity" on links between the monsoons and the cryosphere; and, (iii) Support to the climate panels such as Monsoons Panel and Indian Ocean Region Panel. ICMPO has brought out three issues of CLIVAR Exchanges which include a special issue on monsoon, entitled "Advancing understanding of monsoon variability and improving prediction".

Cooperation with Helmholtz Association, Germany: An MoU between ESSO and Helmholtz Association, Germany for cooperation in the field of Earth System Science was signed on 7th April 2015. The purpose of this MOU is to facilitate understanding that lead to cooperation of activities and program in the field of earth system science. The broad objective of this cooperation is to allow exchange of scientific resources and technical knowledge to support development of programs in related fields. Specific activities include utilizing satellite and airborne data for atmospheric research, studies on South Asian monsoon, ship expeditions, oceanographic, meteorological and climate research etc. As part of this MoU, ESSO-IITM in collaboration with Forschungszentrum Jülich GmbH of Helmholtz Association is planning to undertake aircraft observations in the Upper Troposphere and Lower Stratosphere (UTLS) region to understand the influence of Asian summer monsoon on the UTLS and its feedback, through the links between transport processes and changes in radiation and chemistry of the UTLS.

Cooperation with Qatar Civil Aviation Authority, **State of Qatar:** An MoU was signed between ESSO and Qatar Civil Aviation Authority, State of Qatar on 25th March 2015 for Scientific and technical cooperation.

LoI with Japan Agency for Marine - Earth Science and Technology (JAMSTEC): Ministry of Earth Sciences and Japan Agency for Marine - Earth Science and Technology (JAMSTEC) has signed a Letter of Intent in August 2014 for collaboration in various areas pertaining to earth science.

Cooperation with Woods Hole Oceanographic Institution (WHOI), USA: MoES and the Woods Hole Oceanographic Institution (WHOI), USA entered into a Letter of Intent (LoI) in February 2015 to encourage collaboration in the areas of mutual interest and benefit in the field of Earth System Science and Technology.

Cooperation with State Oceanic Administration, China: After signing an MoU in May 2015, the first joint SOA-MoES workshop was held in Guangzhou, China on 16th December 2015. The workshop identified areas for collaboration in the areas of (i) Polar Research concentrating on (a) Paleo-climate reconstruction studies using sediment and ice cores and (b) Coordination of the polar expeditions, with particular emphasis on logistic support including ship time sharing, weather/ocean forecasting, etc.; (ii) Cooperation towards IIOE-2 to conduct joint studies on physical-biological-biogeochemical processes in the South China Sea, Bay of Bengal, Southwest Indian Ocean and understand their role on Asian monsoon; (iii) Observation and Forecasting by (a) developing models for the improvement of the skill of the prediction of Asian monsoon, (b) development and demonstration of applications in the areas of remote sensing, in-situ observations technology particularly in the autonomous technology and renewable energy and (c) coordination of ship time and observation tools; and, (iv) Capacity building through topical workshops, scientist and student exchange visits etc.

Financial Support: International special scientific events are financially supported by the Ministry that have direct relevance and linkage with the Ministry's activities and vision. It also includes encouragement of young researchers to participate in these events. During 2015-16, financial support of USD 300000 to Committee on Space Research (COSPAR) was given to sponsor certain scientific events for the 41st COSPAR Scientific Assembly and Associated Events to be held during 30th July – 7th August 2016 in Istanbul, Turkey and support participating needy scientists whose papers are accepted for presentation.

Chapter – 9

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Awards/Honours:

Dr. Anish Kumar Warrier, Project Scientist 'B', Antarctic Science Division, has been awarded "K.K. Menon Award in Sedimentology" constituted by the Geological Society of India, Bengaluuru. Dr. Warrier was felicitated with the Award at the Annual General Meeting of the Geological Society of India scheduled at Leh (Ladakh, J & K) on 8thSeptember 2015.

ESSO-INCOIS awarded First Prize in the Science & Technology Expo as part of Swasraya Bharat 2015 organized by Swadeshi Science Movement, Kerala and ICAR-Indian Institute of Spices Research held at Kozhikode during 15-21 October, 2015.

ESSO-INCOIS received the Second Best Prize among various R & D organizations in Expo of World Ocean Science Congress 2015, held at Kochi, Kerala during 05-08 February 2015.

Dr. M.S. Girishkumar, Scientist-C, was awarded for the Krishnan Gold Medal of Indian Geophysical Union (IGU) for the year 2015 for his remarkable contribution to Ocean- Atmospheric sciences during 03-05 November 2015.

Dr. Roxy Mathew Koll - Best Poster Award for his paper presented by Ms Ritika Kapoor at the National Conference on Climate Change: Impacts, Adaptation, Mitigation Scenario and Future Challenges in Indian perspective, Delhi University, March 2015.

Raju Attada - Best poster awarded at Glace India workshop and training program on climate modelling and climate change research, innovation and services, Jawaharlal Nehru University, New Delhi, 09-10 April 2015.

Dr. R. Krishnan - designated Editor, Earth System Dynamics (ESD) - An open-access journal of the European Geosciences Union for an initial period of three years.

Dr. G. Beig - Re-elected as Scientific Advisory Group (SAG) Member of World Meteorological Organization (WMO) Global Atmospheric Watch Urban Research Meteorology and Environment Program, Geneva.

Dr. Suresh Tiwari - awarded Rossby Visiting Fellowship for 2015 by International Meteorological Institute (IMI), Stockholm University, Sweden.

Dr. (Mrs.) B. Padmakumari - Visiting Scientist to University of Maryland, Washington DC and NASA Ames Research Centre, San Francisco under START program of NASA – LCLUC (Land Cover Land Use Change).

Dr. Anoop Mahajan - Kalvi Foundation Fellow of the National Academy of Sciences (NAS), U.S.

Dr. Roxy Mathew Koll - Kalvi Foundation Fellow of the National Academy of Sciences (NAS), U.S.

Dr. A.K. Srivastava-Alexander von Humboldt Foundation Fellowship of Germany (CONNECT Follow-up) for working visit at the Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany.

Dr. O. P. Mishra - received the Professor A. S. Arya Award in the field of Disaster, preparedness and mitigation of Natural Disaster from Indian Institute of Technology, Roorkee.

Dr. O. P. Mishra - received Anni Talawani Gold Medal for his outstanding research contribution in the field of Earth Sciences and Geophysics at the 52nd Annual Convention of Indian Geophysical Union (IGU) held at Goa during 3-5thNovember 2015.

National Maritime Search and Rescue Award - Sagar Manjusha was awarded the “National Maritime Search and Rescue Award” on 17thJuly, 2015 for the rescue/tow operation successfully executed by Sagar Manjusha staff/on board VMC team based on the rescue plan provided by VMC shore team. All coordinated efforts resulted in saving the sinking fishing vessel and twelve fishermen.

Chapter – 10

ADMINSTRATIVE SUPPORT

10.1 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.

10.2 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.

10.3 Budget and Accounts

(Rs. in Crores)

S. No.	Major Head of Accounts	2013-14 Actuals			2014-15 Actuals			2015-16 Budget Estimates			Expenditure 2015-16 upto 31.01.2016		
		Plan	Plan	Total	Plan	Non-Plan	Total	Plan	Plan	Total	Plan	Plan	Total
Revenue Section													
1	3403-Oceanographic Research	#####	46.70	485.33	423.84	43.74	467.58	659.00	50.00	709.00	#####	35.80	412.59
2	3425- Other Scientific Research	#####	22.39	249.53	249.08	27.66	276.74	85.00	34.57	119.57	49.74	28.00	77.74
3	3451-Secretariat Expenditure	0.00	23.53	23.53	0.00	25.04	25.04	0.00	29.70	29.70	0.00	23.68	23.68
4	3455-Meteorology	#####	274.62	394.75	159.16	297.14	456.30	310.00	326.41	636.41	#####	273.84	493.08
Capital Section													
5	5403-Capital Outlay on Oceanographic Research	5.24	0.00	5.24	0.26	0.00	0.26	10.00	0.00	10.00	0.03	0.00	0.03
6	outlay on Other Sceintific and Enviormental Research	7.84	0.00	7.84	16.23	0.00	16.23	0.00	0.00	0.00	0.00	0.00	0.00
7	5455-Capital outlay on Meteorology	77.02	0.05	77.07	51.71	0.01	51.72	115.00	0.02	115.02	50.68	0.00	50.68
Grand Total		#####	**367.29**	######	**900.28**	**393.59**	**1293.87**	**1179.00**	**440.70**	**1619.70**	#####	**361.32**	**1057.80**

Report of the Comptroller and Auditor General of India

table.

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	
1	2007	NIL	NIL	**1 (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'.	NIL	NIL
2	2008	NIL	NIL	**1 (One)** Para 7.1 Report No. CA 3 of 2008 "Non-achievement of the objectives of Modernizing the Accounting and Personnel Management Functions".	NIL	NIL
3	2009	NIL	NIL	**1 (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	**1 (One)** Para 8.1 Report No. CA 22 of 2013 "Irregular Introducation of pension scheme and diversion of funds at INCOIS, Hyderabad".	NIL	NIL
5	2014	NIL	**2 (Two)** Para No. 5.1 of Report No. 27 of 2014 on National Data Buoy Project (NIOT, Chennai). Para No. 5.2 of Report No. 27 of 2014 on "Irregular Payment of Gratuity" (NIOT, Chennai).	NIL	NIL	NIL

10.5 Staff Strength

The sanctioned strength of the Ministry of Earth Sciences including subordinate and attached offices and autonomous institutions is 8170 during the year 2015-2016. The detailed break up is given below.

Ministry Offices	Group A	Group B	Group C	Total
Ministry Headquarters	54	35	66	155
National Centre for Medium Range Weather Forecasting (NCMRWF), Noida	50	18	27	95
Centre for Marine Living Resources and Ecology (CMLRE), Kochi	16	4	15	35
Integrated Coastal and Marine Area Management (ICMAM), Chennai	17	3	6	26
India Meteorological Department (IMD)	465	3900	2692	7057
National Institute of Ocean Technology (NIOT), Chennai	91	54	23	168
Indian Institute of Tropical Meteorology (IITM), Pune	180	64	70	314
National Center of Antarctica and Ocean Research (NCAOR), Goa	47	17	23	87
Indian National Center for Ocean Information Services (INCOIS), Hyderabad	47	27	0	74
National Center for Earth Science Studies (NCESS), Thiruvananthpuram	72	28	59	159
Total	**1039**	**4150**	**2981**	**8170**

Representation of SCs/ STs/ OBCs in Government Services in Respect of Ministry

Group	Representation of SCs/ STs/ OBCs as on 1.1.2016				Number of appointments made during the calendar year 2015											
					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	4	5	0	0	0	0	1	0	1	0	0	0	0	0
Group B	43	8	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Group C	58	22	4	7	0	0	0	0	0	0	0	0	0	0	0	0
Total	150	39	11	14	0	0	0	0	1	0	1	0	0	0	0	0

Representation of Persons with Disabilities in Government Services

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

10.6 Official Language Implementation

Efforts are made constantly for the promotion of the Official Language. The existing Prithvi Vigyan Mantralya Maulik Pustak Lekhan Yojana has been revised and its new resolution is under publishing in the Extraordinary Gazette of India. The number of awards and the amount paid under them have also been revised. A Hindi Fortnight was organized from 1st to 15th September 2015 during which various Hindi Competitions were held to create an atmosphere conducive to use of Hindi in 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 ten employees. An Incentive Scheme for officers for giving dictation in Hindi is in operation. In the years, the Committee of Parliament on Official Language has inspected eight offices under ESSO-IMD and the office of ESSO-NCMRWF at Noida. The year also saw organization of three Hindi

workshops in terms of the stipulation from Department of Official Language. One Official Language inspection of ESSO-CMLRE was carried out on 13th to 14th July 2015.

10.7 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.

10.8 Parliament Matters

The Parliament Section, which caters to the correspondence with the Parliament Secretariats, replied Lok Sabha (102 questions) and Rajya Sabha (32 questions) questions last year.

10.9 Vigilance Activities and Achievements

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.

10.10 Significant Audit Points Printed in Audit Reports of 2015

Paragraph 6.1 of Report No. 30 of 2015

Unfruitful expenditure due to non-functional website – Content managed website developed by the Ministry of Earth Sciences at a cost of Rs. 2.27 crore remained non-functional since February 2012, resulting in unfruitful expenditure.

Paragraph 6.2 of report No. 30 of 2015

Installation and upkeep of meteorological observatories by Regional Meteorological Canter, Kolkata – Maintenance of observatories set up by Regional Meteorological Centre, Kolkata for collection of various types of metrological data was inadequate. This, together with shortage of manpower, resulted in observatories lying defunct, shortfalls in carrying out prescribed inspections of observatories, non-rectification of defective instruments, inadequate geographical coverage of areas under the centre and gaps in collection of meteorological data.

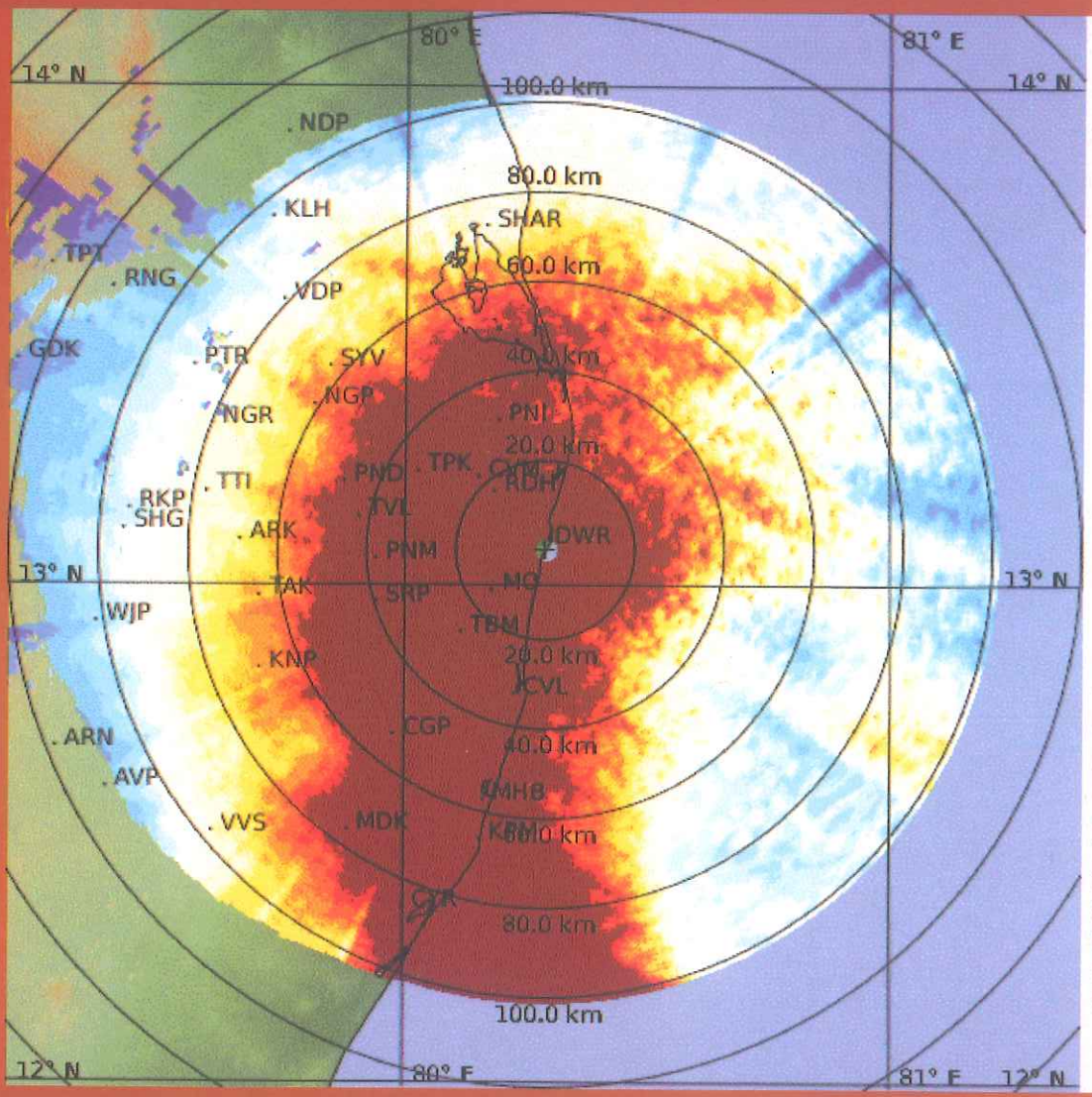
Chapter – 11

ACKNOWLEDGEMENTS

During the year, many scientists and academicians from India and abroad have contributed as external experts in the various committees in the ongoing activities and programmes of ESSO. The Ministry extends its gratitude to all those who have provided their enormous support in both administrative and scientific matters. The Ministry would like to specially thank Dr. Shailesh Nayak, former Secretary for his leadership and direction in the progress of the Ministry during his tenure. The Ministry is further immensely grateful and expresses its gratitude to the Parliamentary Standing Committee on Environment and Forests, Science and Technology as also Parliamentary Committee on Rajbhasha for their constant support, guidance and encouragement.

The various committees constituted by ESSO which participated in the on-going activities and programmes are described below:

1. Program Advisory and Monitoring Committee (PAMC) on Atmospheric Sciences and the Scientific Steering Committee, Monsoon mission chaired by Prof. J. Srinivasan, IISc, Bangalore.
2. PAMC on Hydrology and Cryosphere and the Indian Panel of Changing Water Cycle Programme, Integrated Ocean Drilling Program (IODP) and the NERC-MoES Monsoon Research Panel, chaired by Prof V.K. Gaur, CMMACS, Bangalore.
3. PAMC on Geosciences, chaired by Prof. Ashok Singhvi, PRL, Ahmedabad.
4. PAMC on Ocean Science and Resources chaired by Prof. S. Krishnaswami, PRL, Ahmedabad.
5. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, DRDO, Hyderabad.
6. Research Advisory Council of ESSO-IITM and ESSO-NCAOR, chaired by Prof. U.R. Rao, ISRO, Bangalore.
7. Scientific Review and Monitoring Committee, Monsoon Mission, Research Advisory Council (RAC) of ESSO-NCMRWF, chaired by Prof. D.R. Sikka, Delhi.
8. Research Advisory Committee to review the Performance of Scientific Activities relating to Integrated Coastal and Marine Area Management Project (ICMAM) – chaired by Dr. M Baba, former Director, Centre for Earth Science Studies (CESS).
9. Research Advisory Committee of the Centre for Marine Living Resources and Ecology (CMLRE) – chaired by Dr. Dileep Deobagkar, former VC, Goa University.
10. Scientific Advisory Council of ESSO-NIOT chaired by Dr. P.S. Nair, Emeritus Scientist, ISRO, Bangalore.
11. Scientific Program Committee of the International Symposium on Antarctica Earth Science, chaired by Prof. S.K. Tandon, University of Delhi.
12. Programme Advisory Committee (PAC) of Seismicity and Earthquake Precursor programme and Scientific Deep Drilling investigations in Koyna intraplate zone and Group Monitoring Committee (GMC) of Seismicity and Earthquake Precursor Programme, chaired by Dr. Harsh K. Gupta, Member, NDMA, New Delhi.



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