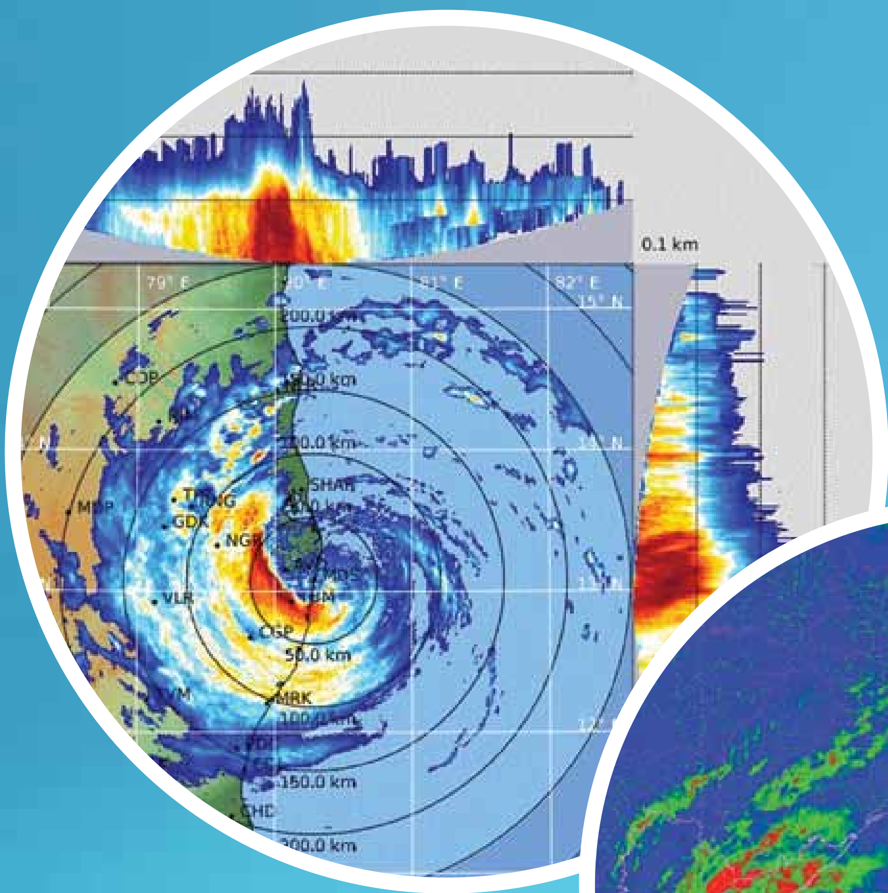
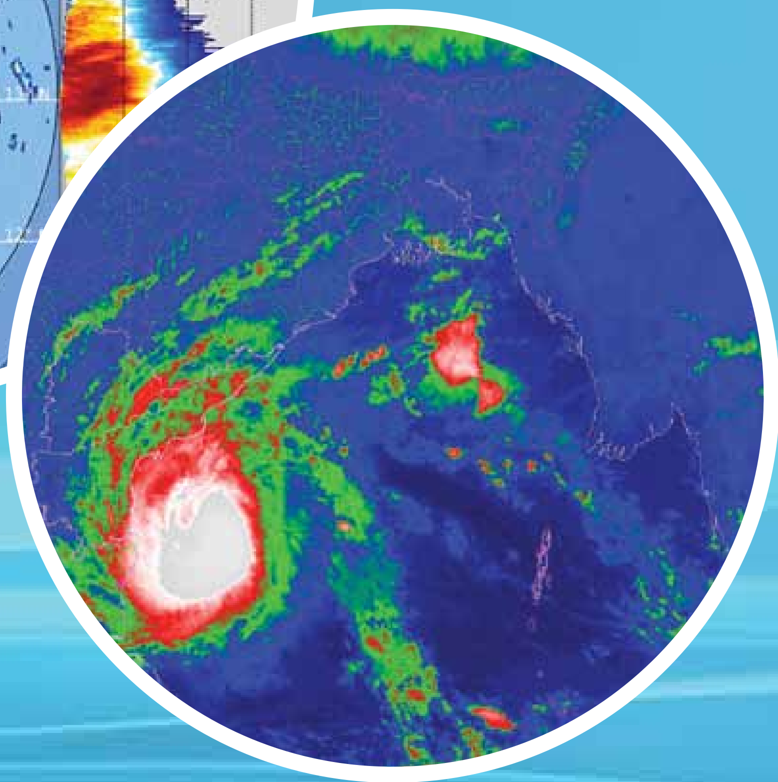
ANNUAL REPORT
2016-17

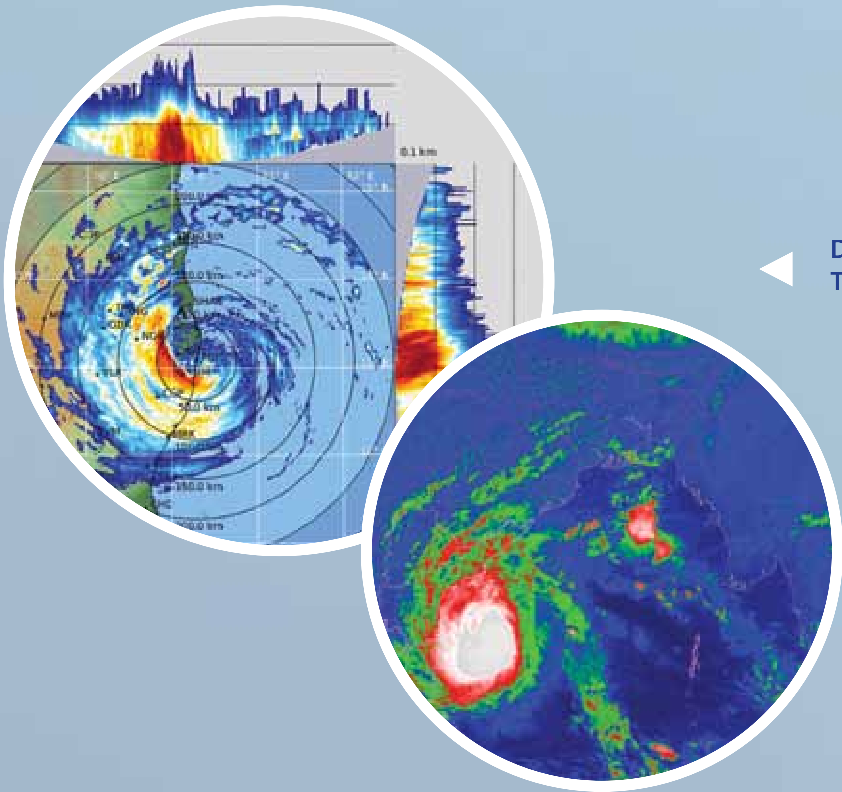




सत्यमेव जयते

Government of India
Ministry of Earth Sciences

Front Cover



DWR and Satellite Image of Tropical Cyclone Vardah

Back Cover

Clockwise:

- Drilling Rig at Pilot Borehole Site in Koyna
- Polarized Autonomous Phase Sensitive Radio-Echo Sounding Antenna to measure ice crystal orientation
- Deployment of RAMA buoy mooring in the Indian Ocean
- Integrated Mining System and
- ORV Sagar Nidhi

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ANNUAL REPORT 2016-17

ESSO

Earth System Science Organization
Ministry of Earth Sciences
Government of India

Contents

1. OVERVIEW

Earth System Science deals with all the five components of the Earth System, viz., Atmosphere, Hydrosphere, Cryosphere, Lithosphere and Biosphere and their complex interactions. The Ministry of Earth Sciences (MoES) holistically addresses all the aspects relating to Earth System Science for providing weather, climate, ocean, coastal state, hydrological and seismological services. These services include forecasts and warnings for various natural disasters. In addition, the ministry has the mandate of conducting ocean surveys for living and non-living resources and exploration of all the three poles (Arctic, Antarctic and Himalayas). The services provided by the Ministy are being effectively used by different agencies and state governments for saving human lives and minimizing damages due to natural disasters. Several major milestones which have been accomplished under the five major programs of the MoES during the last year are illustrated below:

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

During this year 2016, many significant achievements have been made in providing weather and climate services. Many observational campaigns have been taken up such as special atmospheric observations to help us to understand model deficiencies and to improve the models. A high resolution global deterministic weather prediction model has been commissioned for generating operational weather forecasts at a horizontal resolution of 12 km. With this, MoES has attained the same capability as USA in using high resolution weather prediction models. Many major improvements have been made in data assimilation for the ingestion of data from Indian and International satellites in numerical models. Under the Monsoon Mission, operational dynamical model systems have been implemented for extended range and seasonal forecasts. For the first time, forecasts on different time scales during the hot weather season (April to May) including heat waves were issued by the India Meteorological Department.

The quality of weather services saw noticeable improvements achieved in skills of Heavy Rainfall Forecasts and tropical cyclone forecasts. Presently around 19.5 million farmers are directly benefitting from the agro-meteorological services of IMD. For the recent cyclone Vardah, accurate predictions were provided almost 3 days in advance, helping the state government authorities to save thousands of lives.

To address the issue of better measurement and understanding of small-scale processes that drive the variability, seasonality and predictability in the South Asian Monsoon, a large-scale joint India-UK observational campaign was carried out during the period June-July 2016. The campaign involved the deployment of UK's BAe-146-301 atmospheric research aircraft with sophisticated scientific instruments and India's Sagar Nidhi and Sindhu Sadhna research vessels. An observational campaign to understand different physical features of Fog and factors responsible for its genesis, intensity and duration was also initiated during December 2016 at the Indira Gandhi International Airport (IGIA) and at ICAR-IARI in New Delhi. These observations will be useful for improving model forecasts of Fog.

The Climate Centre at IMD Pune has been now recognized as the Regional Climate Centre by the World Meteorological Organisation (WMO) for providing regional climate services. A first version of the Earth System Model (ESM) has been implemented to study the climate change aspects and develop future regional climate change scenarios and to conduct climate impact assessment studies. The ESM will be the first climate model from India to contribute to the forthcoming sixth IPCC climate change assessment process.

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

INCOIS continued to provide forecasts on ocean state, PFZ advisories and species specific advisories for a wide spectrum of users. The ocean state forecasts were also provided before and during the launch day of the Re-usable Launch Vehicle Technology Demonstration (RLV-TD) of the Indian Space Research Organisation (ISRO). The Indian Tsunami Early Warning Centre (ITEWC) monitored 29 earthquakes of magnitude ≥ 6.5 MW during the period 1 January - 31 October 2016. Out of these 29 earthquakes, 2 significant earthquakes have occurred in the Indian Ocean region. These earthquakes did not generate any Tsunami and hence 'no threat' bulletins were issued for India.

On 27th July 2016, Dr. Harsh Vardhan, Hon'ble Minister of Science & Technology and Earth Sciences dedicated the Search and Rescue Aid Tool (SARAT) to the Nation during the XV National Maritime Search and Rescue (NMSAR) Board Meeting. In addition, an experimental version of SARAT was used to provide Search And Rescue support to all the concerned in connection with the missing AN 32 aircraft, which was reported missing off Chennai on 22 July 2016. To facilitate the indication of eco-sensitive zones, potential fishing zones, fishing avoidance zones during the event of oil spills, the third version of the online oil spill advisory was recently inaugurated.

In 2016, INCOIS deployed 23 ARGO floats in the Indian Ocean with sensors to collect physical parameters, of which 11 were equipped with additional biogeochemical sensors. Currently, over 732 active floats are actively working in the Indian Ocean of which 136 were deployed by India. So far, more than 340856 temperature and salinity profiles, 18993 dissolved oxygen and 7614 Chlorophyll profiles were collected by Argo floats in the Indian regions.Ocean Moored buoy Network in the Indian Ocean (OMNI) has been systematically maintaining the twelve deep sea buoy systems with surface & subsurface sensors, four coastal buoys and two tsunami buoys. During the reporting period 14 cruises were conducted to carry out 41 deployments/retrievals. Indigenously developed 500 m depth rated shallow water/ polar remotely operated vehicle (PROVe) was successfully deployed, in the Andaman coral Islands and the vehicle was successfully maneuvered in the undulating reef terrain to record high quality underwater visuals of coral reef biodiversity with spectral irradiance.

1.3 Polar and Cryosphere Research (PACER)

The 35th Indian Scientific expedition to Antarctica was executed with a total of 124 expedition members representing 29 different organizations with 34 projects covering upper atmosphere, astrophysics, geophysics, meteorology, glaciology, geology, biology, environmental sciences, human physiology and medicine. Yoga was introduced as part of a scientific programme. The 36th expedition members were sent in different batches, commencing November 2016. Total of 31 sub-projects/studies covered (i) Atmospheric Science & Meteorology, (ii) Biology & Environmental Sciences (iii) Earth Science & Glaciology with the overall theme being "Climate Change".

The IXth Southern Ocean Expedition was launched on board Oceanographic Research Vessel MV Agulhas [South African vessel] from Port Louis, Mauritius during December, 2016. The observations will be made up to Prydz Bay, the coastal waters of India's third station in Antarctica "Bharati'.

National Centre for Antarctic and Ocean Research (NCAOR), Goa, under the Ministry of Earth Sciences established a high altitude research station in Himalaya called HIMANSH (literally meaning, a slice of ice), situated above 13,500 ft (> 4000 m) at a remote region in Spiti, Himachal Pradesh. This station is equipped with instruments such as Automatic Weather Station, Water Level Recorder, Steam Drill, Snow/Ice Corer, Ground Penetrating Radar, Differential Global positioning System, Snow Fork, Flow Tracker, Thermister string, Radiometer etc. Water Level Recorders were installed at five locations along with a stretch of 130 km of the Chandra river in Western Himalaya for hydrological balance/modeling. Glaciers were monitored for mass balance, dynamics, energy balance and hydrology.

Under the Arctic observations program, the Indian Arctic mooring (IndARC-II) was retrieved on 26th July 2016, following which IndARC III was re-deployed successfully on 27th July 2016. The Ambient Noise Measurement System with a single hydrophone and a data acquisition system was deployed on IndARC-II. IndARC-II collected more than 116 parameters and worked continuously for 373 days in the Arctic waters. During the year, 17 projects covering different aspects oceanography, atmospheric sciences, geology and glaciology were implemented at Ny-Ålesund, Svalbard, Norway.

1.4 Seismology and Geoscience Research (SAGE)

The national seismological network consisting of 82 observatories has been functioning smoothly and a total of 245 earthquake events occurred in and around India (Latitude 0-40° N, Longitude 60-100° E) were detected and auto-located during the period November 2015 October, 2016. These include 40 events of magnitude 5 and above. Information pertaining to significant events was transmitted to all concerned state and central government agencies, dealing with relief and rescue operations in the region and also posted on the associated website. Currently the second phase of upgradation is on which envisages installation of 32 new stations and upgradation of 6 existing stations. It is expected that by the end of the year 2017, a total of 116 stations will be part of the national network.

These observatories are being integrated with the Operational Centre through the VSAT communication facility established under the Integrated Seismic and GPS Network (ISGN).

Seismic micro-zonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface. In order to undertake micro-zonation, studies of 30 selected cities, falling in seismic zones V, IV, III and the State Capitals have been initiated. As a part of this exercise, micro-zonation of Delhi has been completed based on Probabilistic Seismic Hazard Analysis (PSHA).

Scientific Deep Drilling in Koyna which started in 2016 is aimed at setting up of borehole observatory (s) at depth 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, leading to a better understanding of the mechanics of faulting, physics of reservoir triggered earthquakes and preparation of a predictive model. Borehole Geophysics Research Laboratory (BGRL), Karad has undertaken scientific deep drilling and associated investigations in the Koyna seismic zone, Maharashtra.

1.5 Reachout

This programme comprises of the training programs of the Ministry, R & D in Earth and Atmospheric Sciences program for extramural support and the Outreach and Awareness Program. The basic aim of the R & D in Earth and Atmospheric Sciences program is to nurture R&D activities being undertaken in various academic and research institutes of the country and to translate the output into operational use by the Ministry. The Ministry therefore encourages projects from both national as well as international institutes and has constituted special committees to cover each aspect of Earth Sciences. Around 5% of the annual budget of the Ministry is allocated for extramural support.

1.6 International Interface

Ministry of Earth Sciences signed a 15-year contract with the International Seabed Authority (ISA), for exploration of Poly-Metallic Sulphides (PMS) in the Indian Ocean. The contract was signed by Dr. M Rajeevan, Secretary, MoES and Mr. Nii Allotey Odunton, Secretary General, ISA. The ISA is an institution set up under the Convention on Law of the Sea to which India is a Party.

Ministry of Earth Sciences submitted an application to the International Seabed Authority for extension of contract for exploration of Polymetallic Nodules (PMN) for a further period of 5 years (2017-22). The contract signed with the International Seabed of Authority for exploration of Polymetallic Nodules on 25th March 2002 is expiring on 24th March 2017. The PMN 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 the UN. India signed an MoU with the Japan Agency for Marine-Earth Science and Technology

(JAMSTEC), Japan. The advancement of academic research in the field of Earth Sciences for the benefit of peace and human welfare is the prime objective of the MoU. India became a member of the International Energy Agency-Ocean Energy Systems (IEA-OES) through signing of the Implementing Agreement. By becoming a member of the IEA-OES, India will have access to advanced R&D teams and technologies across the world.

1.7 Scientific Publications

There has been an exponential growth in the research publications by scientists of the Ministry during the past few years. A total of 387 research papers were published during 2016-17 by MoES scientists and under various programs of the Ministry (Fig.1.1).

1.8 Budget Expenditure

The plan outlay for the Ministry for the year 2016-17 was Rs.1200 crores which had been reduced to Rs. 1139 crores at the RE stage. The expenditure profile for the last 10 years is depicted in the table below.

(Rs. in crores)

Year	B.E	R.E	Actual Expenditure
2007-08	690	400	359.00
2008-09	750	550	489.56
2009-10	900	793	754.53
2010-11	1000	950	767.43
2011-12	1220	855	818.74
2012-13	1281	820	793.87
2013-14	1281	925	876.00
2014-15	1281	925	900.28
2015-16	1179	1013	901.61
2016-17	1200	1139	682.34*

*As on date

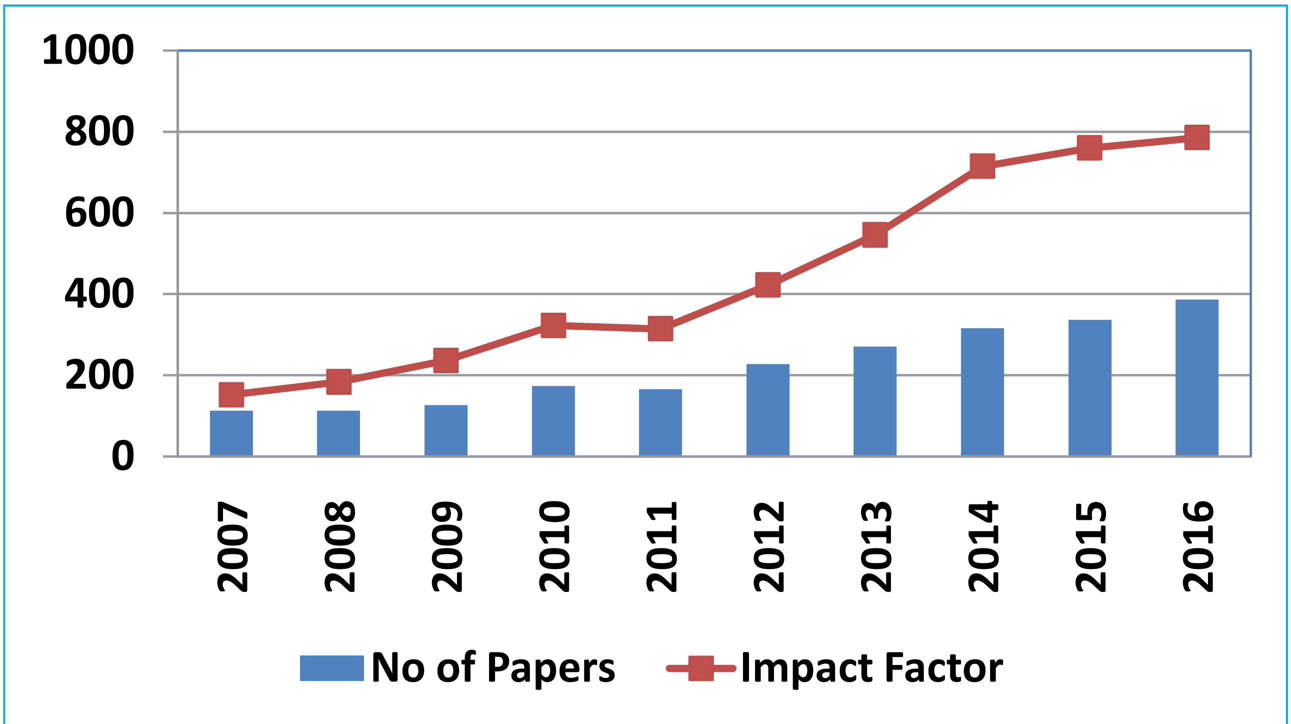


Fig. 1.1: Number of research papers and cumulative impact factor year wise

2. ATMOSPHERE AND CLIMATE RESEARCH, OBSERVATIONS SCIENCE SERVICES (ACROSS)

The Ministry of Earth Sciences is responsible for providing year-round Weather, Climate and Hydrological Services for various users. Both operational and research aspects of these services are implemented through the programme, ACROSS.

During this year, 2016-17, many significant achievements have been made in providing weather and climate services. On the numerical modelling front, a high resolution (12 km) global deterministic weather prediction model has been commissioned for generating operational weather forecasts. Many major improvements have been made in data assimilation in numerical models. Under the Monsoon Mission, operational dynamical model systems have been implemented for extended ranges and seasonal forecasts. In climate services also, a significant achievement was made. The Climate Centre at ESSO-IMD Pune has been now recognized as the Regional Climate Centre for providing regional climate services. For the first time, forecasts on different time scales during the hot weather season (April to May) including heat waves, were issued by the India Meteorological Department. Many observational campaigns also have been taken up as special atmospheric observations help us to understand model deficiencies and to improve the models.

Details of significant achievements made under ACROSS are given below:

2.1 Observing Systems and Services

Maintenance and strengthening of atmospheric observational network is absolutely required to sustain and improve skill of weather forecasts. ESSO-IMD has been augmenting its observing system networks over the past years. During 2016, the following upgradation of the network has been made.

- The Doppler Weather Radars(DWRs) at Goa, Karaikal and Paradeep through joint efforts with ISRO. Indigenously developed DWRsat Cherrapunjee, Bhuj, Gopalpur and Thiruvananthapuram.
- Twelve indigenously developed new Dristhi RVR systems at the Indira Gandhi International Airport Delhi, Lucknow, Jaipur, Amritsar, Dehradun and Varanasi. These RVR systems are developed indigenously by CSIR-NAL.
- Four GPS-based Solar Trackers at Chennai, Thiruvananthapuram, Visakhapatnam and Shillong.
- UV-B Radiometer at Lakshdweep Island stations (Amini & Minicoy).
- High Wind Speed Recorder (HWSR) at Machilipatnam, Naliya (Gujarat) & Safdarjung (New Delhi).
- Two new Current Weather Instrument System (CWIS) at Chennai airport.
- 93 nos. of Digital Station Barometers at different observatories.
- 58 Automatic Rain Gauge (ARG) Stations.
- Black Carbon Monitoring Network of 16 stations (New Delhi, Ranichauri, Varanasi, Nagpur, Pune, Port Blair, Visakhapatnam,

Guwahati, Kolkatta, Jodhpur, Bhuj, Trivandrum, Ranchi, Amini, Chandigarh and Srinagar) for measurement of Spectral Aerosol Absorption Coefficient and Equivalent Black Carbon Concentration.

- 25 ground-based Global Navigation Satellite System (GNSS) receivers collocated with Meteorological sensors all over India for real-time monitoring of total water vapour content in the atmosphere at 10 min intervals.
- Using INSAT-3D Meteorological data, the generation of new images such as day/night time micro physics, for cloud classification, and dedicated cyclone images for use in determination of cyclone intensity and centre have been developed and implemented operationally. The retrieval algorithm of satellite-derived wind products has been modified and implemented successfully resulting in generation of good quality wind products which are being assimilated in the NWP model on operational basis.
- Following the launch of the Global Precipitation Mission (GPM) satellite by NASA, an advanced high resolution precipitation product was released in early 2015 and is being used in IMD-NCMRWF operational daily-merged satellite gauge rainfall analysis.
- GPS-RS/RW flights and Radar observational campaigns at Mandardev (near Mahabaleshwar) are being conducted for better understanding of the atmospheric physical processes and clouds.
- 'Tamhini' located on the leeward side of the Western Ghats in Maharashtra has been identified as the fifth station in India receiving heavy rainfall.

2.1.1 High Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar

The effect of aerosols on cloud droplet number concentration and droplet effective radius is investigated from ground-based measurements over a high-altitude site (Mahabaleshwar Observatory) wherein clouds pass over the surface. First Aerosol Indirect Effect (AIE) estimates were made using i) relative changes in cloud droplet number concentration (AIE_n) and ii) relative changes in droplet effective radius (AIE_s) with relative changes in aerosol for different cloud liquid water contents (LWC). AIE estimates from two different methods reveal that there is systematic overestimation in AIE_n as compared to that of AIE_s. Aerosol effects on spectral dispersion in droplet size distribution plays an important role in altering Twomey's cooling effect and thereby in climate change.

2.1.2 Seasonal variability of aerosol and CCN over HACPL

Aerosol-CCN variability and its relationship has been studied for the first time at HACPL, Mahabaleshwar, a high altitude (1348 m AMSL) site in the Western Ghats, using one year (June 2012 to May 2013) of observations. The present study has been done in two sections i.e. firstly temporal variability analysis (diurnal and seasonal) of aerosols and CCN, followed by determination of CCN to aerosol ratios, investigation of microphysical properties and detailed discussion on possible sources of aerosols in which first temporal variability (diurnal and seasonal) of aerosol and CCN has been analyzed. Overall analysis showed that aerosol and CCN concentration was higher over this high altitude site despite dominant sink processes such as cloud scavenging and washout mechanisms indicating local emissions and biogenic Volatile Organic Compounds (BVOC) emissions from wet forest as major sources.

2.2 Atmospheric Field Campaigns

2.2.1 High-Altitude Balloonsonde Campaign in July-August 2016

Under the Memorandum of Understanding (MOU) between MoES and German Helmholtz Association (HGF), a project entitled "Influence of Asian Summer Monsoon (ASM) on the upper troposphere-lower stratosphere (UTLS): Feedback on monsoon circulation" is being carried out by IITM Pune for understanding processes related to Asian summer monsoon circulation and its impact on the UTLS. A high altitude balloon campaign has been conducted at Nainital, Uttarakhand during the Monsoon (July-August-2016) and the post Monsoon (November 2016) period. High frequency measurements of water vapour, aerosol back scatter, ozone and relative humidity along with meteorological parameters were obtained at the centre of the monsoon anticyclone. These data show events of wave breaking and eddy shedding from the monsoon anticyclone. Observations along with model simulations are being analyzed.

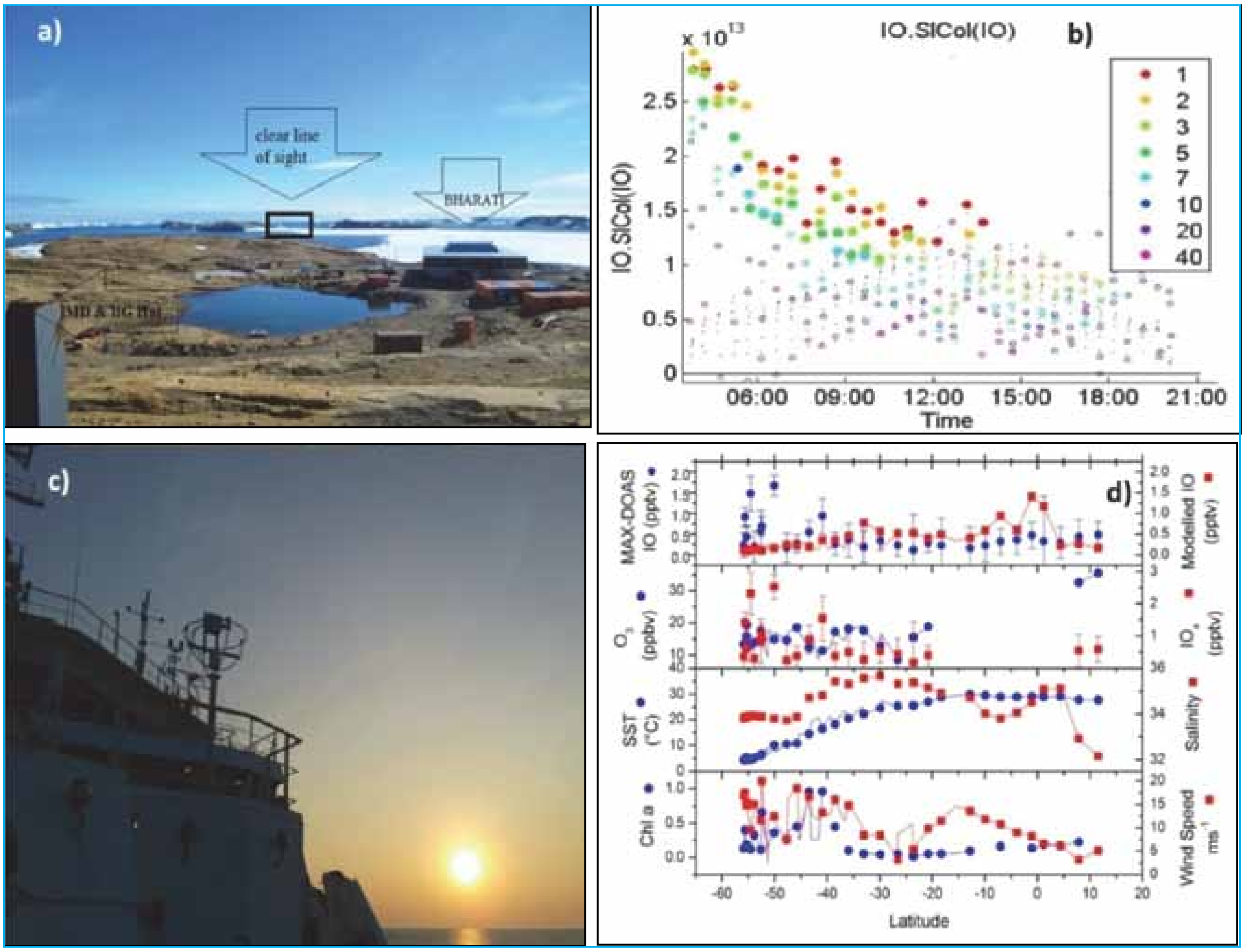


Fig. 2.1: (a) A picture of the site at the Bharati station, (b) Observations of iodine oxide at Bharati, showing the presence of halogen compounds above the detection limit of the instrument, (c) a picture of the instrument aboard ORV Sagar Nidhi during the 8th ISOE, (d) Daily averaged values of measured IO, O_3, calculated IOx and measured oceanic and atmospheric parameters during the 8th-ISOE distributed along the latitudinal transect covered by the cruise. The first panel also shows the modelled IO, simulated using the model CAM-Chem model

2.2.2 *Trace gas observations of reactive species in the remote environment*

IITM Pune has conducted field campaigns to study the role of reactive trace gases such as dimethyl sulphide (DMS) and halogen oxides in the atmosphere. DMS has been implicated in playing a crucial role in the formation of new particles leading to cloud formation at a global level, while the role of halogen compounds in tropospheric and stratospheric ozone depletion has been well recognized. However, large uncertainties still exist on the exact role of these species at a regional scale and observations in the Indian Ocean and over the Antarctica are still rare. In order to improve the observation database, to obtain better emission inventories used for modelling global and regional impacts, IITM has conducted observations on board the oceanographic research vessel Sagar Nidhi during the 8th Indian Southern Ocean Expedition. In addition to cruise-based observations, ground-based observations of halogen compounds have also been made at the two Indian Antarctic research stations, Maitri and Bharati during the 34th and 35th Indian Scientific Expeditions to Antarctica.

2.2.3 *Winter Fog Field Campaign at New Delhi*

An observational campaign to understand different physical features of fog and factors responsible for genesis, intensity and duration has been initiated. IITM and IMD have jointly conducted this observational campaign at the Indira Gandhi International Airport (IGIA) and at ICAR-IARI in New Delhi (Fig.2.2). The main objective of the winter fog campaign is to study the characteristics and variability of fog events over Delhi and associated dynamics and thermodynamics and cloud microphysics. The key findings of the earlier observational campaign organized in the winter of 2015-16 to understand the formation, dissipation and life cycle of fog at the IGI airport are as follows:

- Equivalent potential temperature could be used as a matrix for imminent fog incidence
- Evidence of mini-convective layer dynamics playing an important role in persistent fog events
- Turbulence plays an important role in fog dissipation (direct findings from observations)
- The fog parameterization options are assessed and will be tested in the model
- Evidence of Ramdas layer is found from very high resolution temperature observations
- The CCN activity was found to depend on turbulence
- A high BC layer was noted in the fog layer, which contributed to radiative effects

Phase-II of the campaign was inaugurated on 6th Decemebr 2016. The campaign was conducted till mid-February. The parameters

Fig. 2.2: Tether Sonde Balloon Observations upto 1000 m were taken during 3 to 23 January, 2016.

measured during phase-1 in 2015-16 were measured during the 2016-17 winter as well.

2.2.4 Indo-UK joint monsoon observational campaign:

Under the Implementing Agreement (IA) between MoES and the Natural Environment Research Council (NERC) on *Predicting the Variability of the South Asian Monsoon* three research projects involving Indian and UK scientists will study different aspects of physical processes affecting the monsoon.

I. SWAAMI: South West Asian Aerosol Monsoon Interactions: SWAAMI will combine measurements of the properties of aerosols across northern India and the Bay of Bengal during the pre-monsoon in unprecedented detail with long-term measurements from ground-based networks and data from previous intensive campaigns in order to challenge model representations of aerosols over India and their effects on the monsoon.

II. INCOMPASS: Interaction of Convective Organisation and Monsoon Precipitation, Atmosphere, Surface and Sea: The main objective is to improve predictions of monsoon rainfall on a variety of space/time scales by better understanding and representing the dynamics and thermodynamics of the monsoon as air advances from the moisture source region of the Indian Ocean over the land surface, being modulated by convection operating at different scales along the way.

III. BoBBLE - Bay of Bengal Boundary Layer Experiment: The prime aim of this project is to understand the coupled ocean-atmosphere processes over the Bay of Bengal during different phases of the summer monsoon.

To address the above objectives, a large-scale joint observational campaign was carried out during June-July 2016. The campaign involved the deployment of UK's BAe-146-301 atmospheric research aircraft with sophisticated scientific instruments and India's Sagar Nidhi and Sindhu Sadhna research vessels. The aircraft observations were augmented by special observational programs over land using boundary layer flux towers, radars, additional radiosonde ascents, Microwave Radiometers, etc. The research aircraft (Fig. 2.3) during its 22-day operations

Fig. 2.3: Research aircraft used in the Indo-UK research campaign to understand monsoon physical processes.

from 11 June to 11 July 2016 measured a variety of atmospheric parameters such as: temperature, relative humidity, winds (3 components), short wave radiation, long wave radiation, turbulence etc; cloud microphysical parameters such as liquid water content, ice water content, totals water content, updraft speed, cloud condensation nuclei, cloud droplet number and size, hydrometeor images etc. Aerosol parameters such as aerosol number, size (all size ranges), black carbon aerosol concentration, aerosol scattering and absorption coefficients etc. chemical measurements such as Ozone, CO_2, CO, CH_4, NOx, SO_2 and chemical species in the aerosols etc. About 100 hours of aircraft data has been collected and is being analysed by the Indian and UK scientists.

In BoBBLE the two ships along with six ocean gliders and eight additional Argo floats were deployed in southern BoB during 23 June to 24 July 2016 to study the small-scale processes of air-sea interaction and their impact on the larger-scale monsoon circulation and precipitation.

2.3 Global and Regional Data Assimilation

Data assimilation is an important process in weather prediction and quality of data assimilation is crucial for skilful short range weather forecasts. Assimilation of two new types of observations viz., Megha-Tropiques radio-occultation observations (MT-ROSA) and Meteosat-SEVIRI radiances has been initiated at ESSO-NCMRWF. Further developments on data assimilation during the year are:

i) The global data assimilation system for NCMRWF Global Forecast System (NGFS) was upgraded to a Hybrid GSI with EnKF ensemble. The real-time initial conditions generated at 12 km horizontal resolution using Hybrid-Ensemble system with 80 ensemble members (at 22 km resolution), are used for running the operational global deterministic as well as ensemble prediction systems.

ii) A 12-year (2000-2011) NGFS reanalysis was carried out at 22 km horizontal resolution. Fig. 2.4 depicts the observed daily rainfall over Indian land mass and analysed Wang Wind Index (based on analysed zonal wind shear over monsoon region) for the Indian summer monsoon season computed from the re-analyses dataset and it shows the good agreement of the analysed dataset and the observed features. This reanalysis product is being used for seasonal and extended range predictions.

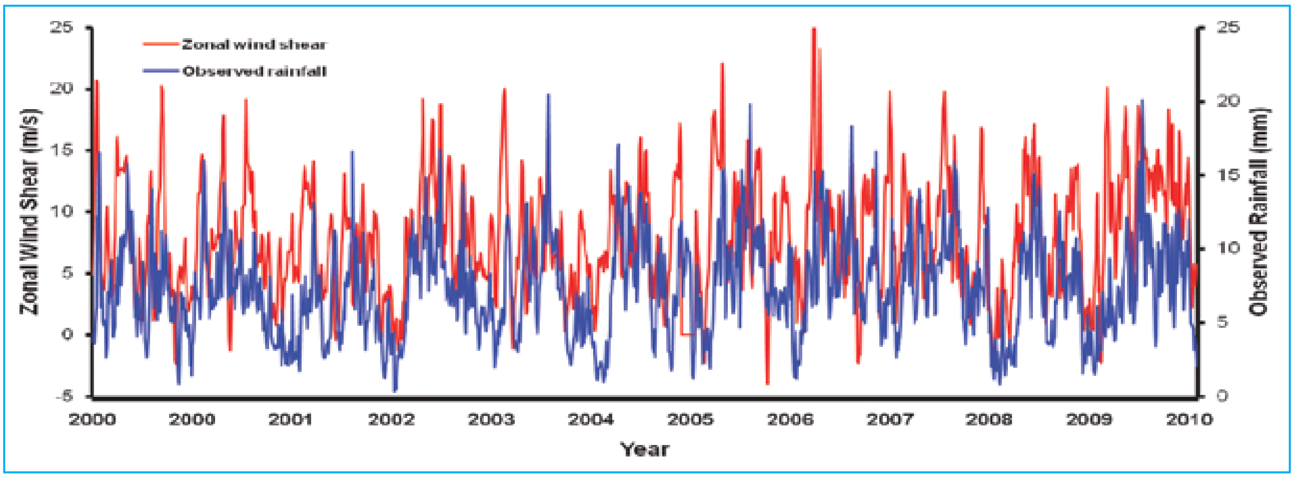


Fig 2.4: Observed daily rainfall over Indian land mass and analysed Wang wind index for Indian summer monsoon season computed from the re-analyses dataset (2000-2011)

iii) NCMRWF Unified Model (NCUM) Data Assimilation System was upgraded to hybrid 4D-Var (variational approach with time-evolving information of the forecast error distribution from ensemble forecasts) system in September 2016 (Fig 2.5). The hybrid system uses various conventional and non-conventional observations including INSAT-3D sounder radiances and Megha-Tropiques SAPHIR radiances and also makes use of the 44 member ensemble forecasts from the NCMRWF Global Ensemble Prediction System.

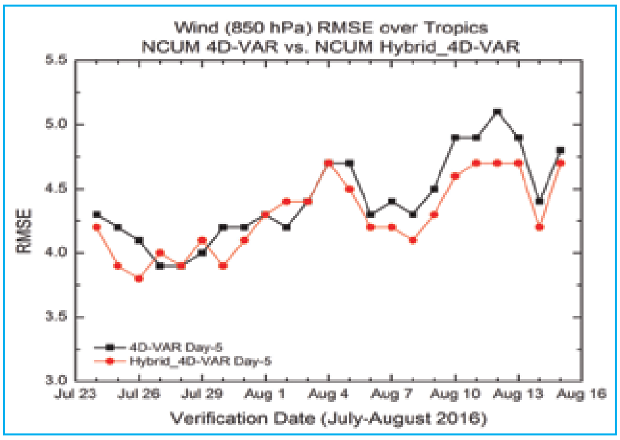


Fig 2.5: Comparison of Day-5 Root Mean Square Error (RMSE) of 850 hPa wind for NCUM (4D-VAR) and NCUM (Hybrid-4D-VAR) DA systems over the Tropic

iv) Assimilation of dust in NCUM system has been initiated to improve the accuracy of dust forecasts.

v) Satellite (MODIS) derived of aerosol optical depth (AOD) is getting assimilated in real time. Data assimilation experiments were also carried out with INSAT-3D AOD.

2.4 Global and Regional Modelling

i) The GFS (*GSM.V13.0.3*) at T1534L64 (~ 12 km) in horizontal resolution and 64 hybrid sigma-pressure layers with the top layer centred around 0.27 hPa (approximately 55 km) was made operational on 01 December 2016. It is now run twice a day (00 & 12 UTC) to give deterministic forecast in the short to medium range. The initial conditions are generated from the NCEP based Ensemble Kalman Filter (EnKF) component of hybrid Global Data Assimilation System (GDAS).

The GFS predicted the rainfall associated with tropical cyclone "VARDAH" reasonably well. The observed spatial rainfall band associated with TC "VARDAH" is shown

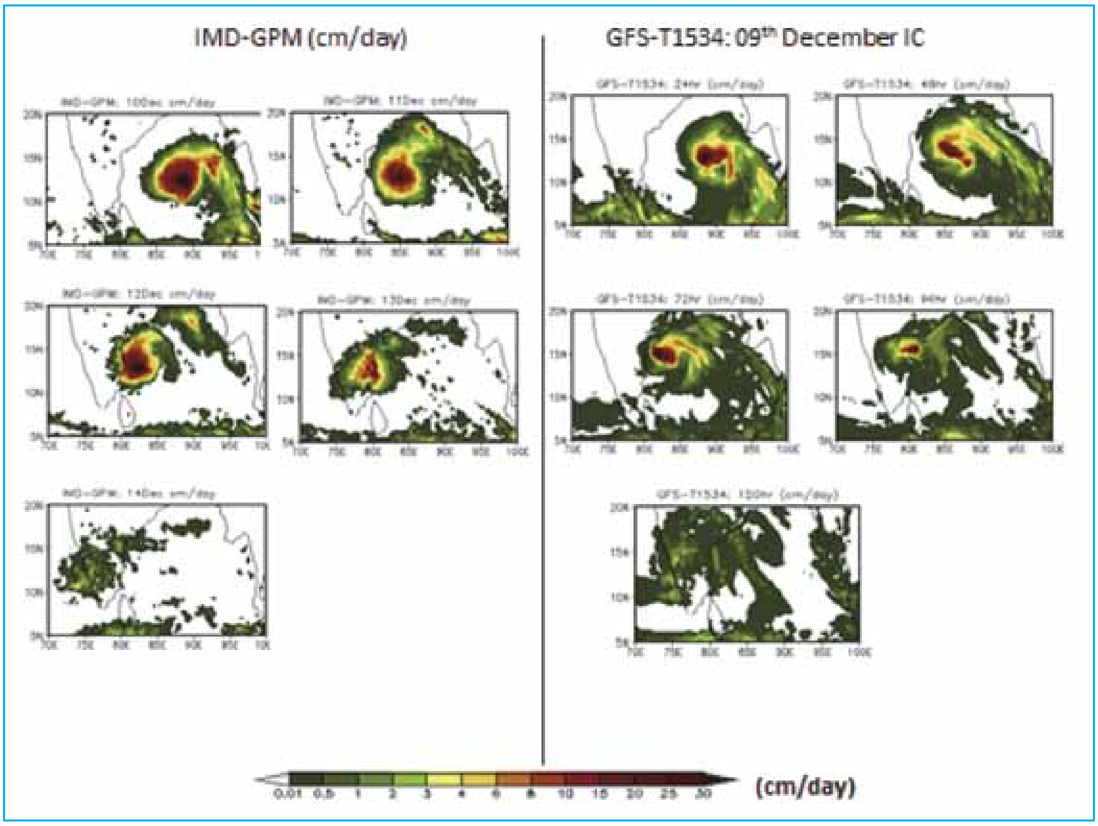


Fig 2.6: Cyclone VARDAH prediction by T1534L64

in the left panel in Fig.2.6. The model forecast with 9 December initial condition (right panel) is able to demonstrate the inner core of heavy rainfall and the outer rainbands as seen in the observations.

ii) A coupled model with a suite of models from CFSv2 coupled model has been developed, implemented and operationalized in July 2016 for generating operational Extended Range Forecast products for different users. This suite of models are (i) CFSv2 at T382 (≈ 38 km) (ii) CFSv2 at T126 (≈ 100 km) (iii) GFSbc (bias corrected SST from CFSv2) at T382 and (iv) GFSbc at T126. The Multi-model ensemble (MME) of the above suite is run operationally for 32 days based on every Wednesday initial condition with 4 ensemble members to give forecast for 4 weeks for (Fig.2.7) days 2-8 (week1; Friday to Thursday), days 09-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday).

iii) The triple nested (27, 9 and 3 km) version (v3.6.1) of Hurricane WRF (HWRF) model with improved physical parameterization schemes and various diagnostic products has been run operationally with 6 hourly intervals for the cyclones over the North Indian Ocean.

iv) NCMRWF Unified Model (NCUM) suite for global and regional deterministic forecasts was upgraded to Version 10.2. This updated version uses Rose/Cylc (Python based model operating environment) in place of UM User Interface (UMUI) which was based on TCL/TK. This system with global (17 km) and regional (4 km) configurations were made operational in August 2016.

v) Regional NCUM at convection permitting horizontal resolutions (4 km, 1.5 km and 330 m) was implemented to be used for various applications like severe weather, fog and thunderstorm predictions for all-India domain as well as city domains. Comparison of model-predicted rainfall with JAXA rainfall (observed) reveals that

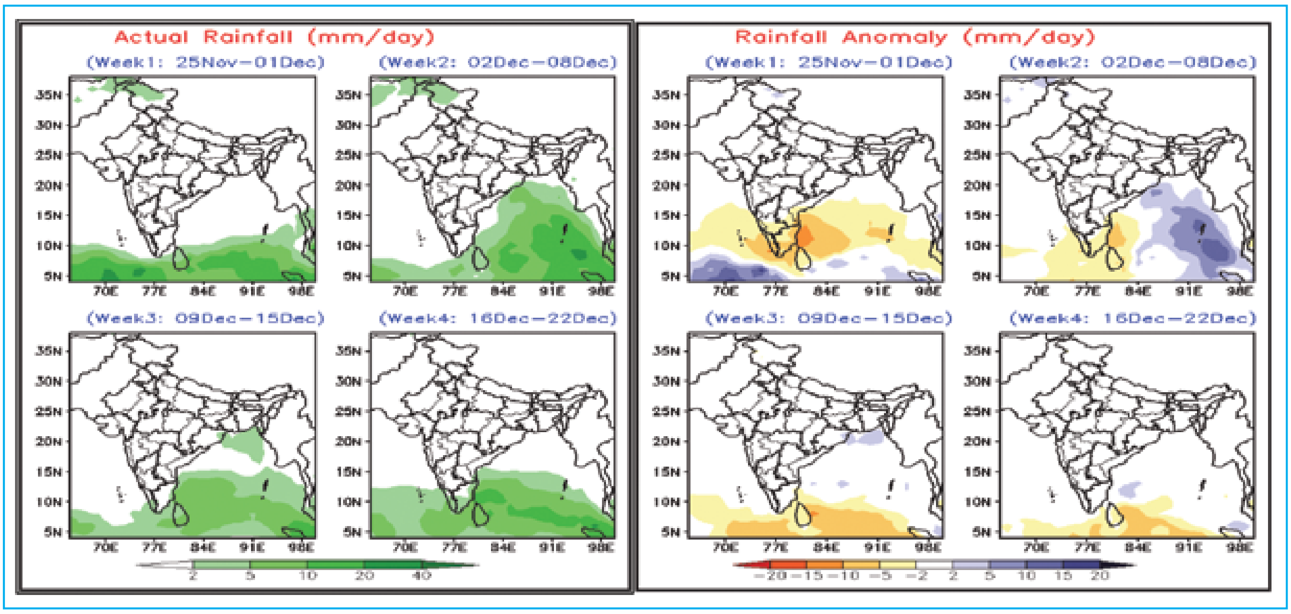


Fig. 2.7: The MME based extended range forecast of mean and rainfall anomaly for 4 weeks based on the initial condition of 23 November, 2016 and valid for 25 November to 22 December, 2016.

the global models predict the diurnal maxima with some delay (early/late). However, the 4 km regional models are able to predict both the phase and the magnitude of diurnal maxima quite close to the observed rainfall (Fig 2.8).

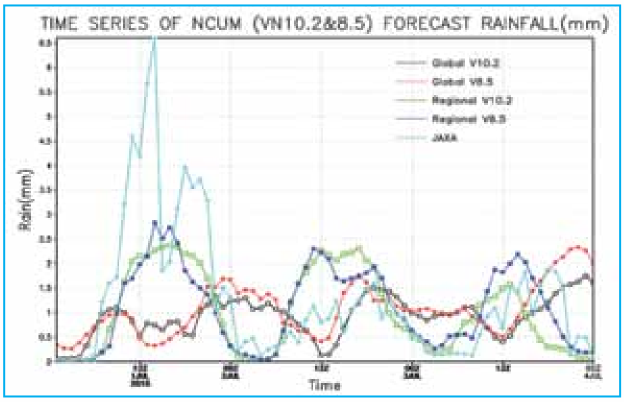


Fig. 2.8: Model predicted and observed diurnal variability of rainfall over central Indian domain (averaged for 77-82˚E & 20-25 ˚N) for 01-03 July 2016

vi) Verification of Chennai floods of December, 2015 against rain gauge, GPM and JAXA rainfall observations revealed that the 1.5 km model is able to predict the location of heavy rainfall accurately over the city (Fig.2.9) The role of the Eastern Ghats orography near Chennai in modulating the NE monsoon rainfall characteristics

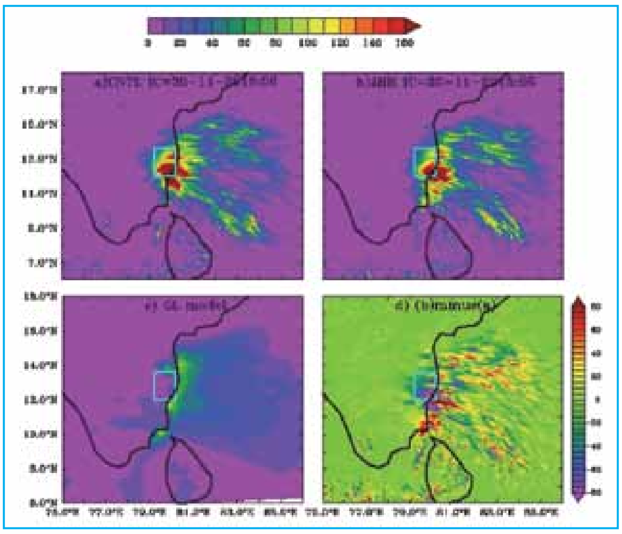


Fig. 2.9: 24 hour accumulated rainfall valid for December 2, 2015 from (a) Control (1.5 km) (b) Experimental run (1.5 km) without Javadi hills of Eastern Ghats, (c) Global model (17 km) - the parent model in which 1.5 km is nested

(pattern and amount) was clearly observed from the runs with and without the orography to the west of Chennai.

2.5 Ocean Data Assimilation and Modeling

i) Global ocean initialization system NEMOVar was implemented and tested with sample ocean input data. This system produces the daily analysis at global ocean at ¼° resolution and assimilates the satellite, in-situ observations of temperature, salinity, sea level anomaly, and sea ice concentration at each day over a 24 hour observation window. Real time run of this system is planned from January 2017.

ii) A high resolution NEMO global ocean model with 75 vertical levels has been implemented. It has 24 levels in the top 100m and 1m resolutionat surface. The model has a tri-polar ORCA 1° grid in the horizontal, with higher resolution (~0.33°) at the equator. The model simulates both sea surface temperature (SST) and sea surface salinity (SSS) fairly well and brings out all the spatial features clearly.

2.6 Global Ensemble Prediction

NCMRWF Global Ensemble Prediction System (NGEPS): Various new forecast products viz., mean and spread of various fields, EPSgram, Spaghetti and Plume diagrams etc. were developed for the 44-member NCMRWF Global Ensemble Prediction System (NGEPS). A tropical cyclone track plotting package was also developed for NGEPS to generate member tracks, mean track and strike probability of Tropical Cyclones.

2.7 Climate Modelling

An Earth System Model(IITM-ESM) has been developed (Fig 2.10) by incorporating earth system components in the Climate Forecast System (CFS) coupled model from National Centers for Environmental Prediction (NCEP, USA), and thereby transforming the CFS seasonal prediction model to a long-term climate model. The first version of IITM ESM (ESMv1) showed significant improvements in the simulation of sea surface temperature and captures dominant modes of climate variabilities and their links with the Indian summer monsoon. In a recent version (IITM-ESMv2), further improvements are incorporated in order to obtain a radiatively-balanced global climate modeling framework, which is required for predicting long-term climate change. Additionally, radiative effects of natural and anthropogenic aerosols are incorporated by specifying time-varying 3-dimensional fields of aerosol optical properties.

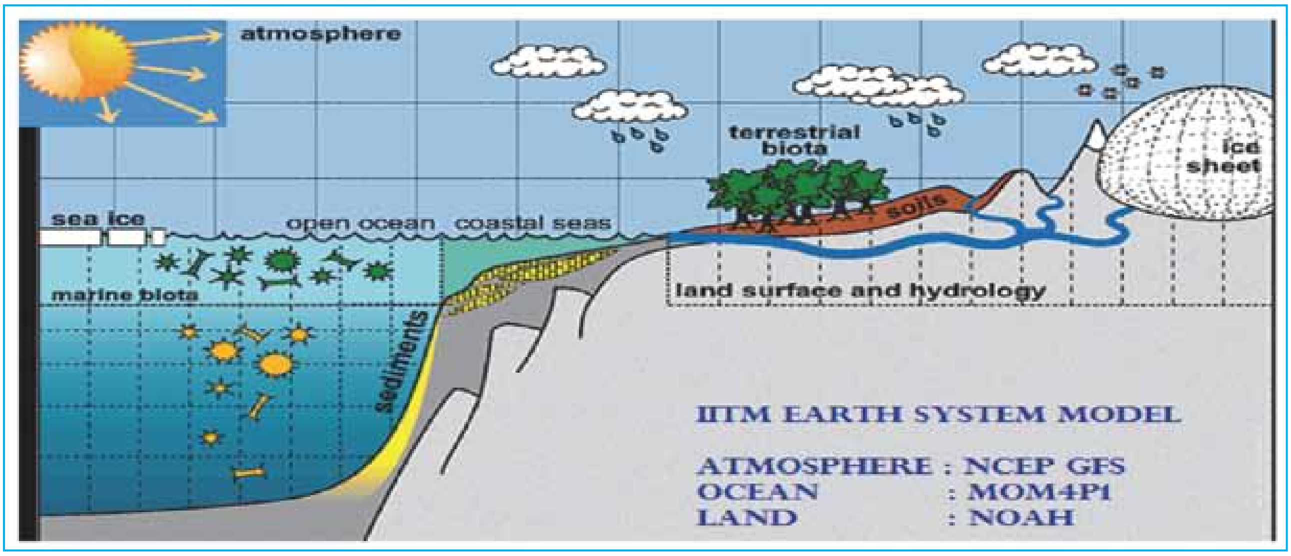


Fig. 2.10: Schematic of IITM-ESM

The IITM-ESMv2 shows improvements in global mean fields and mean precipitation pattern over the Asian monsoon region (Fig 2.11). The IITM-ESM marks a successful climate modeling development for contributing to the forthcoming CMIP6 initiative with DECK, historic and GMMIP simulations, a first from India.

An Earth System Grid Federation (ESGF) data node for archival, management, retrieval and dissemination of CORDEX South Asia and CMIP6 datasets has been developed and is

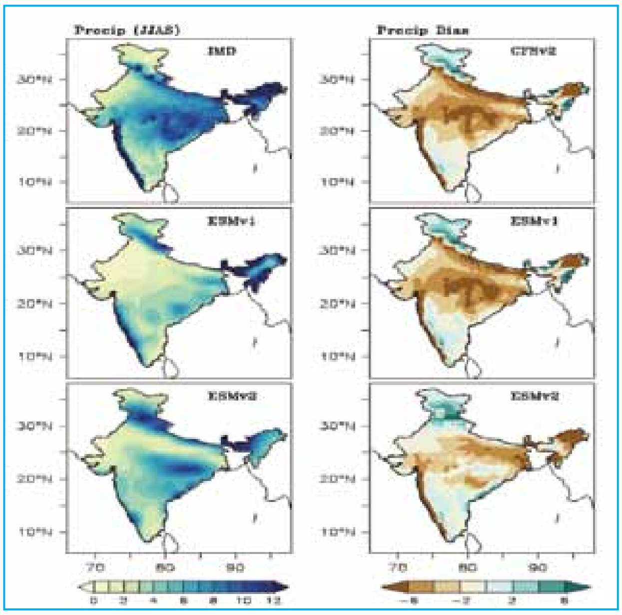


Fig. 2.11: Mean summer monsoon rainfall (mm/day) from (a) IMD data (b) ESMv1 and (c) ESMv2. The bias in summer monsoon rainfall from (d) CFSv2 (e) ESMv1 and (f) ESMv2.

being used to disseminate high resolution climate information published on the ESGF climate data server.

The Commission For Basic Systems (CBS), WMO has recommended formal designation of the Climate Centre, IMD, Pune as a Regional Climate Centre (RCC). The recommendation will be ratified during the next Executive Council of WMO meeting, next year. The quality management system of the Climate Services Division of IMD Pune has received ISO 9001:2008 certification from British Certification Inc.

2.8 Southwest Monsoon and Northeast Monsoon 2016

i) **Experimental Dynamical Seasonal Prediction of 2016 South-West Monsoon:** The CFSv2 (with spectral resolution of T382 ~38 km in the horizontal) has been used to generate experimental forecast for the 2016 South-West Monsoon season rainfall, using the February initial conditions. The model predicted that the 2016 monsoon season (June to September) averaged over the country as a whole is likely to be 111% ± 5% of long period model average (LPMA). Experimental forecasts for the 2016 South-West Monsoon season rainfall were also carried out using initial conditions of March, April and May months. The same model was used to generate the experimental forecast for the 2016 North East Monsoon season rainfall (over Indian region) using the September initial conditions with 47 ensembles.

ii) **Real-time Extended Range Prediction of 2016 Monsoon Season:** Real time extended range prediction of active/ break spells of Indian summer monsoon for the current 2016 monsoon season has been given by the newly developed CFS based Grand Ensemble Prediction System (CGEPS) and the forecasts are being updated in IITM website http://www.tropmet.res.in/erpas/. The CGEPS could predict the dominance of monsoon rainfall over west coast, east coast and northeast India and also, the delay in the progression of monsoon to central India till June 20, reasonably well in advance. It could also predict the active phase of monsoon after June 20, at least 10-15 days in advance.

iii) **Real time prediction of extreme heat conditions:** The extended range prediction for the extreme heat conditions has been initiated and predictions were given during April to June 2016. The extended range prediction system could reasonably provide guidance on the heat wave conditions experienced over various parts of the country during the summer of 2016.

A seasonal outlook for summer temperatures over the country based on the predictions from CFS was issued. The forecast for the 2016 hot weather season which was prepared as the average of 47 ensemble member forecasts suggested warmer than normal temperatures in all meteorological sub-divisions of the country during the 2016 Hot Weather Season (April to June) with seasonal (April-June) average temperatures over northwest India to be above normal by more than 1.0^{0} C. The forecast also suggested above normal heat wave (HW) conditions over central and northwest India.

iv) **Southwest Monsoon during June to September Onset:** Based on an indigenously developed statistical model, it was predicted on 15th May, 2016 that monsoon will set in over Kerala on 7th June with a model error of ± 4 days. However the actual monsoon onset over Kerala took place on 8th June 2016. Thus the forecast for monsoon onset was accurate.

Long Range Forecast: The first stage forecast for the season (June- September) rainfall over the country as a whole issued in April was 106% of the LPA with a model error of ± 5%. The forecast issued in June, 2016 remained the same as 106% of the LPA with a model error of ± 4%. The actual season rainfall for the country as a whole was 97% of LPA.

The forecast for seasonal rainfall for 4 broad homogeneous regions namely North-West India, Central India, South Peninsula and North-East India was 108%, 113%, 113% and 94% of LPA respectively, all with a model error of ± 8%. The actual rainfall over these 4 broad homogeneous regions was 95%, 106%, 92% and 89% of respective LPA.

The monthly rainfall over the country as a whole was 89% of LPA in June, 107% of LPA in July, 91% of LPA in August and 97% of LPA in September.

The forecasts for the monthly rainfall over the country as a whole for the months of July & August issued in June were 107% & 104% respectively with a model error of ± 9%. The actual monthly rainfalls during July and August were 107% & 91% of LPA respectively. Thus the forecast of July rainfall was accurate. However, the forecast of the August rainfall was over estimated.

The forecast for the second half of the monsoon season (August–September) for the country as a whole was 107% with a model error of 8% of LPA against the actual rainfall of 93% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole was an overestimate to the actual rainfall.

The Table below gives the summary of the verification of the long range forecasts issued for the 2016 Southwest monsoon. Fig. 2.12 shows the per cent departure rainfall for 36 meteorological sub divisions during the 2016 southwest monsoon season.

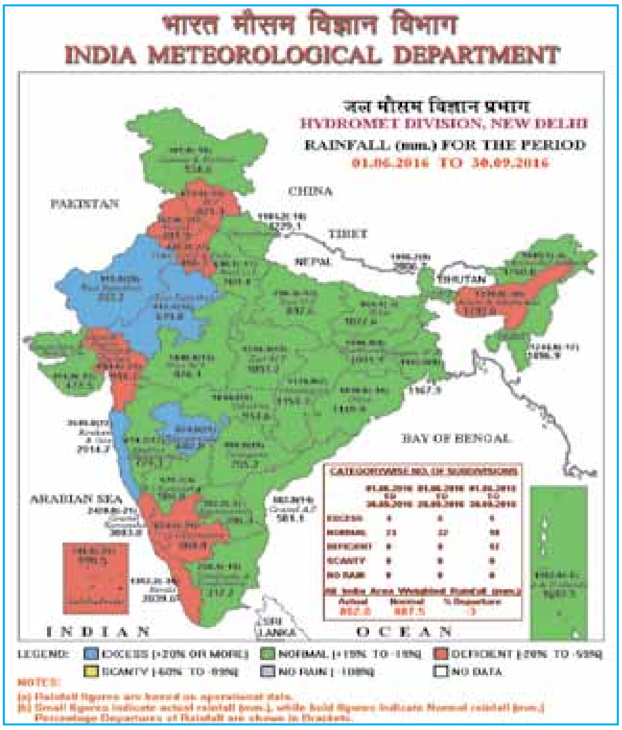


Fig. 2.12: Subdivision-wise southwest monsoon rainfall during June to September, 2016

v) **Northeast Monsoon:** The 2016 forecast of Northeast monsoon rainfall over South Peninsula was released on 21st September. The summary of forecasts is given below:

Table: Details of long range forecasts and actual rainfall

Region	Period	Forecast (% of LPA)		Actual Rainfall (% of LPA)
		22nd April	2nd June	
All India	June to September	106 ± 5	106 ± 4	97
Northwest India	June to September		108 ± 8	95
Central India	June to September		113 ± 8	106
Northeast India	June to September		94 ± 8	89
South Peninsula	June to September		113 ± 8	92
All India	July		107 ± 9	107
All India	August		104 ± 9	91
All India	August to September		107 ± 8	93

Operational forecast for the 2016 northeast monsoon season (October-December) rainfall over south Peninsula (Tamil Nadu, Coastal Andhra Pradesh, Rayalaseema, Kerala and south interior Karnataka) is most likely to be normal (90% -100% of LPA). The LPA of the North-east monsoon season rainfall over the south Peninsula for the base period 1951-2000 is 332.1 mm. However, the observed Northeast monsoon rainfall during October to December, 2016 was 35% of LPA.

vi) **Heavy rainfall events during southwest monsoon 2016:** During the monsoon 2016 season, incessant rainfall associated with the formation and movement of the monsoon low pressure systems in the presence of strong cross equatorial flow often caused flood situations over various areas during different parts of the season. No. of heavy rainfall, very heavy rainfall and extremely heavy rainfall events over different meteorological sub-divisions is shown in Fig 2.13.

2.9 Tropical Cyclone Monitoring and Prediction

There were 10 cyclonic disturbances (depressions and cyclones) over the north

(a) Heavy Rainfall (b) Very Heavy Rainfall (c) Extremely Heavy Rainfall

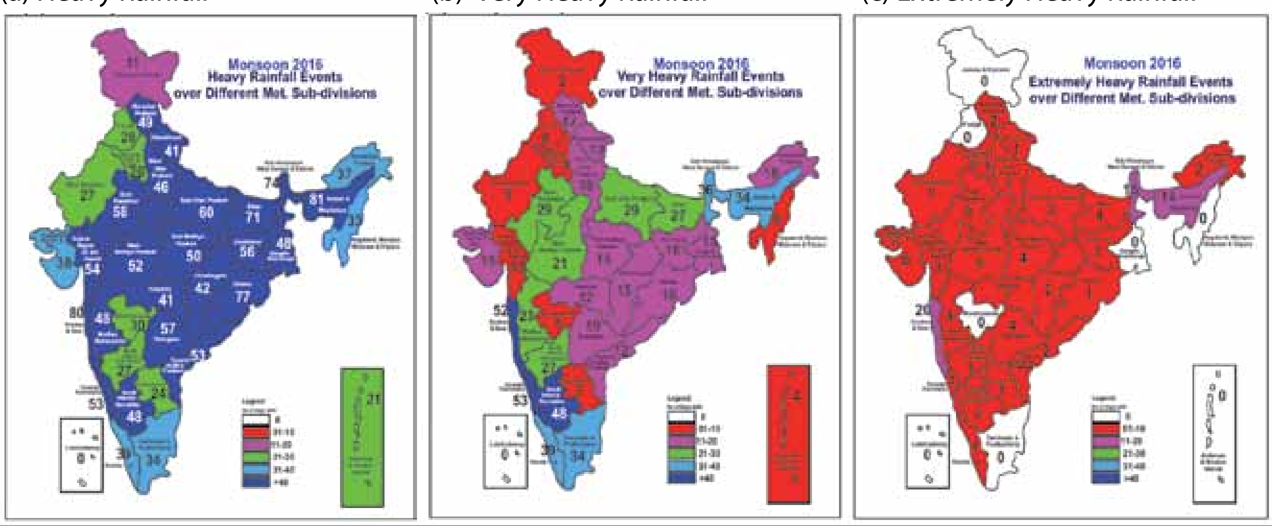


Fig. 2.13: (a) No. of heavy rainfall, (b) very heavy rainfall and (c) extremely heavy rainfall events over different meteorological sub-divisions during the monsoon season 2016.

Indian Ocean (NIO) and adjoining land regions during 2016 against the long period average (LPA) of 12 disturbances per year based on data of 1961-2015. Out of 10 CDs, 4 intensified into tropical cyclones against the normal frequency of 4.5 cyclones per year over north Indian Ocean (NIO) based on LPA. It included 3 cyclonic storms (CS) and one very severe cyclonic storm (VSCS). These cyclones are:

- ***Cyclonic storm, Roanu over Bay of Bengal (17-21 May)***
- ***Cyclonic storm, Kyant over Bay of Bengal (21-28 October)***
- ***Cyclonic storm, Nada over the Bay of Bengal (29 November-02 December)***
- ***Very severe cyclonic storm, Vardah (06-13 December)***

The cyclonic activity over the NIO was near normal during 2016. The activity during the post-monsoon and pre-monsoon seasons was also near normal with the formation of 3 and 1 cyclones during these seasons respectively. Only one cyclone (Vardah) crossed the India coast against the normal of about 2 such cyclones per year.

2.9.1 Cyclone Forecast Verification

The annual average track forecast errors in 2016 havebeen 96 km, 185 km and 292 km, respectively for 24, 48 and 72hrs against the past five year average error of 97.5, 146 and 183 km based on data of 2011-2015. The error has been higher during this year, as all the four cyclones during the year had recurving tracks. However comparing the average error of recurving tracks, the error during 2016 has been significantly less. It is reflected in the assessment of track forecast skill during 2016. The track forest skills compared to climatology and persistence forecast are 68%, 76% and 76% respectively for the 24, 48 and 72 hrs lead period which is much higher than long period average of 2011-2015 (49%, 63% & 69% respectively).

The landfall forecast error is 14 km, 127 km and 180 km for 24, 48 and 72 hrs lead period during 2016 against the average of past five years of 56 km, 93 km and 106 km during 2011-2015. The landfall time forecast error has been 3, 9 and 6.8 hrs for 24, 48 and 72 hrs lead period during 2016 against the average of past five years of 4.2, 4.7, 1.8 hrs during 2011-2015.

It can be seen from Fig 2.14 that there has been continuous improvement in forecast accuracy with decrease in landfall and track forecast errors and increase in skill over the years.

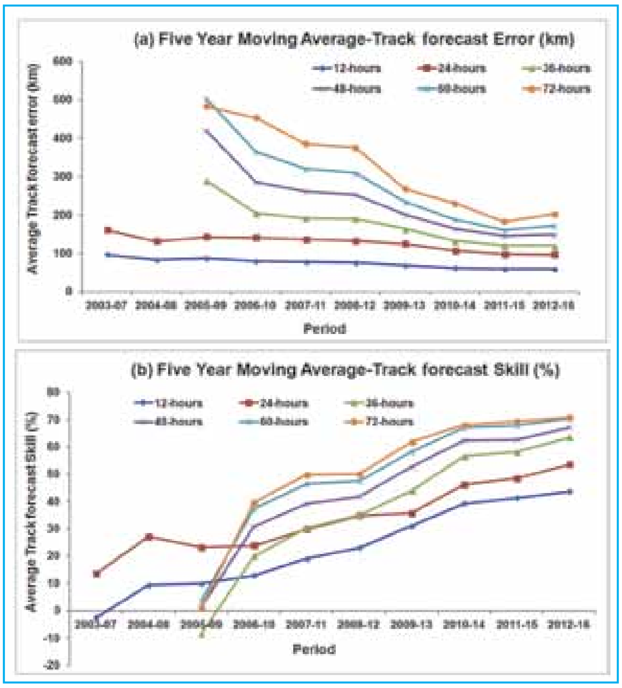


Fig. 2.14: Five Year Moving Average (a) Track Forecast Error (km) and (b) Track Forecast Skill (%) of RSMC, New Delhi over North Indian Ocean.

2.9.2 Forecast of VSCS "VARDAH"

The very severe cyclonic storm (VSCS) weakened into a SCS before crossing north Tamil Nadu coast near Chennai during 1500-

1700 hrs IST of 12th December 2016 with a wind speed of 100-110 kmph gusting to 120 kmph. The observed track of the system during 6th-13th December is presented in Fig 2.15.

With respect to the forecast performance of "VARDAH", there was almost zero error in landfall forecast issued 24 hrs before landfall

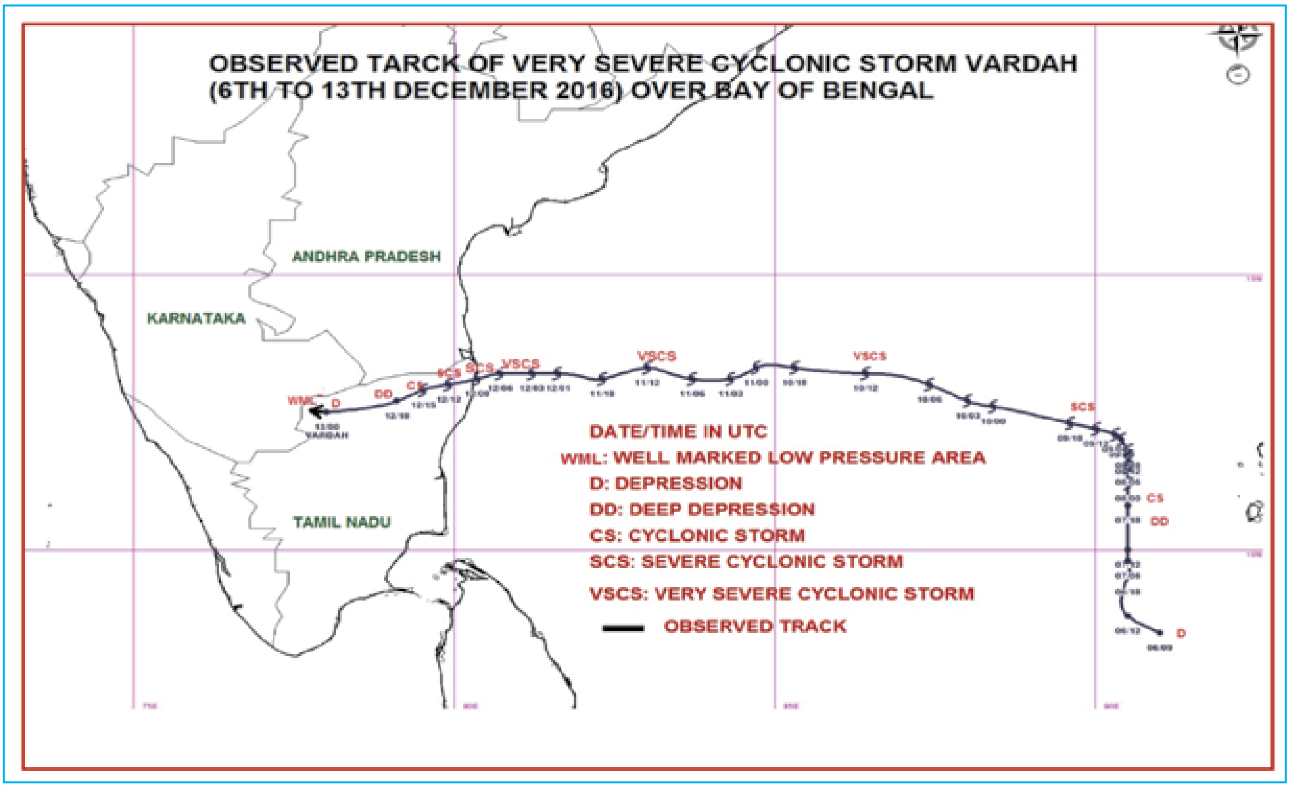


Fig. 2.15: Observed Track of VSCS Vardah during 6th to 13th December, 2016

and about 66 km in the forecast issued 36 hrs before landfall. The adverse weather like heavy rain, strong wind and storm surge were also predicted accurately for Andaman & Nicobar Islands Tamil Nadu, Puducherry, south coastal Andhra Pradesh, Rayalaseema. The track, intensity and landfall forecasts of VSCS "VARDAH" near Chennai were appreciated by disaster managers authorities, state governments, press, electronic media and general public.

2.10 Environmental Meteorology Services

Environmental meteorology services were continued to be provided to the Ministry of Environment, Forests and Climate Change. Environmental impact assessment of more than 2000 thermal power, industrial, coal and mining projects were carried out in 2016. Environmental monitoring of parameters of atmospheric environment was continued with addition of new Black Carbon Monitoring Network of 16 stations for measurement of Spectral Aerosol Absorption Coefficient and Equivalent Black Carbon Concentration.

As a part of System of Air Quality and Weather Forecasting and Research (SAFAR)-Ahmedabad, the Emission Inventory Campaign has been launched on 15 May 2016 in collaboration with Indian Institute of Public Health–Gandhinagar (IIPHG), Ahmedabad. Scientific & technical assistance was provided to Rajasthan Government in development of Air Quality MobileApp "RajVayu" for sharing information about current air quality and weather information for Jaipur, Jodhpur and Udaipur.

To understand the medium range transport of air pollutants (to and from Delhi) and quantification of the share of Stubble air quality campaign in Northern India has been organized during 25th October 2016 onwards. Several sophisticated instruments for monitoring the air quality and weather parameters have been deployed in the mobile van. The cities covered under this campaign are Chandigarh, Amritsar, Bhatinda, Rohtak, Fatehpur and Hissar.

2.11 Agro-Meteorological Advisory Services (AAS) under Gramin Krishi Mausam Seva

The Dissemination of agromet advisories to the farmers through different multi-channel system of All India Radio (AIR) and Doordarshan, private TV and radio channels, newspaper and internet, SMS and IVR (Interactive Voice Response Technology) and PPP mode etc. is being made on wider scale. At present, 19.5 million agriculture dependent households 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.

R & D projects on e-Agromet, experimental surface soil moisture estimation, downscaling of surface soil moisture using SMOS satellite data at 1 km resolution, development of standardized precipitation evapotranspiration index (SPEI) using gridded rainfall and temperature (0.25 x 0.25 degree), 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 and the crop yield forecast for different crops are prepared for communication to Mahalanobis National Crop Forecast Centre (MNCFC), Department of Agriculture & Cooperation (DAC), Ministry of Agriculture, New Delhi.

2.12 Hydro-meteorological Services

The necessary technical and operational support was provided to various Central/State Govt. organizations and other agencies in the field of Hydromet design, flood forecasting, rainfall monitoring for water management and agricultural planning purposes etc. The daily and weekly rainfall statistics for an additional 19 districts was generated from August 2016 taking the total to 660 districts for which these data are being generated. Sub-basin wise Quantitative Precipitation Forecasts (QPF) were generated using operational NWP models and uploaded on ESSO-IMD website for 146 flood prone sub-basins of India to be used as Guidance for forecasters for issuance of operational QPF for river basins. Design storm study in respect of sixteen (16) Hydraulic projects has been completed during the period Jan-Oct 2016, thereby generating a revenue of Rs 30,17,603/-.

2.13 Forecasts for Wind/Solar Energy applications

On request from National Institute of Wind Energy (NIWE), Ministry of New and Renewable Energy (MNRE), NCMRWF started sharing hourly predicted products(up to 72 hours) based on NCUM model, everyday in real time. The products include predicted downward Short-Wave Radiation Flux at surface and surface air temperature along with wind fields. These products are being experimentally used for developing forecasting system for wind and solar energy sectors. NCMRWF also started providing predicted wind data from NCUM Global and Regional models to Energon Power Resource Pvt. Ltd., for 25 locations over India.

2.14 Dissemination

IMD introduced Weather forecast & warnings dissemination service through social media in 2016 through Facebook, Twitter and You Tube.

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).

District level advisory through Meteorological Centres (MCs) and Regional Meteorological Centres (RMCs) were introduced to provide rainfall forecast in different ranges for Day 1, Day 2 & Day 3 along with actual rainfall of the day. Presently thunderstorm forecasts (3-6 hr validity) are being issued for 157 stations which would be enhanced to 197 stations by 2017.

The heat action plan is being implemented by MD in cities across central India since 2016 including Ahmedabad, Surat, Nagpur, Akola, Gondia, Chandrapur, Nanded, Jalgaon, Bhubaneswar and Cuttack. Similarly the wind Chill Temperature Application was developed and implemented w.e.f 15th February 2016 to provide the cold weather outlook.

Development of version 2 of mobile application named "Indian Weather" was completed for Android and IOS and windows OS and ready for release with addition of upto 300 cities and Nowcast warnings for Thunderstorm.

The "Severe Weather Forecast Demonstration Project (SWFDP)" was implemented with RSMC, IMD New Delhi as the regional centre to provide daily Regional Severe Weather Guidance to the member countries including Bangladesh, India, Bhutan, Nepal, Pakistan, Afghanistan, Sri Lanka and Maldives. It is a 3-tier cascading process involving various Numerical Weather Prediction (NWP) centres at global levels, RSMC New Delhi at regional levels and the National Meteorological centres of the member countries. Every day, regional guidance is being provided to member countries on dedicated webpage of SWFDP hoisted in RSMC webpage since 2nd May, 2016. For this purpose the model products available from IMD, NCMRWF, IITM and the other international centres like ECMWF and UKMO are also used in the real time.

3. OCEAN SCIENCE, TECHNOLOGY, OBSERVATIONS, RESOURCES, MODELLING FOR SERVICES (O-STORMS)

The O-STORM is one of the five rationalised schemes of the Ministry relevant to the Ocean services, research, survey and technology. The major components of the O-STORMS program are (i) Coastal Ocean Services through sustained Ocean observation networks and improvement of ocean models, (ii) marine scientific surveys for exploration and exploitation and (iii) development of technology for harnessing the marine resources. O-STORMS is primarily executed by the centres of the Ministry viz., ESSO-INCOIS, ESSO-NIOT, ESSO-ICMAM and ESSO-CMLRE and other national agencies. The details of the achievements during the year are as follows:

3.1 Coastal and Ocean Observation System, Science and Services

A suite of advisory services are provided to cater to needs of various sectors of coastal regions of India and partner maritime countries in the Indian Ocean region. This endeavor encompasses a network of Ocean Observation Systems (OOS), Ocean Information Advisory Services (O-IAS), Ocean Research and Modelling Research, Early Warning System; Ocean Research and Modeling and Marine Living Resources, and Coastal Marine Ecology, Coastal Ocean Marine Monitoring and Prediction System (COMAPS) Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER) and Geotraces.

3.1.1. Tsunami and Storm Surge Early Warning

The Indian Tsunami Early Warning Centre (ITEWC) monitored 29 earthquakes of magnitude ≥ 6.5 MW during the period 1 January - 31 October 2016 (Figure 3.1). Out of these 29 earthquakes, 2 significant earthquakes have occurred in the Indian Ocean region. These earthquakes could not generate any Tsunami and hence 'no threat' bulletins were issued for India.

INCOIS, MHA and Kerala State Emergency Operations Centre jointly conducted tsunami mock drill at Kerala Coast on 10-11 March 2016. The mock drill commenced with an alert of a 9 MW tsunami tremor that originated off the coast of Pakistan. All 9 coastal districts of Kerala had participated in the mock drill and involved various stake holders such as Navy, Coast Guard, Coastal Police, Healthcare Department, Fire and Rescue Services Department and various government agencies.

IOWave16 tsunami mock drill was also conducted during 7-8 September 2016 by IOC/UNESCO where the bulletins were issued to National and Regional contacts for two days (Sumatra and Makran events). In India, the IOWave16 tsunami mock drill was coordinated by ESSO-INCOIS with support from National Disaster Management Authority (NDMA), Ministry of Home Affairs (MHA), National Disaster Response Force (NDRF) and the Coastal States/UTs. Around 40,000 people participated in this exercise in which they were evacuated to safe places from around 350 coastal villages of 33 Districts of 8 States/ UTs during the drill. A new Decision Support System of IOTWMS with enhanced capabilities was made operational during this drill (Fig. 3.1).

Fig. 3.1: IOWave16 participation photos during 7-8 September 2016

3.1.2. Ocean State Forecast Services

ESSO-INCOIS continued to provide forecasts on ocean state for a wide spectrum of users. The Joint INCOIS-IMD Bulletins were issued during different stages of the Cyclone 'ROANU' from 17-21 May 2016 including High wave alerts/ Warnings advisories to Sri Lanka during 15-19 May 2016, and also to the Deputy Director General Meteorology, Maldives during 6 -20 May 2016. Ocean state forecasts were also provided before and during the launch day of the Re-usable Launch Vehicle Technology Demonstration (RLV-TD) of the Indian Space Research Organisation (ISRO). Wave surge forecasts were issued for West Bengal during 10-11 June 2016 and for the entire east coast of India on 19 June 2016.

On 27th July 2016, Dr. Harsh Vardhan, Hon'ble Minister of Science & Technology and Earth Sciences dedicated the Search and Rescue Aid Tool (SARAT) to the Nation during the XV National Maritime Search and Rescue (NMSAR) Board meeting (Fig.3.2). In addition, an experimental version of SARAT was used to provide Search and Rescue support to all concerned in connection with the missing AN 32 aircraft, which was reported missing off Chennai on 22 July 2016.

To facilitate the indication of eco-sensitive zones, potential fishing zones, fishing avoidance zone during the event of oil spills, the third version of the Online Oil Spill Advisory was inaugurated at the 21st National Oil Spill Disaster Contingency Plan (NOSDCP) meeting held at the India International Centre, Delhi on 5 August 2016.

3.1.3. Potential Fishing Zone (PFZ) Advisories

ESSO-INCOIS continued to provide PFZ advisories and species-specific advisories to the user community. The information is being generated and disseminated in smart map

Fig.3.2: SARAT- The Search And Rescue Aid Tool dedicated to the Nation during the XV National Maritime Search and Rescue (NMSAR) Board meeting held in VigyanBhawan, New Delhi on 27 July 2016.

and text form daily, depending on satellite data availability except during fishing-ban, or adverse sea-state alerts (Fig. 3.3).

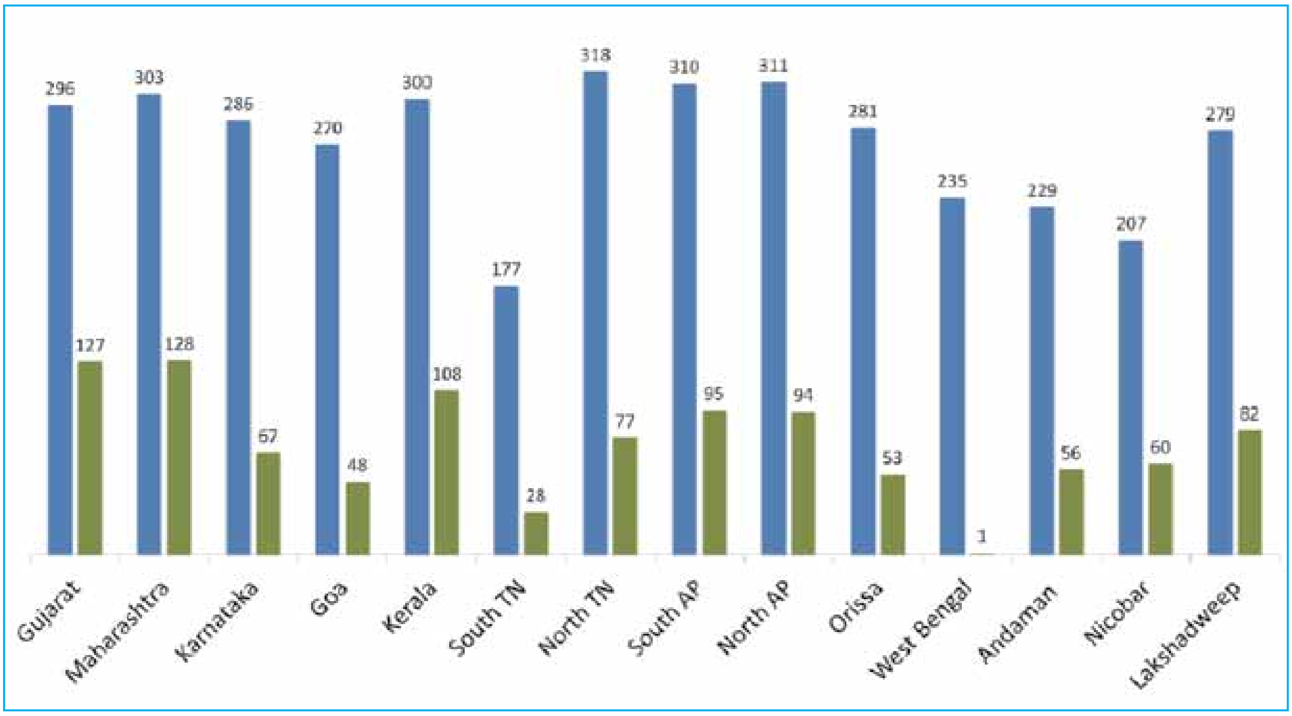


Figure 3.3: PFZ and Tuna PFZ advisory dissemination statistics for2016 (till 2 Nov 2016)

Based on the findings of Satellite telemetry experiments, Tuna PFZ advisories now include maximum fishing depth ensuring better user-experience.

ESSO-INCOIS further pursued its research initiative of mapping sites suitable for Mariculture within Indian EEZ. An atlas – envisaged as an initial decision support system – was prepared depicting overall and parameter-wise suitability, for each month and for all the coastal states. Future efforts will focus on species-specific atlases and an

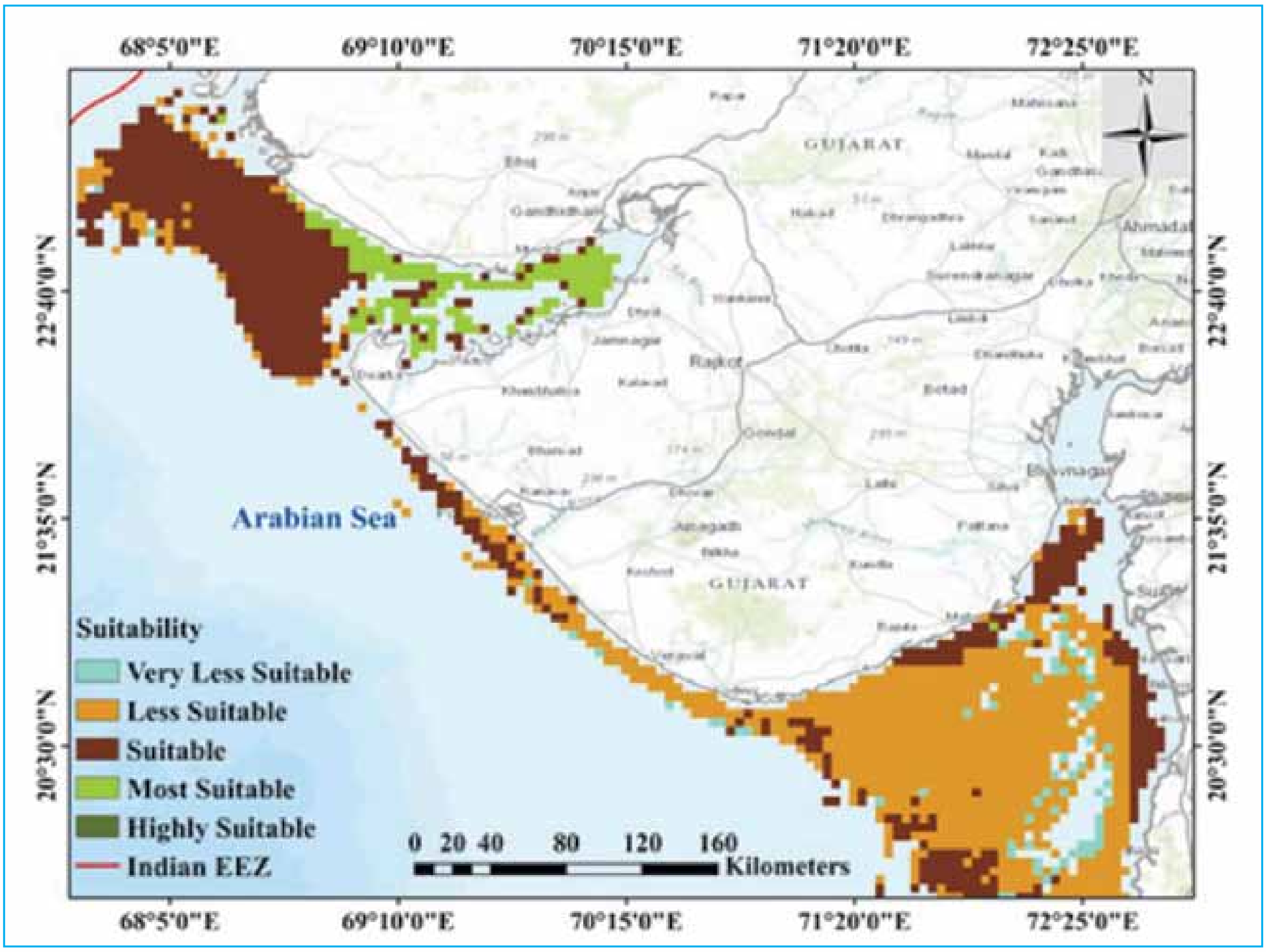


Figure 3.4: A template example of Mariculture atlas under preparation

advisory service similar to PFZ, with the help of satellite and forecast model data (Fig. 3.4).

3.1.4. Data Services of ESSO-INCOIS

As designated National Oceanographic Data Centre (NODC) by the International Oceanographic Data Exchange (IODE) Programme of the Intergovernmental Oceanographic Commission (IOC), ESSO-INCOIS continued to serve as the central repository for the oceanographic data in the country. The INCOIS data centre sustained and strengthened the real-time data reception, processing, and quality control of surface meteorological and oceanographic data. The Data centre also served the ocean science community in their various R&D endeavours by providing tailor-made data and products via request based offline data dissemination mode.

A new monthly marine meteorological climatology was prepared by combining various ship records obtained from Indian Meteorological Department (IMD), Naval Operations Data Processing Centre (NODPAC) and International Comprehensive Ocean-Atmosphere dataset (ICOADS) climatology. The IIOE-2 metadata portal was developed for the ease of search and discovery of data collected under the IIOE-2 program. The INCOIS-Live Access Server (ILAS) was updated with new data products. The notable addition was the OCM-2 data, and new AMSRE-2 data products (such as SST, rain rate, winds, water vapour, and liquid water). The data centre continued to augment both meteorological and upper ocean data obtained from the 12 active NIOT OMNI buoys.

3.2 Ocean Observation Systems (OOS)

The Ministry has a comprehensive ocean observational 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. The details of observations systems deployed, operated, maintained and supported by India and their current status are as follows:

3.2.1. Moored Ocean Observing Network: (MOON)

The MOON is a major program encompasses (i) Ocean Moored buoy Network in the Indian Ocean (OMNI) (ii) Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) (iii) Current Meter Array, (iv) Wave Rider Buoys, (v) Acoustic Doppler Current Meter Profiler (ADCP).

Ocean Moored buoy Network in the Indian Ocean (OMNI) has been systematically maintaining the twelve deep sea buoy systems

Table 3.1: Status of Observation Systems operational during the year

Name of Platform	Target	Commissioned till December, 2016	Data received during October, 2016	Parameters	Type of platform
Argo Float	200	280	132*	Temperature and salinity profiles upto 2000 m	Drifting
Drifters	150	98	16*	Surface Temperature, pressure, currents	Drifting
Moored Buoys	16	19	17	Upto 25 surface meteorological and upper oceanographic parameters including waves, winds, temperature, salinity, currents	Moored
Tide Gauges	36	30	18	Sea level data	Moored
High Frequency(HF) Radars	10	10	8	Surface Currents, and waves	Moored
Current Meter Array	10	11	5	Current profiles in the deep sea	Moored
Acoustic Doppler Current Profiler(ADCP)	20	21	18	Subsurface currents	Moored
Tsunami Buoys	7	9	5	Tsunami waves	Moored
Wave Rider Buoy	16	15	15	Surface waves	Moored

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

with surface & subsurface sensors, four coastal buoys and seven tsunami buoys as envisaged under the XII five year plan (Fig. 3.5). During the reporting period 14 cruises were conducted to carry out 41 deployments/retrievals. Over 172 ship days were utilized to cover a distance of 11,800 nm, for completing the task including deployment of SAIC Tsunami buoy systems in May-June 2016 and the Indo-UK cruise under the Bay of Bengal Boundary Layer Experiment (BOBBLE) programme in July 2016. The buoy systems deployed in the Bay of Bengal captured the signals of cyclone Roanu in May 2016.

Cyclone parameters measured by Buoy systems in BoB (Cyclone Roanu in May 2016)

Cyclone Roanu, the first tropical cyclone of the year 2016, made landfall near Chittagong, Bangladesh on 22 May 2016. OMNI buoys deployed in the Bay of Bengal have captured the signals of the passage of the cyclone, ROANU. The buoys BD11, BD10, BD09 and BD08 were close to the track, while BD13 was away from the track. The coastal buoy CB06 has also recorded the passage of the cyclone ROANU. The variations of meteorological parameters recorded by the buoy systems during the cyclone period are shown in Fig 3.6.

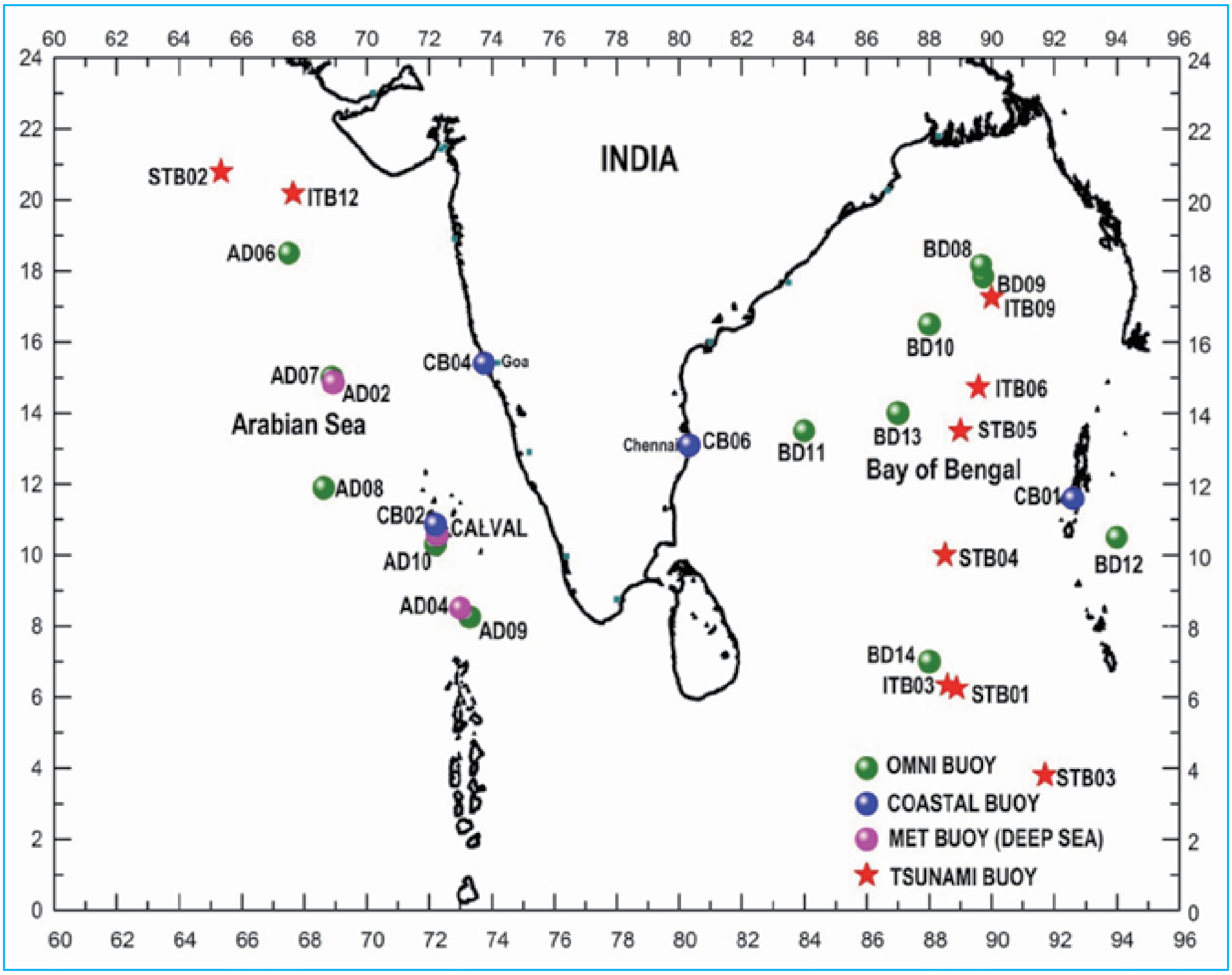


Fig3.5: Moored Buoy Network

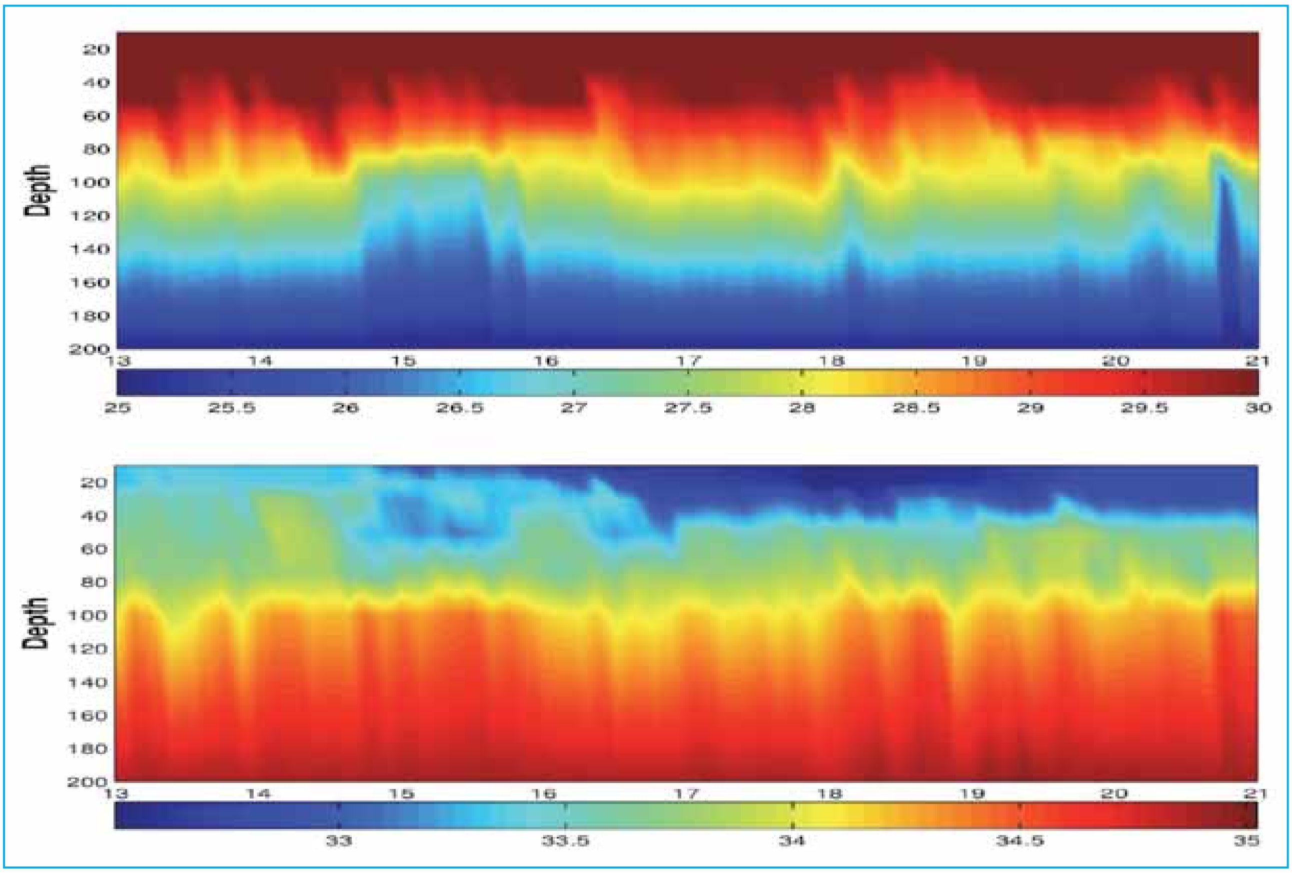


Fig 3.6: Vertical profiles of (a) temperature in °C and salinity in PSU recorded by the buoy BD11 during the passage of cyclone during May 2016

3.2.2. Arctic Observation–IndARC III Mooring

The first Indian Arctic mooring (IndARC-1) was deployed in Polar Waters on 23rd July 2014 with the support of ESSO-NCAOR. The Indian Arctic mooring (IndARC-II) was retrieved on 26th July 2016, following which IndARC III was re-deployed successfully on 27th July 2016. IndARC-II collected more than 116 parameters and worked continuously for 373 days in the Arctic waters. A paper titled "Indian Moored buoy observatory in the Arctic for long term in situ data collection" has been published in International Journal of Ocean and Climate sciences.

3.2.3. Ocean Mixing and Monsoon (OMM) program

Four ship cruises were conducted in the Bay of Bengal during 2016 to study the Ocean Mixing and monsoon process, under the Monsoon Mission. A number of state-of-the art instruments such as underway CTD (nearly 806 profiles of temperature and salinity from

Fig. 3.7: IndARC-III Mooring deployment

top 150 metres), current measurements from pole mounted Acoustic Doppler Current Profilers (500kHz), ship mounted Automatic Weather Stations, ASIMET system, etc. were operated during these cruises. A WHOI mooring deployed during 2014 was recovered in a cruise on board Sagar Kanya. Two cruises were conducted on board Sagar Manjusha to deploy and recover Lagrangian floats and EM APEX Floats.

The data collected under these field campaigns provided new insights on the Bay of Bengal mixing and air-sea interaction process in the near surface layer, which has led to 22 publications in a special issue of Oceanography Magazine (Vol 29, June-2016; Title: Bay of Bengal: From Monsoons to Mixing).

3.2.4. Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA)

To augment and maintain the RAMA array, two cruises were conducted in the equatorial Indian Ocean during 2016 on board Sagar Kanya. (13 February-14 March, 2016 (31 days) in the Bay of Bengal and 23 August-26 September, 2016 (35 days). A total of 12 RAMA moorings were serviced in the past one year. At present 78% (36 out of 46) of the RAMA mooring array sites are occupied. Two cruises are expected to be conducted in the next six months (35 days cruise in the equatorial Indian Ocean and 16 days cruise in the Bay of Bengal during 2017) (Fig. 3.8).

RAMA data are being significantly used for ocean data assimilation (INCOIS-GODAS and HYCOM at INCOIS), validation of Ocean Model Outputs (ROMS, HYCOM, GODAS and ecosystem model at INCOIS), validation of satellite parameter (SST and Sea surface salinity), to generate bias corrected ocean model forcing field (Tropflux), to understand spatio-temporal variability of thermohaline structure and air-sea interaction process in the Indian Ocean. So far, more than 86 research publications from this project.

As a part of augmentation of observations in the Indian Ocean, CSIR -National Institute of Oceanography (NIO) have resulted Goa expanded the current meter mooring network along the Indian coasts from 10 moorings to 18 moorings as of September 2016. In 2016, NIO recovered and redeployed 5 moorings in the west coast and 11 along the east coast. NIO, Goa also maintained 5 active deep-sea current

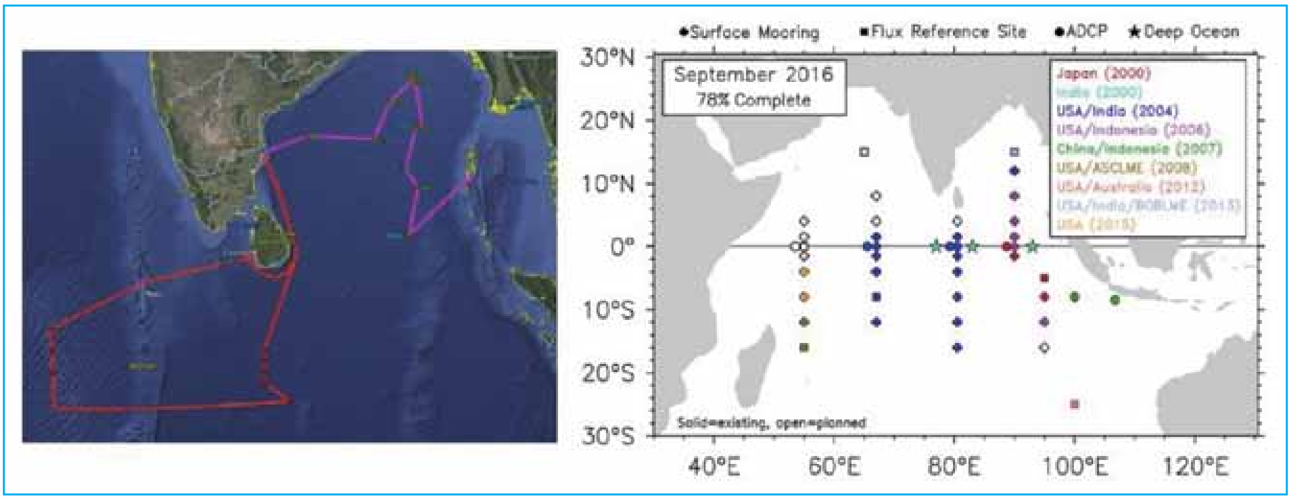


Figure 3.8: (Left) Cruise tracks of the two Sagar Kanya cruises undertaken in 2016 as part of the RAMA program. (Right) The present status of the RAMA array in the Indian Ocean.

meter moorings in the Equatorial Indian Ocean during 2016 with an objective of measuring the equatorial Indian Ocean current system.

In 2016, INCOIS deployed 23 ARGO floats in the Indian Ocean having sensors to collect the physical parameters, of which 11 were equipped with additional biogeochemical sensors. Currently, over 732 active floats are actively working in the Indian Ocean of which 136 were deployed by India. So far, more than 340856 temperature and salinity profiles, 18993 dissolved oxygen and 7614 Chlorophyll profiles were collected by Argo floats in the Indian regions (Fig. 3.9).

Under the Indian XBT program, XBT / XCTD data are collected on monthly intervals along Chennai - Port Blair, Port Blair - Kolkata and Kochi - Kavaratti. During in 2016, 131 vertical temperature profiles (XBTs), 125 vertical temperature / salinity (XCTDs) profiles and 1385 sea surface water samples for the analysis of salinity were collected.

During 2016, CSIR-NIO deployed 20 drifters in the Indian Ocean. Surface current climatology for the Indian Ocean at 0.5° x 0.5° is created using all the available drifter data. More than 50% of the data available are from undrogued drifters.

ESSO-INCOIS is maintaining a network of 7 tsunami buoys, deployed close to the tsunamigenic source regions in Bay of Bengal and Arabian Sea in collaboration with National Institute of Ocean Technology (NIOT), Chennai. In addition to these buoys, real-time data from around 50 tsunami buoys operated by other countries in Indian and Pacific Oceans are also received at ITEWS and the data were made available on the tsunami website (www.tsunami.incois.gov.in). Recently, 4 new SAIC Tsunami Buoys (STBs) were deployed on board ORV Sagar Kanya during May-June 2016 in the Bay of Bengal.

A network of 31 state-of-the-art Tide gauge stations have been established at strategic

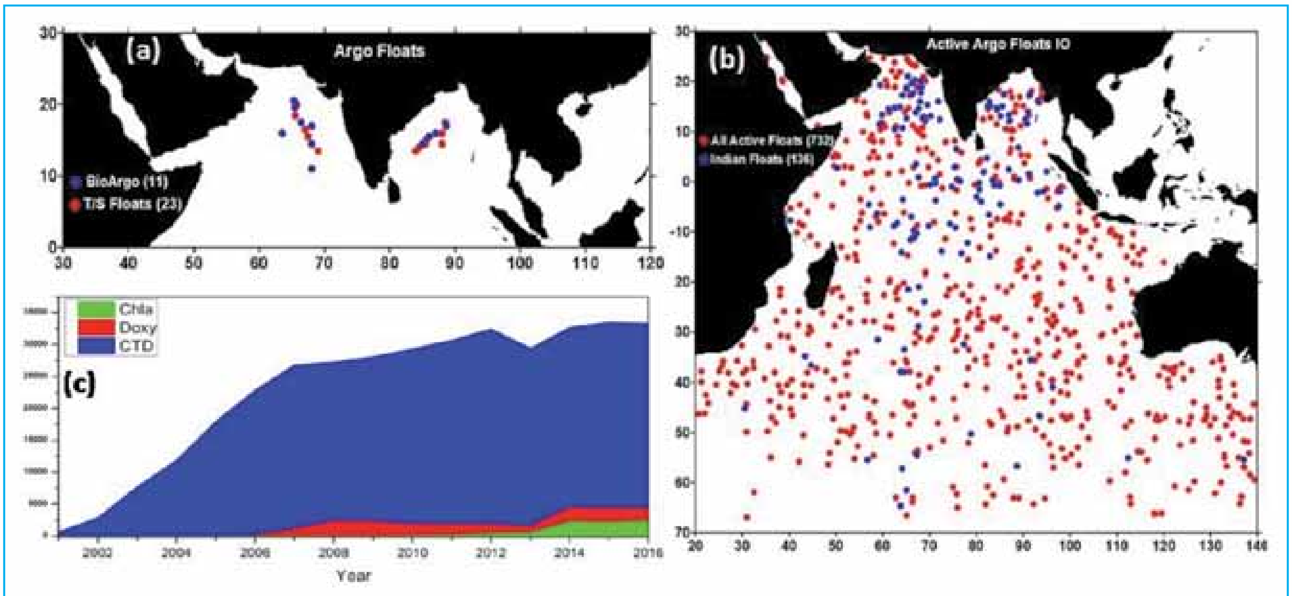


Figure 3.9: (a) Total number of floats deployed by India since 1 January 2016. Blue dots indicate Bio Argo floats and red dots indicate standard T/S floats. (b) Total Active floats in the Indian Ocean. Red dots indicate all active floats deployed by other countries while blue dots indicate all active floats deployed by India. (c) Yearly progress of Argo floats profiles in the Indian Ocean. Blue indicates CTD profiles, red indicates Dissolved oxygen profiles and green indicates chlorophyll profiles. X-axis represents number of profiles

locations along the coasts of Indian mainland and Islands to monitor the progress of tsunami waves and also for validation of the model results. In addition, the centre is also receiving data from around 300 international tide gauges in near real-time which were operated by other countries and the same data is made available on tsunami website. A new wave rider buoy was deployed off Versova, Mumbai during the month of June, 2016. With this new deployment, a network of 15 wave rider buoy has been established in the Indian Ocean region. Two drifted buoys were also tracked, retrieved and redeployed at Gopalpur and Tuticorin.

As part of the 'Integrated Ocean Information System' for the Indian Ocean Countries, ESSO-INCOIS successfully deployed a Wave Rider Buoy, 27 Nautical Miles off a fishing harbour at Frigate Island, Seychelles on 16 March 2016, for better ocean state forecasting for Seychelles. The buoy deployment was accomplished in coordination with Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) and the Seychelles National Meteorological Services (SNMS). To maintain Coastal HF Radar Network along the Indian Coast to measure near-shore ocean surface circulation and to receive real time data at NIOT and INCOIS. The network includes ten numbers (5 pairs) of HF Radar Remote Stations and two Central Stations (NIOT and INCOIS).

3.3. Ocean Modeling:

3.3.1. Ocean Modeling and Data Assimilation

ESSO-INCOIS continued to provide ocean analysis using the Global Ocean Data Assimilation System (GODAS). Several in situ as well remote sensing data are being assimilated using 3D-VAR technique to the GODAS system. Data assimilation scheme based on the Localized Ensemble Transform Kalman Filter (LETKF) is integrated with the global setup of Modular Ocean Model (MOM) and LETKF setup with Regional Ocean Modeling System (ROMS) is being tested.

Statistical validations of ecosystem parameters simulated by the ROMS model shows that the model is capable of simulating the variability of these parameters quite realistically, though there are some difficulties for the model to simulate their magnitude accurately. High resolution setups of ROMS for the coastal waters around India are now being integrated with the ecosystem module.

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 system for the Bay of Bengal is now setup and the statistical validations of the simulations were carried out.

Simulations of wave parameters by the Wavewatch III model for the open ocean has been validated with in-situ observations from wave height meters installed in the moored buoys. The analysis of the results shows that the model has a very good skill in simulating the wave parameters for the Indian Ocean domain.

3.3.2. Upgradation of GODAS with MOM4p1

INCOIS-GODAS is now upgraded into the latest MOM4p1 version base model, and presently running in semi-operational mode. The newer version of GODAS improves upon the older version both in simulating the sea surface temperature and surface currents.

24 locations data are provided to all the coastal States and Central Pollution Control Board (CPCB). These data are invaluable in assessing the health of Indian marine environment and indicate areas that need immediate and long-term action. A pilot study for Chennai coast is in progress to predict the likely changes in water quality parameters based on real-time

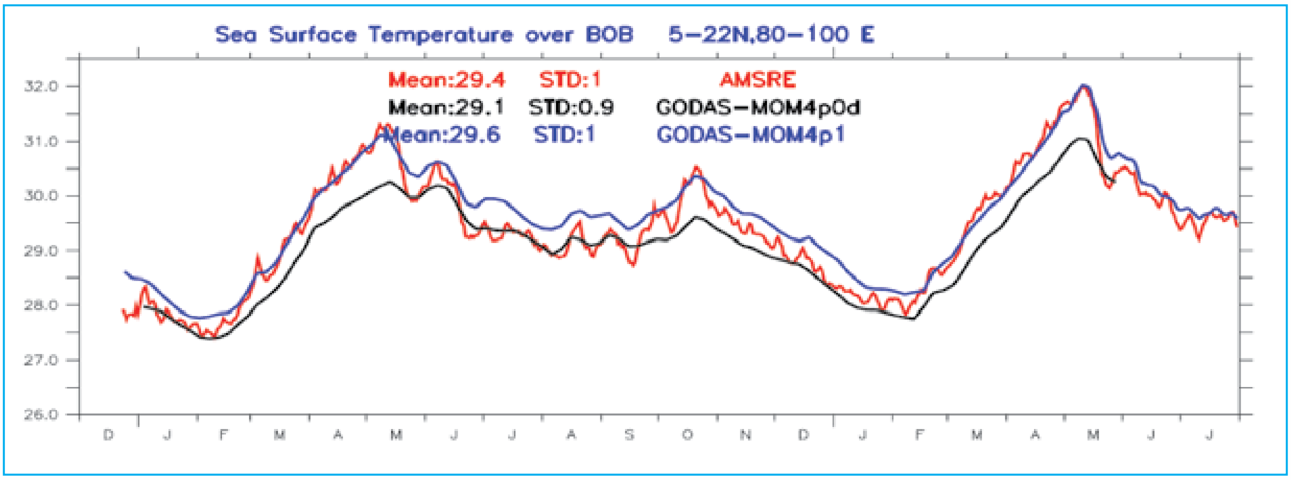


Figure 3.10: Time series of GODAS SST comparison with independent AMSRE observation over Bay of Bengal during January 2015 to July 2016.

3.4. Coastal Research

The coastal research primarily deals with four specific multi-disciplinary areas viz., coastal pollution, coastal processes, coastal vulnerability and coastal ecosystems, with a view to provide scientifically-informed inputs to the decision makers and public for the better utilization and management of coastal areas.

3.4.1 Coastal pollution - Sea Water Quality Monitoring along Indian Coast

The multi temporal and spatial data on coastal pollution and water quality are being collected in the coastal waters of India (started as the COMAPS programme in 1991) for the past 25 years. This is probably the only baseline data available in the country to study the long term pollution trend in coastal waters. The data on environmental parameters being collected at

observation. It is proposed to extend similar program to other coastal cities of the country.

Water quality parameters for 36 locations along 30 km of Chennai coastline are being monitored since January 2013. Water quality index map for Chennai coastal waters based on monthly water quality indicative parameters *viz.,* DO, BOD, pH, change in temperature, turbidity, total phosphorous, nitrate and E. Coli, infer most of the coastal water falls under "BAD" category (Fig 3.11).

Sea Water Quality Criteria (SWQC) for heavy metals have been prescribed for limiting the pollution levels to protect the marine organisms and being considered by MoEF for notification in the Environment Protection Act (1985) amended in 1998.

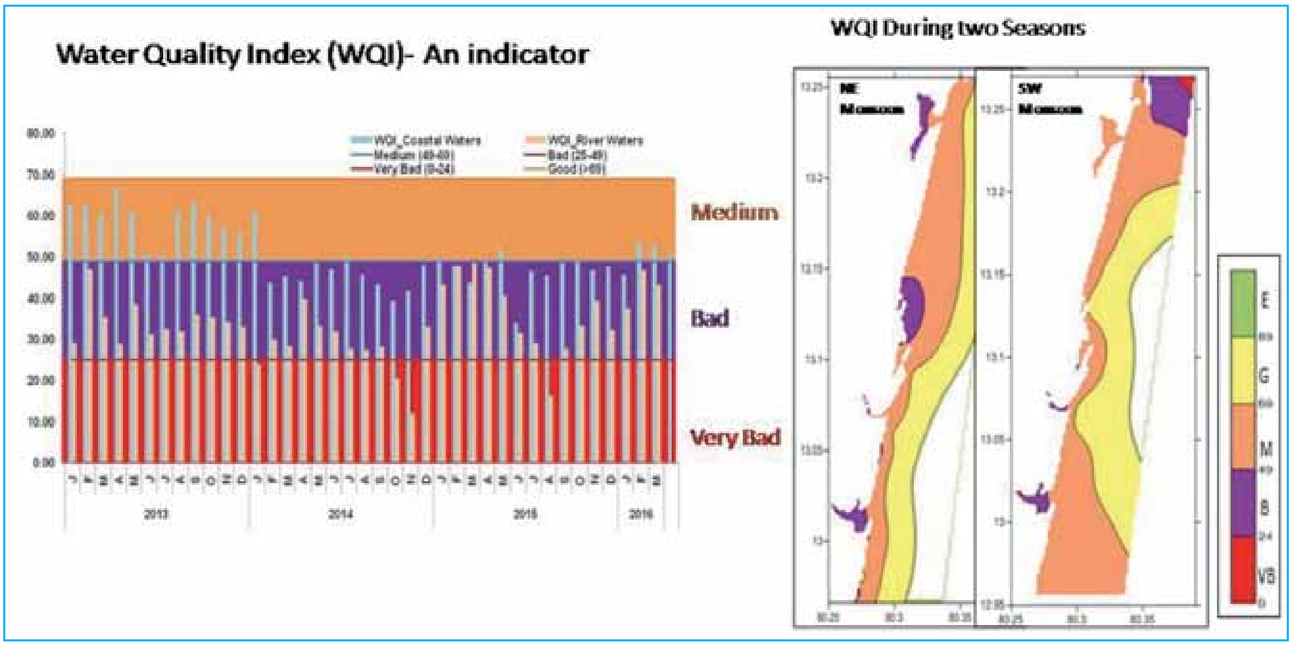


Figure 3.11: Seasonal variation of Water Quality Index for Chennai coast.

3.4.2 Coastal processes

Regular monitoring of shoreline and its spatial and temporal trends are required to address the coastal erosion and management related aspects. The shoreline changes, its behavior, erosion, accretion status and related morphological characteristics of Indian coast is being monitored as baseline data using remote sensing, field and mathematical modeling and GIS tools. In 2016-17, a study was carried out for 5908 km long mainland coastline and 517 maps at 1:25,000 scales were generated depicting shoreline changes using 8 data sets i.e. LANDSAT5 (1990), LANDSAT7 (2000), CARTOSAT-1 (2008), LISS-III (2008), LISS-IV (2012,13,14,15) to compute the shoreline changes for 1990-2015. The analysis of last 25 years data suggests that about 38.5%, 32.5% and 29% of the coasts are eroding, accreting and stable nature, A web based coastal service on shoreline change is developed to disseminate the information to all stakeholders using public domain tools i.e. GEO-Server. The overall shoreline changes of Indian coastal are given in Table 3.2.

3.4.3. Coastal vulnerability

At the behest of United Nations Development Programme (UNDP), the biophysical vulnerability of coastal areas to climate change was carried out. The work was to develop an integrated approach coupling geospatial tools, field survey and coastal models to assess the biophysical vulnerability of three coastal states namely Andhra Pradesh, Odisha and Maharashtra. The coastal vulnerability index (CVI) for every 1Km of the coastal stretch was calculated for different scenarios (with and without habitats, varying SLR conditions) to identify the highly vulnerable coastal stretches. Based on model outputs, coastal stretches with high CVI were identified for coastal protection measures which could be either through eco-restoration, eco-conservation (Green options) or eco-engineering (hybrid options) (Fig. 3.12).

Table 3.2 State-wise erosion and accretion pattern of the entire Indian coast

Sl. No	State	Coastal Districts	Coastal Length (km)	Erosion		Stable		Accretion	
				(%)	Km	(%)	Km	(%)	Km
1	Tamil Nadu	13	972	43	434	31	302	26	237
2	Puducherry	2	41.3	70	29	22	09	08	03
2	Andhra	9	978	32	320	18	180	50	478
3	Odisha	6	474	32	147	11	52	57	275
4	West Bengal*	3	422	67	283	10	41	23	98
5	Kerala	9	542	36	191	28	153	36	198
6	Karnataka	3	282	29	79	29	131	42	72
7	Goa	2	58	42	24	22	13	36	21
8	Maharashtra	5	734	53	187	21	458	26	89
9	Gujarat**	15	1404	41	579	27	379	32	447
	Total		**5908**		**2273**		**1718**		**1918**

* Including Islands, ** Including Daman & Diu

3.4.4. Coastal ecosystems

To understand the biogeochemical processes and to develop an ecosystem model for the coastal waters of Cochin periodic sampling is being conducted along five transects with 25 locations within the 50m depth contour. The generated physical and biogeochemical data are being utilized for the simulation of hydrodynamics, water quality, nutrients and chlorophyll through a processes response physical-biogeochemical coupled model. The 3-dimensional distribution of dissolved oxygen (DO) and Chlorophyll in the water column has been simulated. The surface chlorophyll distribution showed a higher concentration in the northern region compared to the southern region. The primary production along the Cochin coastal waters during the monsoon season was found to be ~ 2.4 and 1.4 times higher than that of post- and pre-monsoon respectively. The coastal waters of Cochin act as a significant contributor for the emission of carbon dioxide throughout the year to the atmosphere. Over a decade there has been an increase of 15% of pCO_2 from the reported values from the central and coastal Arabian Sea. The marine invertebrate based indices calculated for the coastal waters of Cochin indicated relatively 'poor to moderate' Ecological Quality status in the inner shelf and 'good to high' in the mid-shelf region. The poor ecological status in the inner shelf is due to trawling, urban sewage and dredging.

3.5. 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.

3.5.1. Monitoring and Modelling of Marine Ecosystems (MMME)

Studies conducted to elucidate the changes in the planktonic community associated with

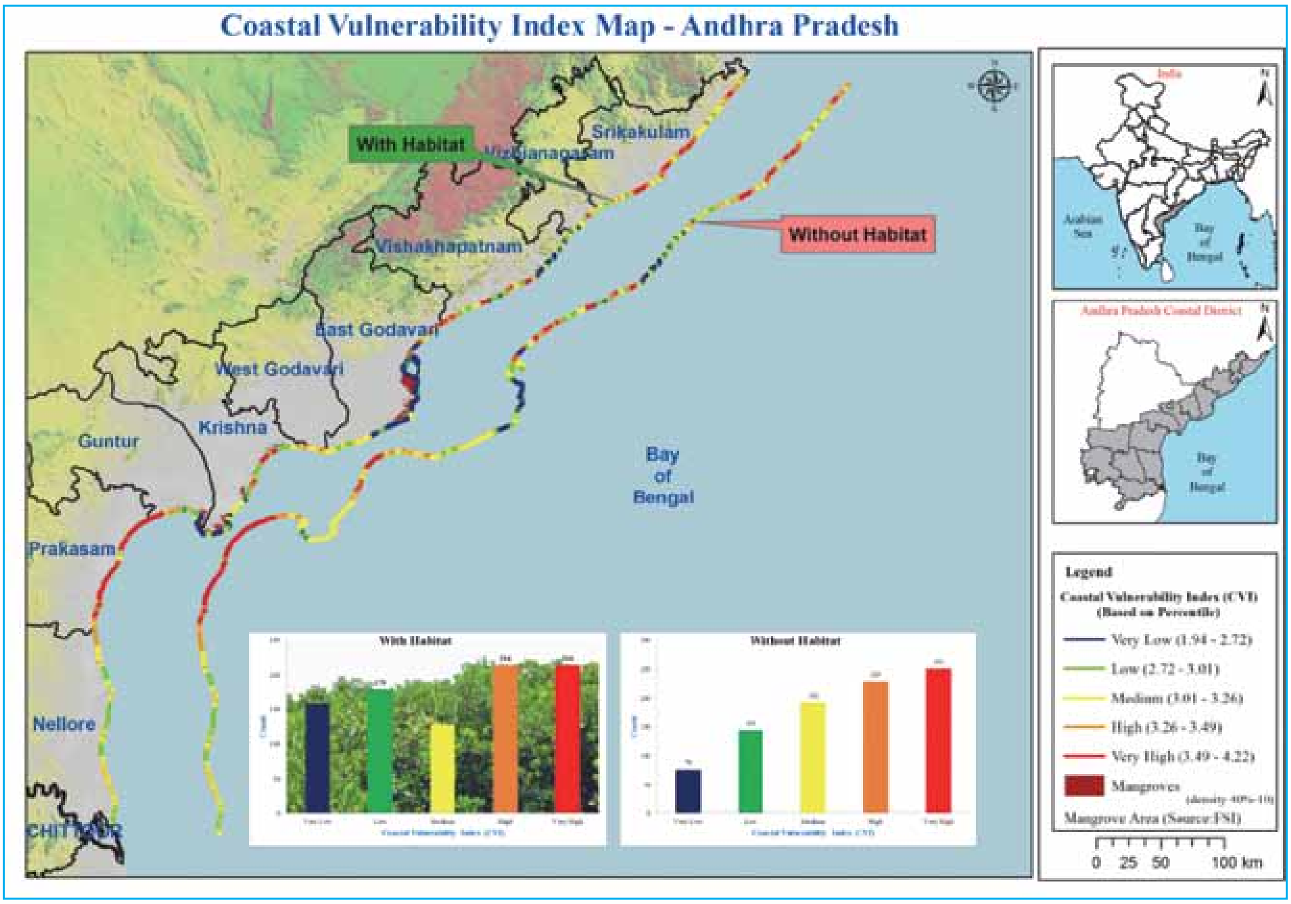


Fig. 3.12: Biophysical vulnerability of Andhra Pradesh coast

summer monsoon coastal upwelling along the South East Arabian Sea (SEAS), in response to varying climatic events like ENSO/IOD etc showed that delay in the onset of upwelling during the strong El Niño year of 2015 compared to 2009, coincided with less number of non-copepod taxa and increased abundance of active predators like chaetognatha. The mesozooplankton community and copepod species assemblage showed intra seasonal variation during summer monsoon with significant change in the copepod species assemblage (*Calanidae* during onset of Summer Monsoon and *Paracalanidae* during peak phase of Summer Monsoon). Low abundance of *Temoraturbinata* as an indicator of upwelling was noticed, showing a shift in the planktonic community. Cataloguing the larval forms of small coastal pelagic (*Sardinellalongiceps, Rastrelligerkanagurta, Stolephorscommersonnii*) were done on the basis of survey from 151 stations along the SEAS.

3.5.2. *Deep-Sea and Distant Water Fishery (DSDWF)*

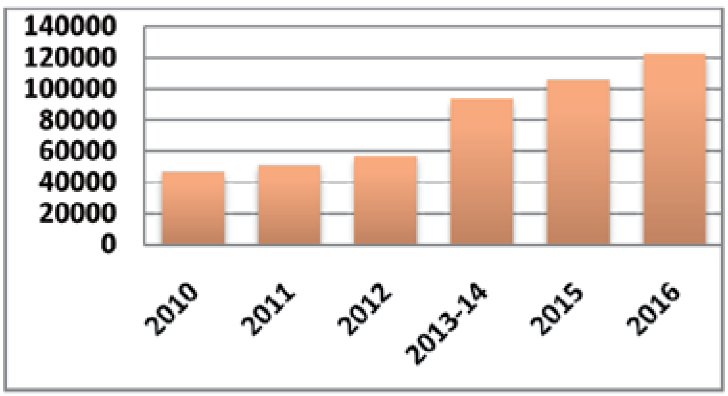
During the period, 2 deep sea fishery cruises were conducted, one each in the South Eastern Arabian Sea and Andaman waters. A total of 12 bottom trawl operations were carried out (4 in Andaman waters, 8 in SEAS). Three new grounds were identified from the Andaman Islands between the Latitude 12 to 12.5° and Longitude 92.4° to 93.1. (Depth 200 to 600 m; average CPUE-200 kg). The catch composition was dominated by finfishes (68%), followed by crustaceans (17%), elasmobranchs (6%) and others (6)%. 14 news reports of deep sea fishes were documented. Elliptic Fourier analysis was performed to understand the inter-intra species shape variability of otolith with respect to the species and stock of the deep sea fishes of genus *Hoplostethus*. Two international cruises wereconducted (Central Indian Ocean and Northern Arabian Sea) to study the Myctophid resources and 10 new records of myctophid fishes were observed from the Indian waters.

3.5.3. Indian Ocean Biogeographic Information System (IndOBIS)

During the period, over 20,000 occurrence records of marine organisms from the Northern Indian Ocean region were collected, subjected to quality control and added to the existing database, updating the total number of records to 1,25,000. These records are currently accessible at the website, www.iobis.org. A species of mushroom soft coral, *Anthomastus* sp. nov. (Phylum: Cnidaria, Class: Anthozoa, Subclass: Octocorallia), collected from Andaman Sea has been identified as new to science. A new record of polychaetes swarm collected from 500m depth off Vizag, (Latitude 17°09.535′N and Longitude 83°24.116′E) has been identified as *Treadwelliusbifidus*Fauvel, 1932. The detailed biological studies revealed that large aggregation might be attributed to its spawning period. 221 voucher specimens were added to the existing collection maintained in FORV Referral Centre updating the total number of voucher specimens to 1131. Many of these collections are rare and new records to the Northern Indian Ocean and are being described for the first time from the Indian EEZ (Fig. 3.13).

3.5.4. Technology Development on MLR (MLR-TD)

Under MLR-TD programme, a Field Research Station on marine ornamental fish production has been functioning at Agatti, Lakshadweep since 2009. The Centre maintains different



Anthomastus sp. nov.

Treadwellius bifidus Fauvel, 1932

Eggs inside the abdomen of females

Fig. 3.13: Record of marine organisms in the Indian Ocean

variety of ornamental fishes for spawning and rearing experiments apart from clown and damsel fishes whose breeding has been perfected. Presently, around 800 -1000 nos of juveniles of different species of clowns in the size range 3-3.5cm are produced within a period of 3 months. Hatchery produced fish juveniles are given to the Islanders Society-MAFTA (Marine Aqua-tech Fish Farmers Association) as part of alternate livelihood programme. As part of biodiversity surveys in Lakshadweep waters, 2 new species each of crab, polychaete worm and nudibranch, and several new records of shrimps, squids, and other marine organisms have been documented.

3.5.5. FORV Sagar Sampada

During the period, FORV Sagar Sampada undertook four cruises in the Arabian Sea, Andaman Water and Bay of Bengal with a total of 75 days out at sea. The vessel was utilized by Kerala University for Fisheries and Ocean Studies (KUFOS), Cochin University of Science and Technology and CMLRE to undertake the various activities of Marine Living Resources Program (MLRP) carried out by CMLRE. The major studies undertaken were on Deep Sea Demersal Fishery & Integrated Taxonomic Information System, Indian Ocean Bio – geographic Information system & Census of Marine Life, Harmful algal Bloom (HAB) and Benthic Productivity, Gelatinous zooplankton and Mesoscale eddy.

3.6. Biogeochemistry (SIBER):

The main objective of the proposed *Sustained* Indian Ocean Biogeochemical and Ecological Research (SIBER) national programme was to establish long-term observation platforms - one each within the core of the OMZ in the Arabian Sea (Lat. 17°N, Long. 68°E; Arabian Sea Time series; ASTS) and at the site of INCOIS's Bay of Bengal Observatory (Lat. 18°N, Long. 89°E; Bay of Bengal Time Series; BoBTS) - for regular visits by research ships and deployment of sediment traps and other moorings. The aim is to carry out multi-disciplinary research at fixed sites covering, core physical, chemical and biological parameters.

During the year 2015-16, both ASTS and BOBTS have been sampled twice using research vessels RV Sindhu Sankalp and RV Sindhu Sadhana. In addition to the open ocean time series sites, observations were also being carried out at the Candolim Time Series site (CaTS) located off Goa. In 2015-16, both The Mandovi and Zuari estuary were sampled 5 times covering different seasons during 2015-16.

3.6.1. International Study of marine biogeochemical cycles of Trace Elements and their isotopes: GEOTRACES (India):

Towards understanding the trace elements and isotope biogeochemistry in the Indian Ocean a total of 4 major expeditions were undertaken in the Indian Ocean. Successful installation and operation of clean seawater sampling on board research vessel has been a major accomplished to study isotopes as tracers of water masses in the Indian Ocean, which had improved the measurement capability to determine dissolved concentration of Fe in seawater for the first time paving way and determined to study its sources, sinks, internal cycling and impact on the biogeochemistry of the India ocean and implications to carbon cycle.

3.7. Ocean Technology

Development of technology is an essential prerequisite for sustainable harnessing of ocean resources and is pursued by National Institute of ocean technology, an autonomous institute under the Ministry of Earth Sciences (MoES). The significant developments are enumerated below:

3.7.1. Andaman coral reef exploration using Polar/Shallow water Remotely Operated Vehicle

The Andaman and Nicobar Islands of India are hot spots of biodiversity with their unique coral reef bio-reserve which are prone to periodical bleaching due to global warming. For the first time in India, indigenously developed Remotely Operated Vehicle (PROVe) was deployed during March – April 2016 in the Andaman Sea (North Bay and Chidiyatopu) and the Bay of Bengal (Jolly Buoy, Grub Island and Red Skin Island) Islands up to a depth of 30 m. Under water visuals had shown the coral debris and boulders caused by the 2004 Tsunami. The rejuvenation of the coral reef colonies like branching corals, stony coral, brain coral at different areas of the study region were recorded in the ROV (Fig 3.14).

3.7.2. Integrated Mining System for Mining Polymetallic Nodules from 6000 M Depth

Development of the Integrated Mining System (IMS) for mining the Polymetallic Nodules from 5400 metre water depth in the Central Indian Ocean Basin (CIOB) area allotted by International Sea Bed Authority (ISA) reached an advanced stage of development, with module level tests being pursued and design configuration of the deep water sea bed mining machine (MM) and the high pressure pumping frame (PF) being formalized. The Mining Machine equipped with a sea bed locomotion system comprises nodule collecting and conveying system, nodule crusher and a lift pump to pump crushed nodule slurry to the Pump Frame.

Presently, module levels tests and sea trials are planned in maturing of the composite system for reliability and safety. Pilot mining demonstration is tentatively planned in 2018-19.

3.7.3. Manned Submersible

Manned submersible personnel sphere simulator model with 2.1 m diameter is designed in-house with the capability for housing 3 personnel inside. The simulator is fabricated using mild steel material with provision for motion in multiple degrees of freedom.

Fig. 3.14: Photographs of Corals taken using PROVe

Fig 3.15: Schematic of the Integrated Mining System & Skid for testing positive displacement pump

3.8. Coastal Engineering

3.8.1 Engineering Investigations for the 'Kalpasar' Project of Government of Gujarat:

During the year, wave model is revised with latest version of swan code. Simplification of Sediment transport model is carried out and validated for spring climate. Reservoir sediment flushing studies were carried out for efficiency.

3.8.2 Design of the Offshore reef with beach nourishment for coastal protection at Puducherry:

Design Beach profiles for nourishment were arrived based on site specific conditions. Requirement of 1.0 million m^3 of sand identified for nourishment. Various configurations of structures are studied to increase life of nourished beach while minimizing erosion effects on north side. Design for a Hybrid Solution was arrived in consultation with an international consultant. The structural design and installation methodology of Nearshore reef with rock boulders and steel structure was completed. Approval from PCZMA was obtained for the project and the EIA report is being pursued with Ministry of Environment, Forest and Climate Change for the required approvals. The specifications are being finalized to identify the vendors and initiate the work during 2017.

3.8.3. Development of digital map showing shoreline changes along the Indian coast:

An audit of the structures installed for shoreline protection at Tamil Nadu coast has been carried out and digital map for Tamil Nadu showing engineering structures and their effects on the shoreline morphology is under preparation. The entire Tamil Nadu coast is divided into 7 zones for the study. The shoreline change maps for 4 zones are completed.

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

Design of Lidar based data collection platform at Jakhau, Gujarat for M/s Suzlon is completed, environmental clearance is obtained from GCZMA and contractor has been identified for implementation during fair weather window. A detailed report on data collection platform at Gulf of Khambhat has been submitted to Ministry of New and Renewable Energy, National Institute of Wind Energy and FOWIND for implementation.

3.9. Ocean Energy and Freshwater

3.9.1 Wave powered device:

Wave energy powered navigational buoy was sized to suit the 196 mm UDI turbine which was used in the last Backward Bent Ducted Buoy (BBDB) sea trials. Experimental and CFD studies on the new design are being carried out. Structural design for the fabrication of the navigational buoy is being finalized.

3.9.2 Current turbines:

The 0.8 m diameter straight bladed horizontal axis current turbine fitted below a floating platform continuously generated power during 3 week long sea trial that ended on 8th June 2016 at a location near Port Blair in the

Andamans. Current velocity at site and turbine parameters were measured at site during the sea trial and a thorough study of the turbine performance was carried out. The turbine performance matched the laboratory testing results satisfactorily.

3.10. Ocean Science and Technology for Islands

3.10.1. Marine Algal Biotechnology:

Two new compounds namely methyl pyropheophorbideandmacrocyclicphane esters, possibly a photosensitizer and multi drug resistance reversing compound were extracted from spent biomass of *C. vulgaris*. Completed the structural characterization for lutein and confirmed that the lutein present in *C. vulgaris* to be a simple form with a molecular mass of 569.43. The growth medium for mass culture of pennate diatom *Amphiprorapaludosa* (AT-49) isolated from the Andaman coast was optimized by Central Composite Design and maximum fucoxanthin production of 14.1 mg/g dry biomass was achieved.

3.10.2. Microbial Biotechnology:

New actinomycete*Streptomyces* sp. isolated from 2000 m deep sea sediments was found to produce multiple prodiginines, a family of tripyrrole compounds. Five analogs of antibiotic prodigiosin were identified and characterized and one fraction was found to be active against *Methicillin-resistant Staphylococcus aureus* (MRSA). Sesquiterpenes and ascotricinswere also extracted from the deep sea fungus *Ascotricha* sp. isolated from 1700 m depth.

3.10.3. Open Sea Cage Culture:

A geospatial analysis was carried out to map potential cage farming/mariculture sites across the Exclusive Economic Zone of India. The analysis revealed that a technically suitable vast sea space will be available for sea farming between 5 and 100 m depth zone. This technical suitability was arrived based on 10 environmental parameters: a) depth, b) sea surface current, c) significant wave height, d) total suspended matter, e) sea surface temperature, f) salinity, g) dissolved oxygen h) chlorophyll-'a', i) nitrate and j) phosphate. Further analysis identified the availability of huge suitable area for mariculture including Islands which accounts for 14.9% of the total EEZ of the country (Fig. 3.16).

Fig. 3.16: Demonstration of Open Sea Cage Culture

As requested by the State Fisheries department of Andhra Pradesh, open sea cage culture demonstration of cobia in Tuplipalem was initiated in collaboration with the State Fisheries Department of Andhra Pradesh.

3.11. Marine Sensors, Electronics and Ocean Acoustics

3.11.1. Development of Buried Object Scanning/Detection Sonar (BOSS)

The SONAR system is tested for its performance in ATF tank. Array configuration is changed from along track to across track. Various configurations and different combinations of hydrophones and transmitters are experimented to ensure the functioning of the sub systems and complete system. The results reassured proper functioning of subsystems/ system which were damaged during the deluge.

3.11.2. Development of Drifter buoy with INSAT Communication (Pradyu):

Drifter buoys are built with sensors for sea surface temperature (SST), barometric pressure, salinity and thermistor string up to 15m water depth using 6 temperature sensors. Trial production of drifter buoys under transfer of the technology to two Indian industries is achieved. Industries produced 20 drifters and delivered to NIOT during Feburary 2016. System functionality and performance observation is being carried out at NIOT. 8 drifters have been deployed at Indian Ocean observations (5 systems deployed in the Bay of Bengal & 3 systems deployed in the Arabian Sea).

3.11.3. Ambient noise measurements in Polar region:

Arctic Measurements-Kongsfjorden: The Ambient Noise Measurement System with a single hydrophone and a data acquisition system, deployed in the Arctic along with IndArc 2 mooring in July 2015, was retrieved successfully on 28th July 2016, with 280 days of noise time series measurements. A new ambient noise system with two hydrophones, was deployed along with IndArc mooring on 29th July 2016, in Arctic Kongsfjorden region.

3.12. Seafront Facility

Efforts are made to set up the seafront facility at Nellore, Andhra Pradesh. Application for Coastal Regulation Zone (CRZ) clearance submitted to Andhra Pradesh Coastal Zone Management Authority (APCZMA) in June 2016 and follow up is in process. Survey for laying the approach road is completed by Roads & Bridges Division and Panchayath Raj Division of AP Government and the detailed project report (DPR), is awaited from them. The work on providing water supply at Chittedu site has been completed by Rural Water Supply and Sanitation (RWS&S). Four numbers of container-based laboratories have been established for analysis related to cage culture, micro algal culture and ballast water treatment in the Seafront facility at Pamanji, Nellore.

3.13. Ocean Survey & Mineral Resources

3.13.1. Geoscientific Studies of the Exclusive Economic Zone (Eez)

India has a coastline of 7500 km long with an Exclusive Economic Zone (EEZ) round 2.2 million km^2 (nearly two-third of the landmass of the country). Considering the intrinsic need for high accurate base maps of the EEZ for planning and execution of scientific and exploration programmes of the country, comprehensive swath bathymetric surveys of the EEZ by utilizing state-of-the-art technologies of multi-beam echosounder (MBES) was launched by the Ministry of Earth Sciences (MoES). Area covered thus far and proposed to be covered in future by participating organizations i.e. National Centre for Antarctic and Ocean Research (NCAOR), Goa, National Institute of Technology (NIOT), Chennai, National Institute of Oceanography (NIO), Goa and Geological survey of India (GSI) under Ministry of Mines is depicted in the map below (Fig. 3.17).

A total of nine expeditions, each about 35 days, were undertaken during 2016-17, by NCAOR (four in the eastern offshore and five in the western offshore region) onboard RV-MGS Sagar and ORV SagarKanya. A total of more than 12,00,000 sq.km. area has been surveyed in the deep-water domains.

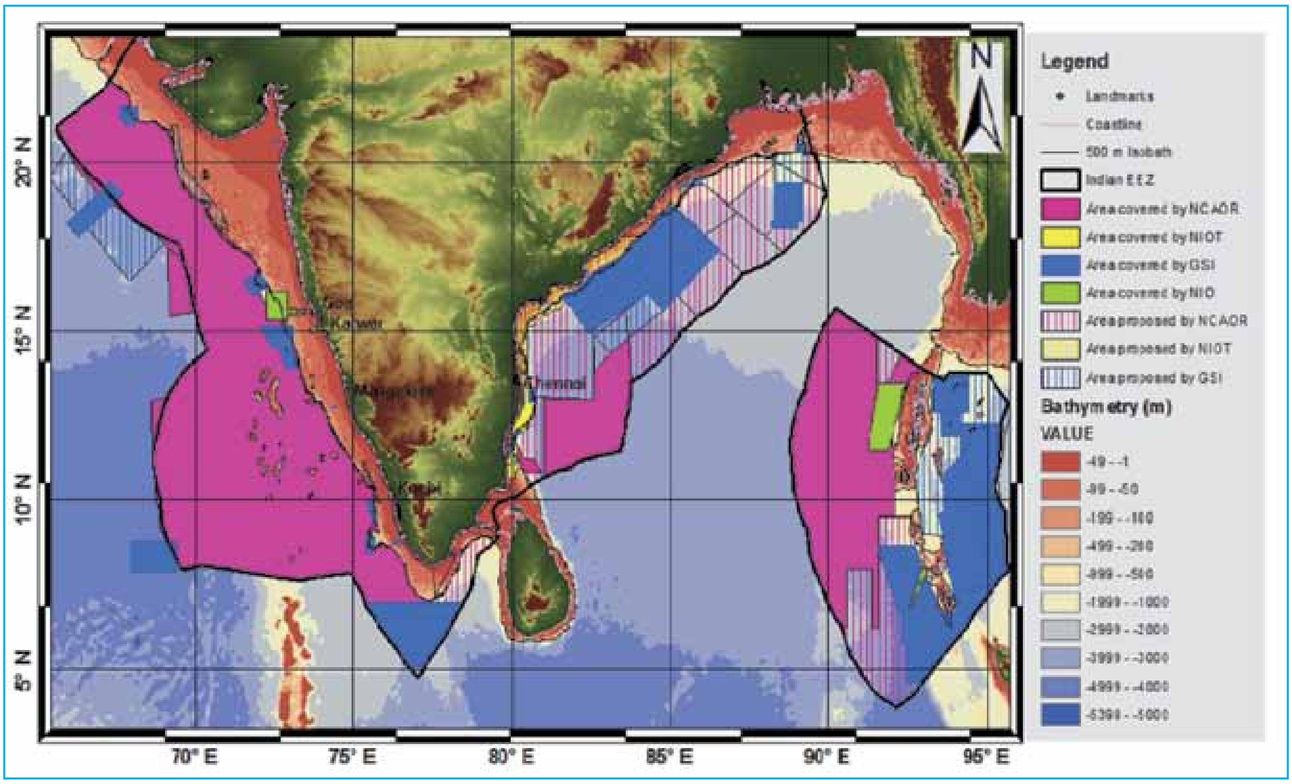


Fig. 3.17: Overall Status of Survey: Total area covered and proposed.

Various geomorphological features such as seamount, knoll, river channel, abyssal plain and hill etc. have been mapped and identified during the course of the surveys. Geomorphic observation and analysis to explore the role of various geophysical agents in shaping the bathymetry was also carried out. The various forms of datasets collected, processed and analyzed were converted to GIS compatible formats supplemented by meta-data file. The main objective is to develop state-of-the-art archival and retrieval facility.

3.13.2. Delineation of India's Continental Shelf

The project aims to gather, analyse and document the requisite scientific and technical information that would help define Indian extended shelf boundaries beyond 200 M as per the provisions of the United Nations Convention on the Law of the Sea (UNCLOS). India submitted its first partial submission for an extended continental shelf beyond 200 M to the UN Commission on the Limits of the Continental Shelf (CLCS) under the provisions of Article 76 on 11th May 2009. Additional geophysical surveys around Indian continental margins were carried out and data processing was completed to explore possibilities of additional partial submissions by India.

3.13.3. Indian Endeavours towards the International Ocean Discovery Program (IODP):

The International Ocean Discovery Program (IODP) is an international marine research endeavor that explores Earth's structure and history recorded in oceanic sediments and rocks beneath and monitors sub-sea floor environments. During 2016, Indian scientists took part in following IODP expeditions: (1) SW Indian Ridge Lower Crust/Moho [IODP-360, Nov 30, 2015-Jan 30, 2016], (2) Southern African Climates and Agulhas Current Density

Profile [IODP-361, Jan 30-Mar 31, 2016], (3) Sumatra Seismogenic Zone [IODP-362, Aug 6 - Oct 6, 2016].

3.13.4. Exploring the Origin of the Largest Geoid Low on the Earth:

The Indian Ocean Geoid Low (IOGL) is one of the most intriguing geophysical observations in the Indian Ocean. It appears as a very long wavelength feature (> 15,000 km) covering the entire Indian Ocean and dominated by a significant low of -106 m south of Sri Lanka. The first phase of the acquisition has been completed and tomographic modeling and inversion of seismic data is underway. The second phase of passive Ocean Bottom Seismometer (OBS) deployments is underway to characterize the crustal and upper mantle structure in this region.

3.13.5. 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 square km, located about 2000 km away from her southern tip. MoES submitted an application to International Seabed Authority for extension of contract for exploration of Polymetallic Nodules (PMN) for a further period of 5 years (2017-22). The existing contract is expiring on 24^{th} March 2017. During the year 2016-17, an independent exercise of identifying richest nodule fields which together can form an FGM (First Generation Mine), in which contiguity of blocks is not a factor is carried out. The average abundance of all the 42 blocks of the scattered FGM is 9.63 kg/m^2 and the average grade is 2.35%. Sediment and water samples collected from Test Mine Site (TMS) and Test Reference Site (TRS) areas were analyzed for baseline data like grain size distribution, geotechnical properties, water column chemistry, profiles of salinity, temperature, turbidity with depth, pore water nutrients, Sediment chemistry, density of macro and meiofauna, microbiology and biochemical parameters.

3.13.6. Studies On Hydrothermal Sulphides

Government of India, signed a 15-year contract with the International Seabed Authority (ISA), for exploration of Poly-Metallic Sulphides (PMS) in Indian Ocean. Two cruises onboard ORV Sagar Kanya were undertaken in the prospecting area in South West Indian Ridge (SWIR) region to study chemical and physical signatures of the water column to locate hydrothermal plume signatures, if any, in the region. CTD and grab samplings were carried out in the region, where some promising signatures of hydrothermal activity were inferred. Analysis and interpretation of the data/samples collected were carried out to understand the various geological, biological and hydrodynamic processes prevailing in the region to infer clues about hydrothermal activity in the region. Petrographic studies of rock samples from SWIR indicated that the rocks belongs to the lower stratigraphic level of oceanic crustal segments are exposed at the higher structural level at the sea floor. It is inferred that such structural features are the good target areas for hosting hydrothermal deposits because of their high permeability efficiency.

4. POLAR SCIENCE AND CRYOSPHERE

Variability in polar environment has large global impacts. The changes in ice cover, snow variability etc have a perceptible influence on global water cycle. Also the climate anomalies in the polar regions may influence the low latitudes by modification of oceanic 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 illustrates the activities in various polar science disciplines, which are mainly carried out by the National Centre for Antarctic and Ocean Research (NCAOR), Goa.

4.1 Scientific Studies in Antarctica

4.1.1 Cryosphere & Climate

Genesis and implications of calcium nitrate in Antarctic snow: The association between Ca^{2+}, an important proxy indicator of mineral dust and NO_3^-, in Antarctic snow studied using 41 snow cores (~1m each) along two coastal–inland transects from the Princess Elizabeth Land and central Dronning Maud Land (cDML) in East Antarctica revealed the formation of $Ca(NO_3)^{2-}$ in Antarctic atmosphere. Correlation statistics showed a strong association (at 99% significance level) between NO_3^- and Ca^{2+} (Fig. 4.1), attributed to the interaction between calcic mineral dust and nitrogen oxides in the atmosphere, leading to the possible formation of calcium nitrate ($Ca(NO_3)^{2-}$). Forward and back trajectory analyses revealed that Southern South America (SSA) is an important dust emitting source to the study region, aided by the westerlies. The study indicates that the input of dust-bound NO_3^- may contribute a significant fraction of the total NO_3^- deposited in Antarctic snow.

Nitrogen and sulphur chemistry at the Arctic air-snow interface: The aim of this study

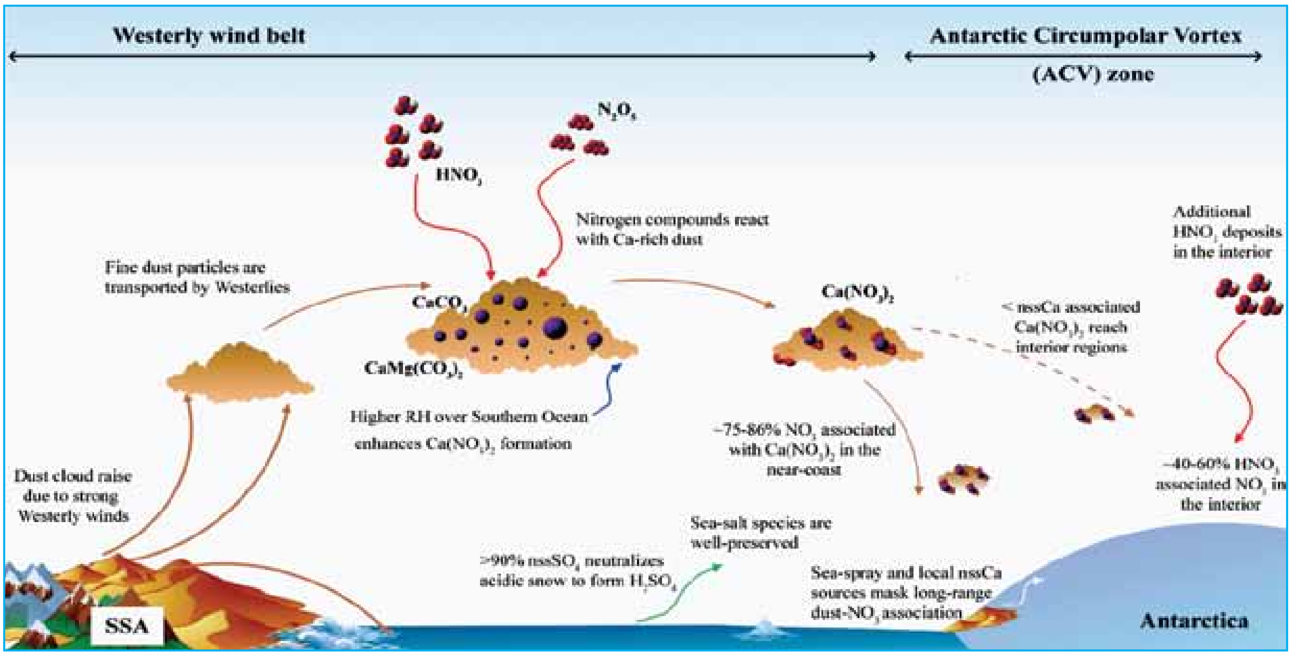


Fig.4.1: Schematic diagram depicting physical processes and chemical reactions involved during the mineral dust transport from Southern South America (SSA) before depositing over Antarctica.

is to understand the glacier-climate inter-relationship in response to climatic variability at Ny-Ålesund, Arctic. In order to understand the above, air and snow measurements were carried out using a particulate sampler equipped with denuders and filter packs for simultaneous collection of trace gases (HNO_3, NO_2, SO_2 and NO_y) and aerosols. The studies showed that the aerosols were ammonium rich and fully neutralized resulting into alkaline conditions. These alkaline aerosols and the prevailing high humidity conditions favor the uptake of HNO_3 in aerosols with the subsequent release of HCl resulting in the formation of ammonium nitrate aerosols over ammonium sulphate. In comparison to gaseous HNO_3, the dry deposition of pNO_3^- was more significant which contributed 62% to the total nitrogen budget (Fig. 4.2).

ice duration in two sediment cores-SK 200/22a and SK 200/27 are not continuous. There is a significant absence of sea ice during Marine isotopic stage (MIS) 5 and MIS 1, this being a reflection of their (SK 200/22a and SK 200/27) position in sea ice free modern Polar frontal zone (PFZ) and Permanent open ocean zone (POOZ) (Fig 4.3). Sea ice is then expected to be at the core sites only during glacial periods. The advance phases in sea ice coverage occur during glacial periods (MIS 2, 3 and 4) (Fig 4.3). Despite the advance and retreating pattern of sea ice recorded at the site SK 200/22a, sea ice presence was assumed to be of less than 1 month/year. The Sea Surface Temperature (SST) would have been close to 4°C from MIS 4-2 suggesting the presence of Antarctic polar front (APF) at the core site SK 200/22a. The summer SST at the site SK 200/27 would have

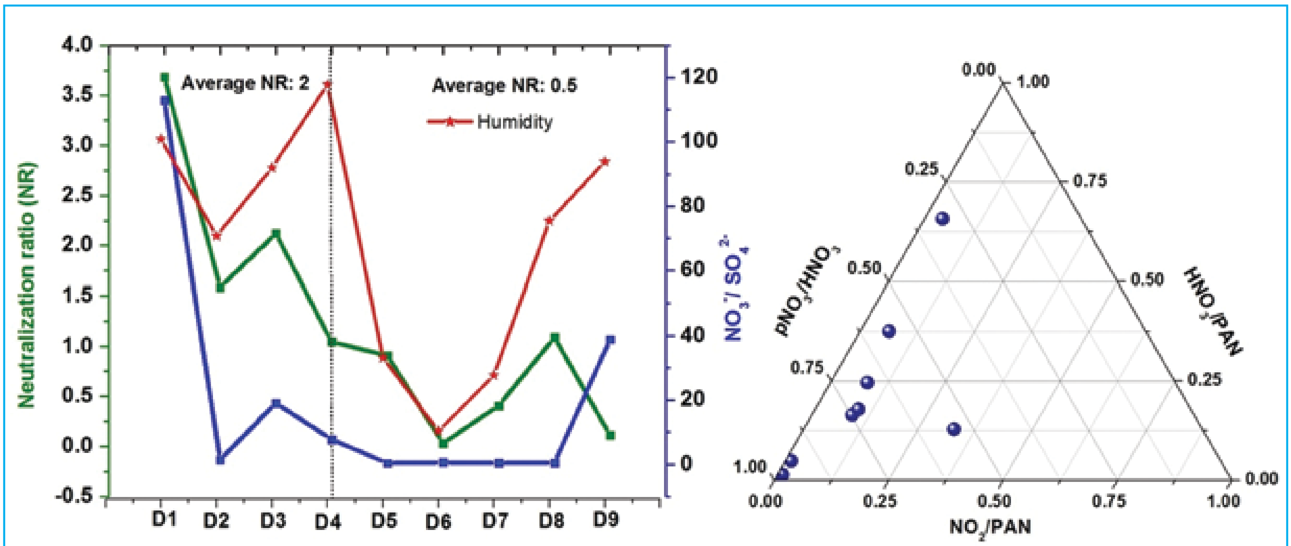


Fig.4.2: Variation of Neutralization ratio of aerosols with Humidity against NO_3^-/SO_4^{2-} and Ternary plot shows the formation pathway of pNO_3^-

4.1.2 Past Climate and Oceanic Variability

Millennial scale sea-ice and frontal variability from Indian sector of Southern Ocean: A down-core record of sea ice diatoms through the last glacial cycle allows to document the variability of sea ice progression and retreat in the Indian sector of the Southern Ocean. Records of sea

been significantly lower (<4°C) during MIS 2 and 4 complementing the sea ice presence of about 1 month/year and also indicating the shift of the APF probably located north of the site SK 200/27 during glacial periods. Compared to the current position of Sub-Antarctic front (SAF) at the core site (~43°S), the higher abundance of SAZ diatoms during late MIS 5 (~78 kyr), probably suggest that the SAF might have been positioned nearly 5-6°south of its present position during late MIS 5 (~78 kyr: Fig.4.3). Sea ice retreat at last glacial termination was very rapid and mainly related to SST changes. Conversely, sea ice advance during the full glacial periods, when SSTs were relatively stable, is believed to result from a positive feedback of sea-ice on atmospheric processes such as albedo, air temperature and zonal winds, thus enabling a northward migration of the winter ice edge to ~ 50°S.

Geochemical Studies using surface sediments from an Arctic fjord: Investigation of Carbon and nitrogen concentrations and isotopes ($\delta^{13}C$ and $\delta^{15}N$) of sedimentary organic matter (SOM) at an Arctic fjord namely Kongsfjorden shows a clear spatial gradient in bulk geochemical parameters, largely driven by the glacial-marine contrast (Fig. 4.4). Organic matter concentration increases with increasing distance from the glaciers. The bound inorganic nitrogen (ammonium attached to the clay minerals) forms a significant proportion of total nitrogen concentration (~77% in the inner fjord to ~24% in the outer part). On removing the bound nitrogen, the C/N ratio shows that the SOM in the inner fjord is made up of terrestrial carbon while the outer fjord shows mixed marine-terrestrial signal. The marine organic matter is anomalously more depleted in

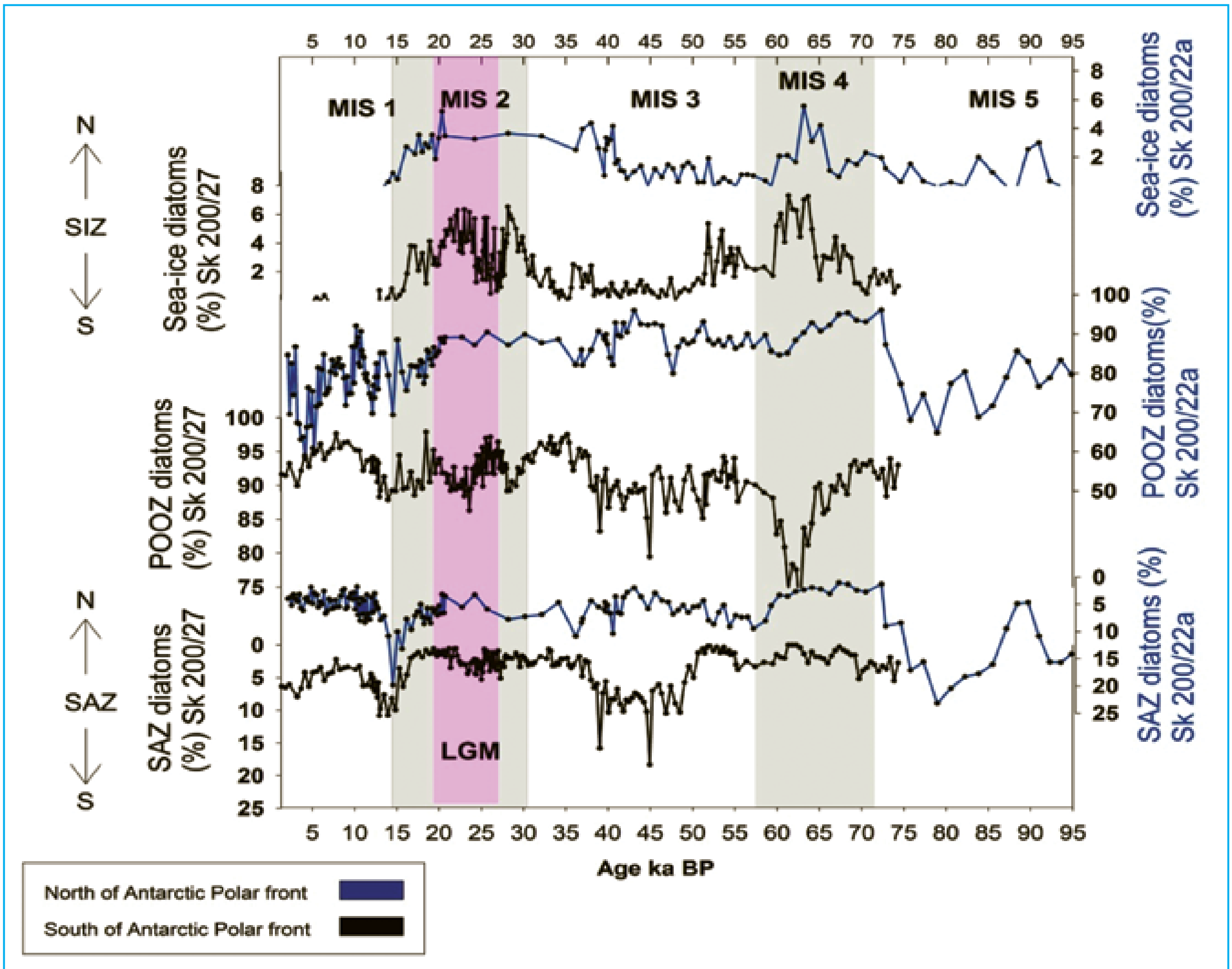


Fig.4.3: Glacial-interglacial variation of SIZ, SAZ and POOZ diatom assemblage at the site SK 200/22a and SK 200/27.

^{13}C (~-24 ‰) than the terrestrial organic matter (~-22.5‰), which implies that there may be errors in overall marine vs. terrestrial carbon sequestration budget for the Arctic region due to poor constraining of end-member isotopic composition in such marginal settings.

4.1.3 *Polar Remote Sensing:*

Monitoring Antarctic iceberg calving events using LISS-IV / IRS-P6 satellite data: Icebergs were tracked in the vicinity of Larsemann hills and neighbourhood, Ingrid Christensen coast, Princess Elizabeth land, east Antarctica using satellite data to quantitatively analyse iceberg

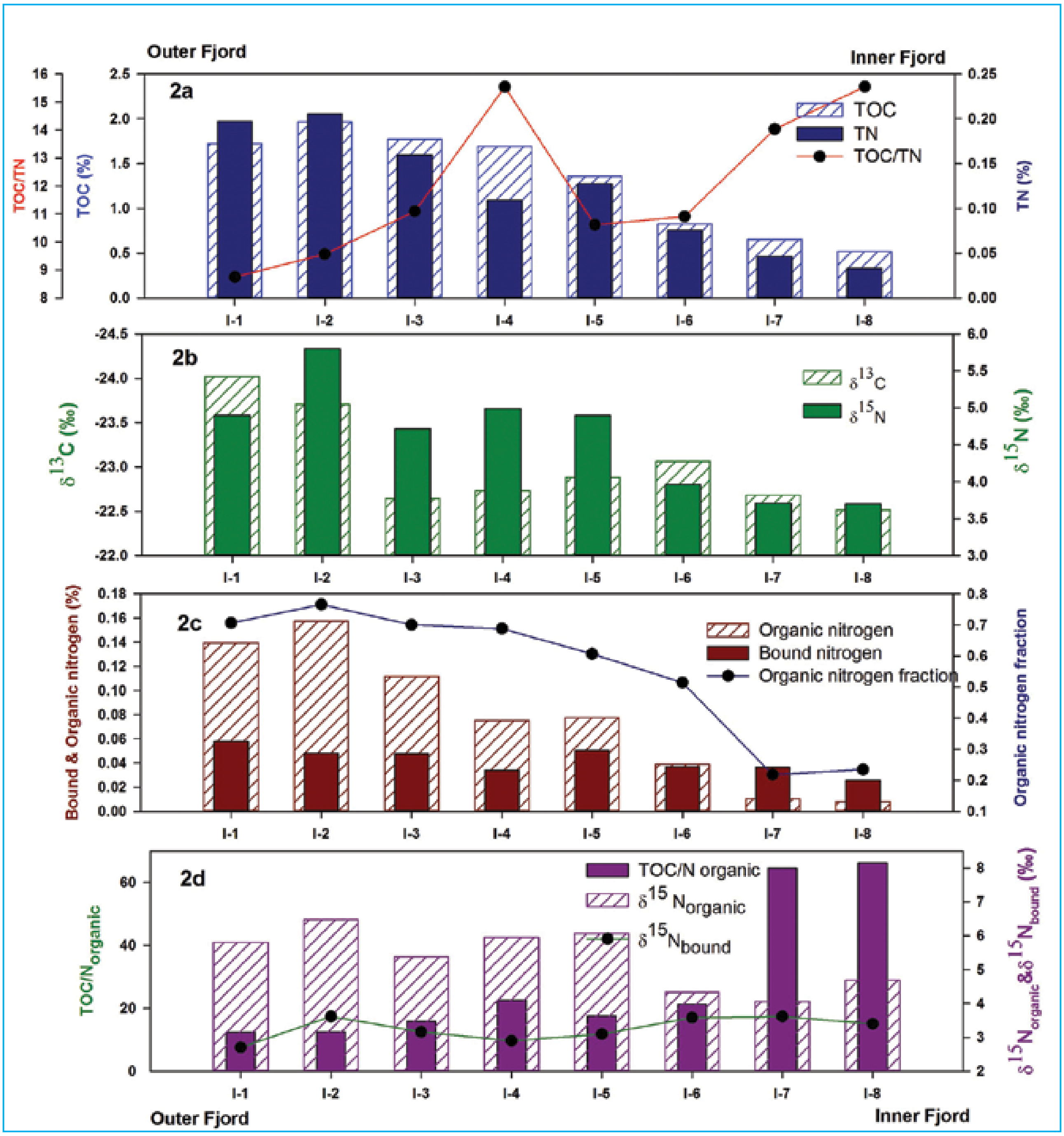


Fig.4.4: Spatial gradient in the bulk geochemical parameters along the fjord axis (a) Spatial variability of Total Organic Carbon (TOC), Total Nitrogen (TN) and TOC/TN of surface sediments along the fjord axis (b) $\delta^{13}C$ and $\delta^{15}N$ of surface sediments (c) Relative proportion of bound-inorganic nitrogen concentration and organic nitrogen concentration in surface sediments (d) TOC//$N_{organic}$, $\delta^{15}N$ bound and δ15Norganic of surface sediments.

calving, changes in iceberg numbers, rate of iceberg disintegration, and rate of iceberg drift in the Prydz bay. A total of 369 icebergs were identified on the basis of their shape, size and texture for analysing the changes in their dimensions because of melting or disintegration. Analysis estimates that the number of icebergs is decreased by 70 from 2013 to 2015, suggesting the complete disintegration of these icebergs over the ≈1 year period. In case of 369 common icebergs, the total surface area has decreased by 12.5%, suggesting the melting of icebergs in the given time period. The average deviation of the newly disintegrated icebergs from the coastline is found to be 51 m for 384 days.

Extraction of bathymetric information of Antarctic shallow lakes using High spatial Resolution multispectral satellite imagery: High spatial resolution pan-sharpened images from WorldView-2 (WV-2) were used for bathymetric mapping around Larsemann Hills and Schirmacher oasis, east Antarctica. Two different models: (a) Stumpf model and (b) Lyzenga model were used to extract the bathymetry values from multispectral imagery. The derived depths were validated against the *in-situ* measurements. Results indicated a high correlation (R=0.60~0.80) between estimated depth and in-situ depth measurements, suggesting that the coastal blue band in the WV-2 imagery could retrieve accurate bathymetry information compared to other bands.

4.1.4 Operations, Management and Research Support for the Antarctica Expeditions

XXXV (35^{th}) Indian Scientific Expedition to Antarctica: The XXXV (35^{th}) Indian Scientific Expedition to Antarctica was flagged off from Goa in multiple batches with the first batch departing on 4^{th} November 2015. A total of 108 expedition members (scientists and logistics) from 26 different organizations travelled in and out of Antarctica over a period of five months starting from November 2015 to April 2016 wherein the Voyage Expedition returned in early April-2016. Some of the major projects implemented by the Indian Scientists at Maitri and Bharati during the summer through winter months of 2015-16 comprise (by the agencies indicated against each):

- Geophysical studies in Polar Regions: Indian Institute of Geomagentism
- Observation of Meteorological Parameters, Solar Radiation and Ozone (ESSO-IMD).
- Variations of Meteorological Parameters, Energy Fluxes and study of Ice Sheet Dynamics using Remote Sensing and In situ Measurements. SASE, DRDO.
- Climate Change Research and Space Weather Studies. SPL, Department of Space.
- Monitoring of DakshinGangotri glacier snout and snow accumulation / ablation on parts of ice sheet and ice shelf in central Dronning Maud Land, East Antarctica- Geological Survey of India.
- Effect of yoga practices in Antarctica – DIPAS & SVYSAA University.

Environmental Monitoring of the Maitri Station Premises: The environmental conditions around Maitri station were monitored. Variations in combustion-related (Black Carbon) aerosol emissions at Maitri station, since 2014 were studied. In addition to that, water quality was also monitored in various lakes around Maitri. Twenty five physico-chemical and heavy metal parameters were determined at environmental lab established in Tirumala hut at Maitri station. A new food incinerator system has been commissioned and made operational at Maitri station. In addition, new advanced water treatment system was commissioned to treat the grey water generated from Maitri station (Fig. 4.5).

Antarctic Treaty Consultative Meeting and Committee for Environmental Protection: The XXXIX Antarctica Treaty Consultative Meeting (ATCM) and XIX Committee for Environmental Protection (CEP) meetings were held in Santiago, Chile. A Background Paper (BP) *'Follow-up to the Recommendations of the Inspection Teams on Maitri Station'* outlining the implementation of recommendations of Inspection Teams was submitted to ATCM.

Council of Managers on National Antarctic Programme (COMNAP) and Antarctic Specially Managed Area (ASMA-6) Larsemann Hills Group meeting: The COMNAP XXVIII meeting at Goa was attended by representatives from 29 COMNAP Member organizations. The ASMA-6 *Larsemann* Hills Group meeting represented by Australia, China, Russian Federation, Romania and India was held in Conjunction with COMANP in order to discuss Logistic, Scientific and Environmental issue as well exchange of information among the parties.

Fig.4.5: New Advance Waste water Treatment System Commissioned at Maitri Station

XXXVI (36th) Indian Scientific Expedition to Antarctica: The XXXVI expedition members were sent in different batches, commencing November 2016. Total 31 sub-projects/ studies would cover (i) Atmospheric Science & Meteorology, (ii) Biology & Environmental Sciences (iii) Earth Science & Glaciology with the overall theme being the "Climate Change".

4.2 Scientific Studies in Arctic

During the year, 17 projects covering different aspects oceanography, atmospheric sciences, geology and glaciology were implemented at Ny-Ålesund, Svalbard, Norway.

4.2.1 Long-term monitoring of Kongsfjorden for climate studies:

Routine Conductivity Temperature Density (CTD) observations were done on a biweekly interval over the entire Kongsfjorden as well as Krossfjorden during June-October 2016. The IndARCII mooring deployed in Kongsfjorden in the year 2015 was retrieved, serviced and deployed as IndARCIII at the same location. Bacterial community structure of water sample collected from outer and inner fjord was assessed in order to understand the effect of Atlantic water intrusion and inflow of glacial melt water on the bacterio-plankton community composition as a function of spatial as well as temporal variation.

4.2.2 Monitoring of Arctic precipitation and clouds:

The frequency of occurrence of warm mid-latitude air masses entering into the Polar Regions were studied by monitoring of precipitation and clouds using microwave rain radar (MRR), ceilometer and microwave radiometer installed in the Atmospheric Science Laboratory at Ny-Ålesund.

4.2.3 Mass balance studies of Arctic glaciers:

Two glaciers VestreBroggerbreen and Feiringbreen were monitored to understand glacier velocity and mass balance budget of Arctic glaciers in the context of climate change. In addition, geomorphological, pro-glacial area, and snout mapping of both the glacier and snow/water chemistry were carried out.

4.3 Himalayan Studies

The Himalayan glaciers play a significant role in the global climate and are highly sensitive to the on-going warming. Various glaciological studies were carried out in selected six benchmark glaciers *(Sutri Dhaka, Batal, Bara Shigri, SamudraTapu, Gepang and Kunzam)* of western Himalaya to understand glacier impact on hydrology, ecology and climate of Himalaya region. A Field Research Station named "Himansh" was established at Sutri Dhaka and inaugurated in October 2016. This station is equipped with instruments such as Automatic Weather Station, Water Level Recorder, Steam Drill, Snow/Ice Corer, Ground Penetrating Radar, Differential Global positioning System, Snow Fork, Flow Tracker, Thermister string, Radiometer etc (Fig. 4.6). Water Level Recorders were installed at five locations along with a stretch of 130 km of Chandra River in Western Himalaya for hydrological balance/modeling. Glaciers were monitored for mass balance, dynamics, energy balance and hydrology.

4.3.1 Debris control on glacier thinning-a case study of the Batal glacier, Chandra basin:

Presence of debris cover on the surface of glaciers can significantly alter the surface energy balance and influence the climatic response of glaciers. High surface melting

(-2.0 cm. w.e.d^{-1}) in the debris free glacier while low surface melting (-0.6 cm. w.e.d-1) was observed in thick debris covered ice. A high degree of negative correlation (r = -0.82,

Fig. 4.6: Field Research Station "Himansh" at Sutri Dhaka, Chandra basin, H.P

$p < 0.05$) between ablation rate and debris thickness in Batal suggest a significant control of debris thickness over ablation rate.

4.3.2 A geospatial analysis of SamudraTapu and Gepang Gath glacial lakes in the Chandra basin:

Geospatial studies carried out in two major proglacial lakes of SamudraTapu and Gepang Gath (Chandra basin, Western Himalaya) showed substantial expansion in their area and volume over the last four decades (1971-2014). The results show that increased melting of the feeder glaciers over this period is major contributor to expand the volumes approximately 20 times of both the lakes SamudraTapu and Gepang Gath (Fig. 4.7).

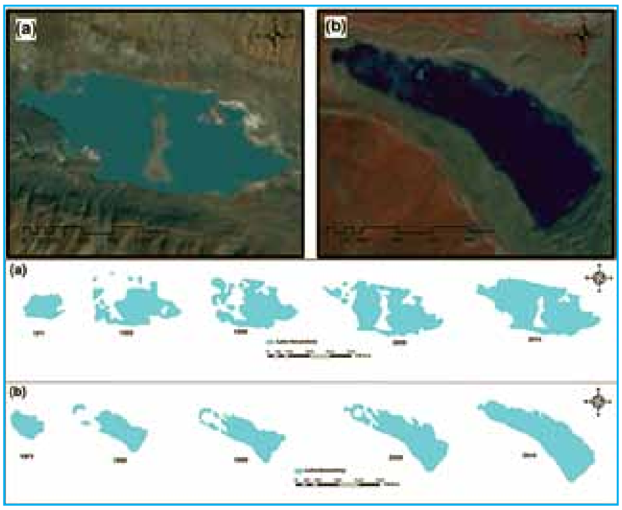


Fig.4.7. Expansion of proglacial lakes' SamudraTapu, (a) and Gepang Gath (b) since 1972, studied by using corona and landsat satellites images.

4.3.3 Microbial diversity of Himalayan glacier cryoconites:

The diversity of bacterial and fungal life at the Hamtah and Chhota Sigri glaciers in Himalaya (Fig 4.8) and their physiological and biochemical characters were studied. Cryoconites and pit profile sediment samples were processed for bacterial isolation on different isolation media and temperatures. The emerging colonies were isolated, purified and their colony characteristics studied.

4.4 Southern Ocean Studies:

Observations of water mass modification by mesoscale eddies in the subtropical frontal region of the Indian Ocean sector of Southern Ocean: Two eddies (one cyclonic and the other anticyclonic) in the subtropical frontal region (STF) of the Indian Ocean sector of Southern

Fig. 4.8: Sampling Area in Himalaya. i) Hamtah Glacier, ii) Chotta Sigri glacier, iii) Cryoconite holes.

Ocean (SO) and their role on the watermass modification are described here using the hydrographic data collected during the austral summer (February) of 2012 and 2013 (Fig.4.9). The cyclonic eddy transports cold, fresh and deeper Antarctic Intermediate Water (AAIW) to the much shallower depths, but the anticyclonic eddy pushes the warm, high saline Subtropical Surface Water (STSW) to deeper depths. Significant change in the properties of watermasses (in terms of temperature and salinity) viz. STSW (colder by ~1°C and less saline by ~1 psu) and Subtropical Mode Water (STMW; temperature decreased by ~0.5°C and salinity by ~0.7 psu) were noticeable in the centre of cyclonic eddy. On the other hand no such changes were found in the STMW properties in the anti-cyclonic eddy region. A striking feature observed both in the cyclonic and anti-cyclonic eddy was the freshening of AAIW and this is consistently evident in the observations.

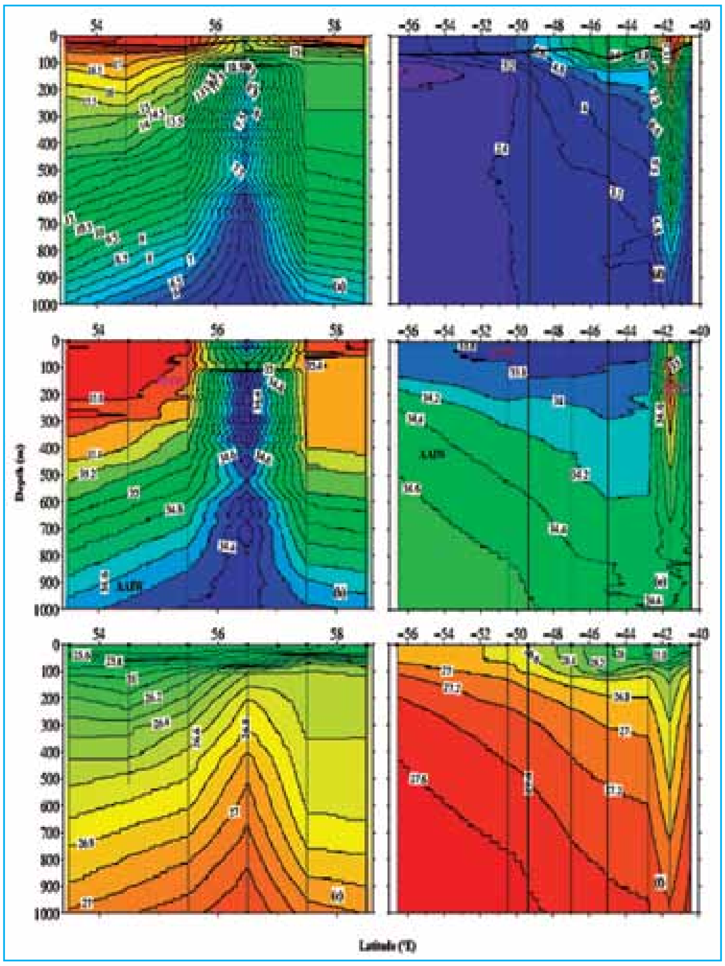


Fig.4.9: Vertical section of temperature (a, d), salinity (b, e) and density (c, f) along 40°S section (depth versus longitude, Left panel) and along 57° 30' E section (depth versus latitude, Right panel). Black vertical lines in the figure represent the CTD locations and black horizontal line in the figure (a) and (e) represents the mixed layer.

Freshening of Antarctic Bottom Water (AABW) in the Indian Ocean sector of Southern Ocean: The AABW which accounts for around 30–40% of the global ocean mass in the abyssal layer is a key contributor in the global overturning circulation and is also an important sink for heat and CO_2. Produced at a few specific high latitude regions of the SO, the formation of AABW is sensitive to climatic forcing. Observations in the Indian Ocean sector of Southern Ocean (IOSSO) have revealed a rapid reduction in salinity and density of Antarctic Bottom Water (AABW). Earlier studies reported that the rate of freshening between 1995 and 2005 (0.01) is greater than that observed between 1970 and 1995 (0.005). The results obtained from the in-situ data corroborate with the model data, exhibited an increased rate of freshening in the period 2006–2010. Swifter freshening in the same direction from 2006 to 2010 has been portrayed with the AABW becoming warmer (~ 0.05°C), fresher (~ 0.01) and lighter (~ 0.01 kg m^{-3}). The AABW observed in the present study could have originated from Weddell Sea or CapeDarnley polynya. The decadal changes indicate an enhanced sea-ice formation, due to increased positive phases of Southern Annular Mode (SAM), which may have led to the increase in fresh water input, resulting in freshening of AABW.

Latitudinal $\delta^{13}C$ and $\delta^{15}N$ variations in particulate organic matter (POM) in surface waters from the Indian Ocean sector of Southern Ocean and the tropical Indian Ocean: Surface water samples collected from meridional section in the Indian Ocean (between 3°N to 53°S) during the austral summer 2012 revealed that $\delta^{15}N_{(POM)}$ varied over a wide range, with higher $\delta^{15}N_{(POM)}$ in the nitrate-depleted subtropical waters, whereas $\delta^{13}C_{(POM)}$ had a significant relation with temperature and an inverse relation with total CO_2 (tCO_2) beyond 40°S. The spatial variations of $\delta^{13}C_{(POM)}$ and $\delta^{15}N_{(POM)}$ are influenced by biological community and structure. The selective enrichment of $\delta^{13}C_{(POM)}$ in TIO surface waters was attributed to the dominance of picoplankton and associated biological processes. Beyond 40°S, a combination of both physical forces and changing biological community influenced the $\delta^{13}C_{(POM)}$ and $\delta^{15}N_{(POM)}$. The dominance of dinoflagellates and their non-discriminative uptake of C and N in the subtropical front and diatoms, at the nutrient rich polar front waters play a major role in the latitudinal variability of POM characteristics.

Phytoplankton community structure at the juncture of the Agulhas Return Front and Subtropical Front in the Indian Ocean sector of Southern Ocean: The merged Agulhas return Front (ARF) and Subtropical Front (STF) in the Indian Ocean sector of Southern Ocean (SO) is characterized by high mesoscale turbulence, which results in sporadic, short lived phytoplankton proliferation. The biota, mainly the phytoplankton community from such a complex hydrodynamic region and its response to the mesoscale turbulence are areas of interest for investigation. Hence, during the sixth Indian expedition to SO, a two day time series was occupied at the ARF and STF merged region (40° S 58°30'E) from 13 to 15 January, 2012. The vertical profiles of phytoplankton (based on pigment indices) indicated variation in the percentage contribution of phytoplankton functional groups (Micro, Nano and Pico). Though the overall community structure was dominated by the nanoplankton group, drastic shifts in the community were observed at 120 m depth at six hourly intervals. From the present study, it is evident that the flagellate group is the ideal one to survive in such a complex regime.

Response of bacteria and phytoplankton from subtropical and polar fronts of Southern Ocean to micronutrient amendments: Effect of micronutrient amendments including cobalt (Co), copper (Cu), and iron (Fe) on growth as well as changes in microbial assemblages, and the responses of Phytoplankton as well as bacterial community to those micronutrient amendment was examined using ship borne measurements during the austral summer of 2012 and 2013 in the subtropical front and Polar Front in the Indian Ocean sector of SO respectively. This study was useful to discern the availability of micronutrients, iron in particular, in governing the bacterial community structure in the subtropical front. Also, this study revealed that phytoplankton growth in this region was not only limited by the availability of Fe but also of Co and Cu. In addition, under micronutrient amendments the bacterial abundance as well as BC structure did not correlate with Chla or phytoplankton community shifts.

5. SEISMOLOGY AND GEOSCIENCES RESEARCH (SAGE)

5.1 Seismology

5.1.1 Observational Seismology, Earthquake Monitoring and Services:

The national seismological network consisting of 82 observatories has been functioning smoothly and a total of 245 earthquake events occurred in and around India (Latitude 0-40° N, Longitude 60-100° E) were detected and auto-located during the period November, 2015- October, 2016. These include 40 events of magnitude 5 and above. Information pertaining to significant events were transmitted to all concerned state and central government agencies, dealing with relief and rescue operations in the region and also posted at website.

During the period of report, a major earthquake (Magnitude 6.8) occurred on 4th January 2016 at 4:35 hrs IST in Manipur (about 30 Km west of Imphal), which was severely felt in the epicentral and adjoining areas and caused damage in the epicentral region and Imphal valley. This is considered to be the largest earthquake in the down going Indian lithospheric slab beneath the Indo-Burmese wedge (IBW) since the last Mw 7.3 earthquake, occurred on 6 August 1988. The event is also the largest to be recorded instrumentally, within the state of Manipur since the establishment of the WSSN in 1964. The main shock and its significant aftershocks have been detected and located by the national seismological network of NCS. In addition, three earthquakes of magnitude >6.8 occurred in Burma (13 April 2016 M 6.9 and 24 August 2016 M 6.8) and Tajikistan (7 December 2015 M 7.2) which were strongly felt in various parts of Indian region.

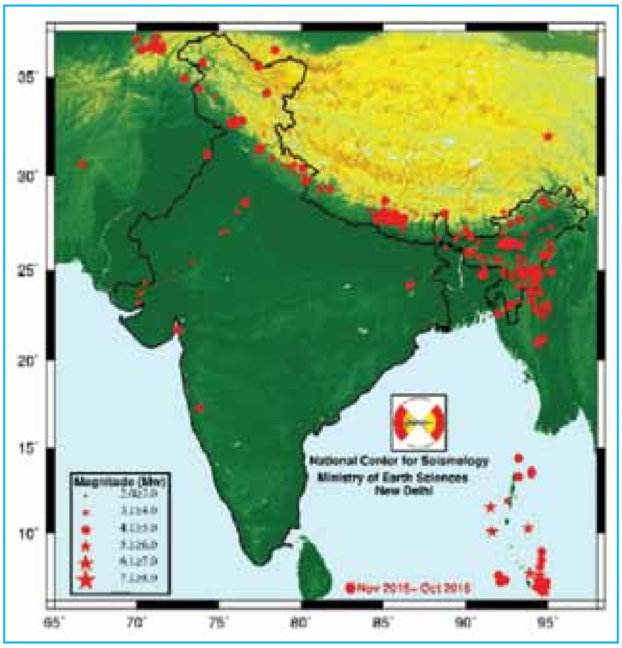


Fig. 5.1: Seismicity during the past one year

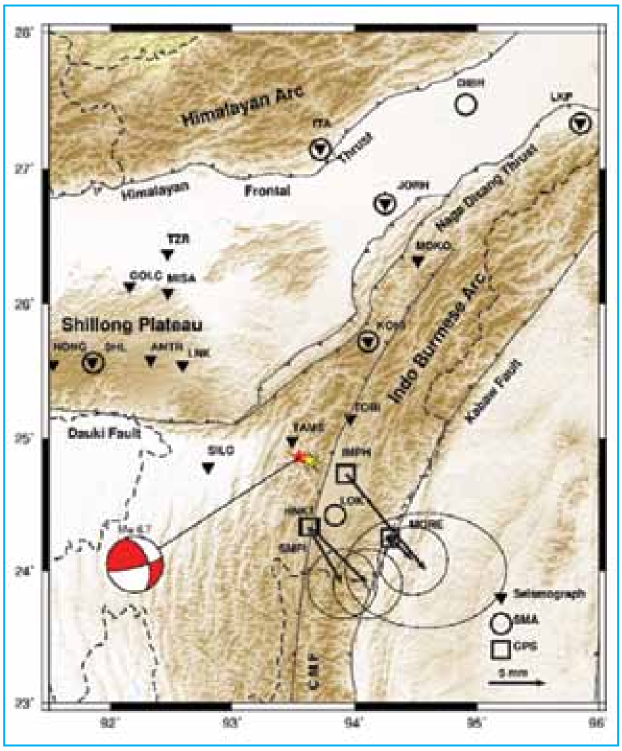


Fig. 5.2: Indian network of Broadband seismographs, strong motion accelerographs (SMA) and GPS sites which recorded the earthquake. Red star is the estimate by National Centre for Seismology, whereas the two yellow stars denote the estimates of EMSC (left) and USGS (right).

The earthquake bulletins were prepared on monthly basis and archived vis-à-vis sent to the International Seismological Center. Earthquake data were supplied to various scientific, academic and R&D institutions for research purposes. Also, on request basis, the earthquake data and site specific seismicity reports were supplied to industrial units, power houses, river valley projects etc.

5.1.1.1 Upgradation of Seismological Network:

With a view to precisely locate the smaller events, a project has been implemented to augment the existing network. The first phase of upgradation has been completed with up-gradation of 38 stations and installation of 2 new stations. Currently the second phase of up-gradation is going on, which envisages installation of 32 new stations and upgradation of 6 existing stations. It is expected that by the end of the year 2017, a total of 116 stations will be part of the national network. These observatories are being integrated with Operational Centre through VSAT communication facility established under the Integrated Seismic and GPS Network (ISGN).

5.1.2 Microzonation of selected cities:

Seismic microzonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface. In order to undertake microzonation, studies of 30 selected cities, falling in seismic zone V, IV, III and State Capitals has been initiated. As a part of this exercise, Microzonation of Delhi has been completed based on Probabilistic Seismic Hazard Analysis (PSHA). Earthquake sources and parameters used in the study covers 350 km radius area from Delhi, (Latitude 24.0° – 31.5° N and Longitude 74.0° – 81.5° E). The area includes part of Himalayan region where a magnitude of M 6.9 occurred in 1999 (Chamoli). Work related to microzonation of other identified cities has also been initiated and in this direction base maps have been procured.

5.1.3 Probabilistic Seismic Hazard Analysis (PSHA) of 40 selected cities:

Under a project sanctioned to IIT, Kharagpur Probabilistic Seismic Hazard Analysis (PSHA) of 40 cities has been performed for probable integration with other hazard attributes on GIS platform. PSHA for 40 cities has been carried out based on underlying seismogenic source zones in the Indian subcontinent employing the earthquake catalogue, supplemented by records of historical earthquakes (occurring prior to 1900, and as late as 0819 AD), focal mechanism data from Global Centroid Moment Tensor database and published literature, fault database published by Geological Survey of India and formulation of a layered seismogenic source zonation with different hypocentral depth ranges. In this study, eleven tectonic provinces viz. (i) Bengal Basin, ii) Indo-Gangetic Plain, (iii) Central India, (iv) Kutch Region, (v) Koyna Warna Region, (vi) Western Ghat Region, (vii) Eastern Ghat Region, (viii) Kashmir Himalaya, (ix) West Central Himalaya, (x) Darjeeling-Sikkim Himalaya, and (xi) Northeast India were identified based on the underlying tectonic setup and the past seismic activities for the Probabilistic Seismic Hazard assessment of 40 cities in India as depicted in Figure 5.3. The PSHA model for each city comprises of spatial distribution of seismic hazard in terms of Peak Ground Acceleration (PGA) for both 10% and 2% probability of exceedance and

5%-damped Pseudo-Spectral Acceleration (PSA) predicting the hazard estimate for both 475 and 2475 years of return periods.

5.1.4 Precursory observations associated with Manipur Earthquake of M 6.8:

Under a project funded to Manipur University, a multi-parametric geophysical observatory (MPGO) has been set up in Imphal to generate long term data base on different geophysical parameters. The observatory houses various equipments like borehole seismograph, borehole accelerograph, GPS, radon monitoring system, magnetometers, Magneto-Telluric (MT) system etc. The earthquake of M 6.8 occurred on 4th January, 2016 in Imphal was very well recorded by the observatory. The event provided an opportunity to study the precursory changes in different geophysical observations, recorded at MPGO, Manipur. Data were analysed and it was observed that apparent resistivity in the frequency range of 0.0001 to 0.1 Hz show abrupt co-seismic decrease on XY-polarization plane. Anomalous Radon count was visible to some extent in the Radon time series and co-seismic ground uplift was very distinct in the GPS time series. The results obtained so far show that the multi-parameter approach holds promise and long-term monitoring needs to be continued for statistical validation.

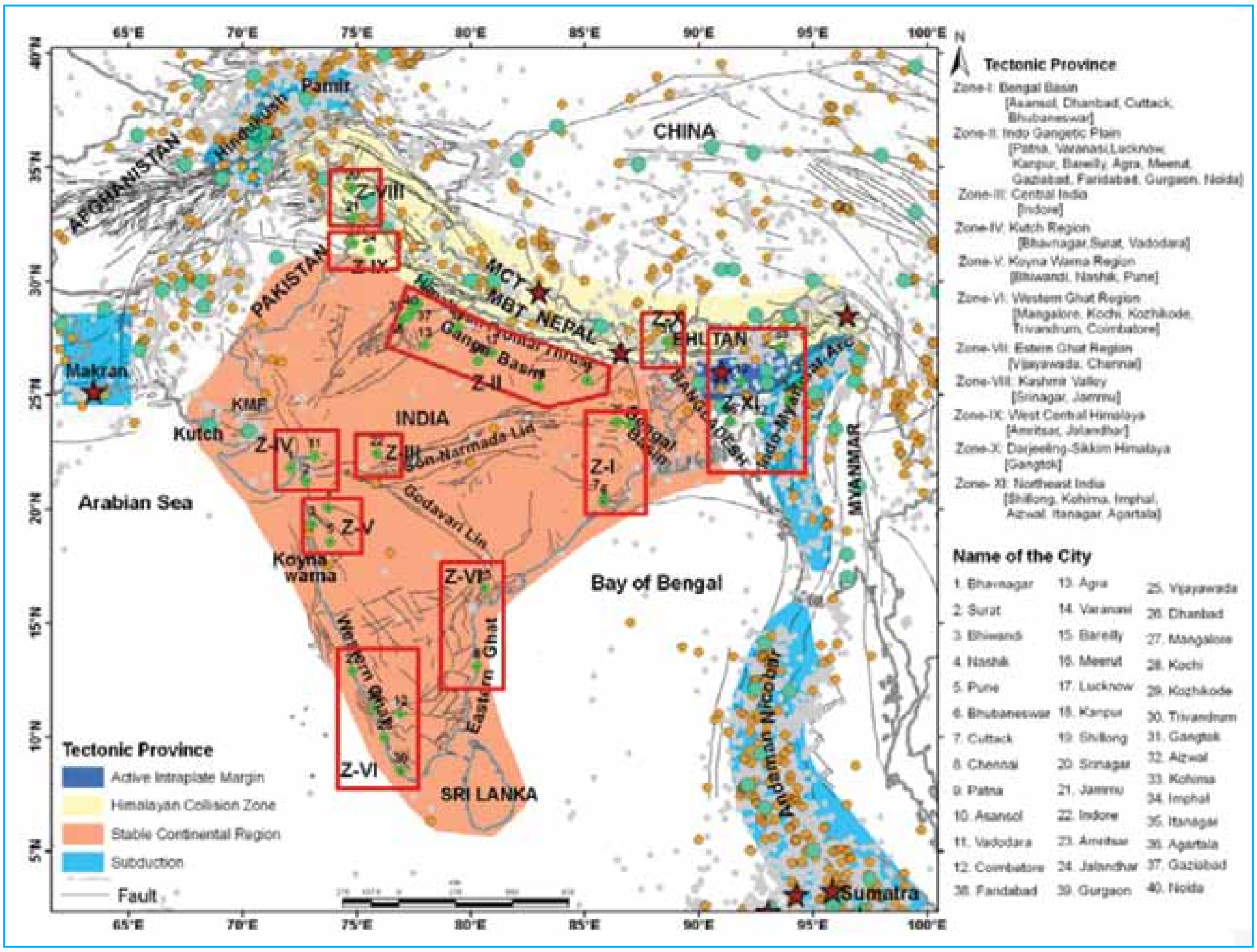


Fig. 5.3: Seismotectonic map of the Indian Subcontinent with eleven Tectonic Provinces viz. (i) Bengal Basin, ii) Indo-Gangetic Plain, (iii) Central India, (iv) Kutch Region, (v) Koyna Warna Region, (vi) Western Ghat Region, (vii) Eastern Ghat Region, (viii) Kashmir Himalaya, (ix) West Central Himalaya, (x) Darjeeling-Sikkim Himalaya, and (xi) Northeast India identified for PSHA

5.1.5 *Active Fault Mapping:*

Identification of an active fault is critical for realistic assessment of the seismic hazard, particularly for critical structures like nuclear facilities, large dams, and defence installations. A major programme on Active Fault Mapping (AFM) has been initiated to map and characterize the active faults in the country and to prepare a library of active fault data that would help in undertaking seismic hazard assessment in different parts of the country. Three areas, namely, North-west and Central Himalaya, North-east Himalaya and Kachchh regions have been selected as priority areas to start with. In this context, two comprehensive projects for two regions viz. NW & central Himalaya and Kachchh region, Gujarat were evolved. These projects are being implemented in multi-institutional mode. Data generated through this programme would have direct utility in seismic hazard assessment and other important projects such as laying of railway lines, construction of power plants and underground tunnels.

5.1.6 *Scientific Deep Drilling in the Koyna Intra-plate Seismic Zone, Maharashtra:*

Scientific Deep Drilling project in Koyna is aimed at setting up of borehole observatory 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, leading to a better understanding of the mechanics of faulting, physics of reservoir triggered earthquakes and preparing a predictive model.

Borehole Geophysics Research Laboratory (BGRL), Karad has undertaken scientific deep drilling and associated investigations in the Koyna seismic zone, Maharashtra. The plans for drilling of the first 3km-deep pilot borehole in Koyna region including, downhole measurements and sampling are in place. Drilling of Pilot hole has already started in December (Fig.5.4). A Drilling Information System (DIS) has been configured and tested, specifically, for the Koyna drilling project in collaboration with ICDP.

Fig. 5.4: Snapshot of drilling rig at Pilot borehole site

During the course of the past one year, a number of basic laboratory facilities have been set up at the temporary premises of BGRL to cater to routine investigations. *Petrology Laboratory* including, facilities for preparation of thin sections and microscopy has been established. Petrography and microstructure studies on core samples from Koyna-Warna area are being carried out to characterize deformation processes. *Geothermal Laboratory* has been established with capabilities to measure thermal conductivity of cores and cuttings. *Core Scanning Laboratory* housing a high resolution 360° scanning system is now functional.

Geological core logging and petrological studies on Deccan basalt and underlying basement granitoids in the Koyna-Warna region have been carried out to characterize the deformation processes associated with seismic and other tectonic activities. Variations in rock strength are found to correlate well with structural features. Thermal conductivity measurements carried out on drill cuttings of basalt and granitic basement rock have brought out clear-cut differences in thermal properties between the two formations consistent with the measured geothermal gradients. BGRL provided core samples to several research groups in the country to carry out multi-disciplinary studies.

Bhoomi Pujan function for construction of BGRL building complex comprising a state-of-the-art core repository, main laboratories, office building and other infrastructure at Hazarmachi, Karad was held on Feb 01, 2016 in the presence of Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences, Dr. M Rajeevan, Secretary to Govt. of India, MoES and other distinguished dignitaries (Fig. 5.5). The construction activities have made commendable progress during the past few months.

5.2 Geological and Geophysical studies:

5.2.1 Crustal Processes:

5.2.1.1 High-grade granulite terrain:

A quarry in Trivandrum block was selected to investigate the redistribution of chemical elements, particularly the heat-producing elements Th, U and rare earth elements (REE) associated with crustal melting and channeling of fluids liberated during the crystallization of the melts following peak pressure-temperature

Fig. 5.5: Dr. Harsh Vardhan, Hon'ble Union Minister, Science & Technology and Earth Sciences at Bhoomi Pujan ceremony of BGRL on Feb 1, 2016 at Hazarmachi, Karad, Maharashtra.

conditions. Zircons and monazites in the metasediments indicate Paleoproterozoic high temperature metamorphism and anatexis. The scientists of NCESS, Thiruvananthapuram engaged in the study found that some of the meta-sedimentary rocks are polymetamorphic with HT metamorphism at about 1960-1900 Ma and then again at 570-530 Ma. The study inferred that the Trivandrum block could be part of the Paleoproterozoic supercontinent Columbia, as well as the latest Neoproterozoic to Palaeozoic supercontinent Gondwana.

A four stage evolution crustal model has been proposed for the formation of Charnockites (felsic ortho granulites) of the Kerala Khondalite Belt in southern India. a) All these magmatic events are fairly well correlated with the major episodes of crustal growth observed in the once contiguous continental fragments of East Gondwana.

5.2.1.2 Palaeofluids in the petroliferous basins of Western offshore, India:

Sidewall cuttings and core samples from RV-1 of Ratnagiri offshore, Mumbai and KK-4C-A-1 non-producing wells in non-proven Ratnagiri and Kerala-Konkan basins were studied by NCESS in collaboration with ONGC, Govt. of India. Preparation of wafers from RV-1 has been completed. About 20 samples from 600 samples of Kerala basin have been prepared. Photoluminescence (PL) emission technique was used to determine the American Petroleum Institute's (API) gravity of HCFIs. The relation between API gravity and fluorescence emission ratio was established using crude oil samples with known API gravities in terms of an empirical equation the value at F620/F560 and its feasibility was verified with the HCFIs from Mumbai offshore basin (Fig.5.6). The feasibility of a 785 nm laser was explored to

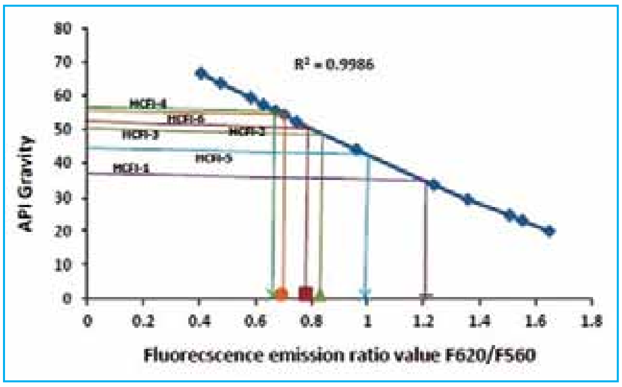


Fig.5.6 Relation between API gravity and fluorescence emission ratio at F620/F560

characterize the HCFIs in the two well samples. The presence of aromatic compounds was found and the results are correlated well with the data from GC-MS.

5.2.2 Coastal Processes:

5.2.2.1 Locally and remotely generated wind waves in south-western shelf Sea (SWSS) of India:

The study primarily focused on analysis of generating and controlling factors of wave features in SW shelf of India. The presence of short period northwest waves persist for several hours to a few days in this region during pre and post monsoon season because of the change in direction of wind field in the northeastern Arabian Sea. Similar nature of wave pattern can be observed during Shamal and non-shamal period also. The directional spectra during monsoon season for this region is entirely different from that observed in the other part of western shelf sea. In addition to this, the wave height in this region increases from north to south in contrast to other parts of this shelf sea during monsoon season. The co-existence of monsoon swells and southern ocean swells during monsoon season leads to strong directional bimodality in swell frequency range. The sea breeze plays important role in diurnal variation of wave climate of SWSS. However, there is a phase lag in maximum significant wave height between southern and northern SWSS during the months of January to March but there is no phase lag for zero crossing periods.

5.2.2.2 Coastal monitoring system for the west coast:

Recent reports on the increase in number of extreme events and their intensities during the last few decades require continuous monitoring of the coast. Accordingly NCESS, Thiruvananthapuram has taken up a specific study which has two major components viz. collection of primary data and in-house development of software tools to derive vital information on the parameters that influence the coastal and beach processes. A remotely operable Video Imaging System has been installed at Valiathura beach in Trivandrum and which is probably the first of its kind installed along the Indian coast for continuous beach monitoring. The installation of the various components of the beach monitoring system at Valiathura was completed during July, 2016 and the entire unit was commissioned on 29th September 2016.

5.2.3 Atmospheric Processes:

In India, regions adjoining the Western Ghats are known to have relatively high (~118) lightning incidences. A study has been carried out by NCESS, Thiruvananthapuram on cloud parameters. The nature of spatial and temporal distribution of past incidents, type of thunderclouds which cause lightning, the topography, proximity to mountain range and sea point to the possibility of the Western Ghats mountain weather aiding in Cumulonimbus (Cb) cloud formation are important areas of study. In addition, as the weather in Western Ghats region is conducive for the formation of clouds, it is an ideal site to study the precipitation microphysics, cloud formation and its propagation over southern India. As part of the programme the team of scientists have identified the network of location for establishment of lighting sensors across the Western Ghats in collaboration with IITM, Pune.

5.2.4 Natural Resources and Environmental Management (NREM):

5.2.4.1 Hydrological response of river basins to climate changes:

The west coast of the Indian peninsular region is home to many small river basins with catchment area < 10000km^2. These rivers are fed essentially by precipitation from SW and NE monsoons. Therefore, any change in monsoon precipitation will have a direct effect on the socio-economic and environmental settings of the region. A study was undertaken by NCESS to know the effect of climate change on the discharge characteristics of four important river basins draining the Kerala part of SW India such as Chaliyar (River Length: 169km/Catchment Area 2933km^2, Bharathapuzha (209km/6186km^2), Periyar (244km/5398 km^2) and Pamba (176 km/2235 km^2) as an example. The study shows an increasing trend in the maximum temperature and a declining trend in the number of rainy days in all the four river basins, indicating that there is a potential risk for the water resources in these basins. This was confirmed by the falling trend in the annual and seasonal stream flow during the same period. Among the studied river basins, the Periyar river showed the maximum decline in the discharge due to the severity of the natural and anthropogenic reasons because of its peculiar geo-environmental setting. The results of the study points to the imminent need for integrated catchment treatments to improve health of the hydrological system of the rivers in general and Periyar river in particular.

5.2.4.2 Isotopic studies of water samples in the upper catchments of Periyar river, SW India:

A study was carried out by NCESS on oxygen and hydrogen isotopes. Stable isotope ratio for oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) in groundwater is an excellent tool to identify the sources of water as well as the different processes such as evaporation and mixing. The plots of $\delta^{18}O$ versus $\delta^{2}H$ for both the surface and ground water of Periyar river catchment reveals its close affinity with rain water indicating that the water reaching the river did not get enough time to interact with the channel substrate because of the high gradient, rocky nature of the terrain (fig. 5.7). This is very evident from the plot of Local Meteoric Water Line (LMWL) established for rainwater. The LMWLs for surface and groundwater were falling very close to that of rainwater. An inter-comparison of the isotopic compositions of rainwater with those of the adjoining regions reveals not much deviation in their isotopic composition. Studies are in progress to discriminate the effects of natural and anthropogenic signals in the surface and ground water regimes of the Periyar river basin, which hosts one of the fast developing urban – cum- industrial center's in South India, the Kochi City.

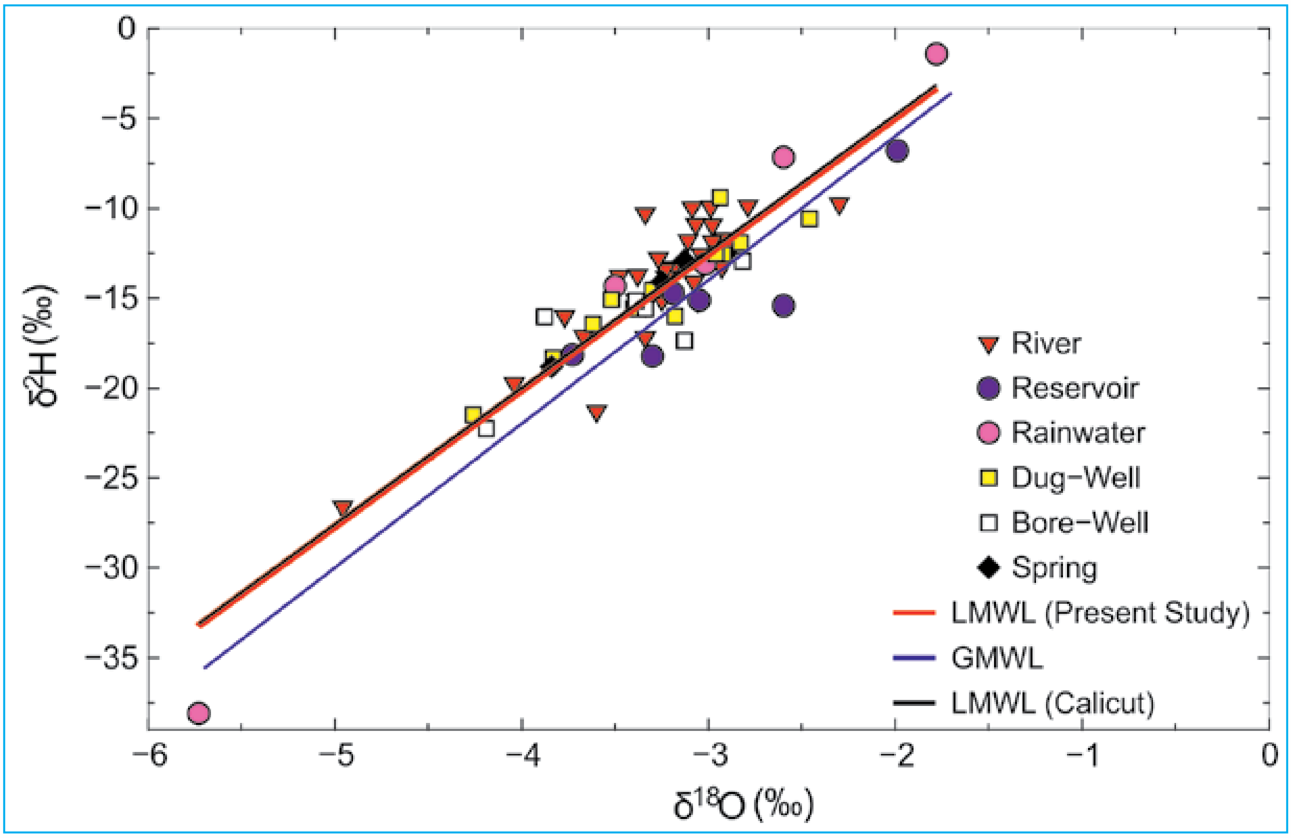


Fig 5.7: Relationship between $\delta^{18}O$ and $\delta^{2}H$ of rain, river and groundwater samples of Periyar river.

5.2.5 Setting up of a national facility for Geochronology:

A national Geochronology Facility is being set up at Inter-University Accelerator Centre (IUAC), New Delhi to cater to the need of geoscientists of the country. This facility will have two major machines, viz. Accelerator Mass Spectrometry (AMS) and 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.

6. RESEARCH, EDUCATION, TRAINING AND OUTREACH (REACHOUT)

The programmess of ESSO-MoES are interdisciplinary in nature. To achieve the goals, specialized manpower in the field of earth system science is required. 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, 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.

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 forecasts. 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.

6.1 Centre For Advanced Training in Earth Systems Sciences and Climate (CAT-ESSC)

The Centre for Advanced Training in Earth System Sciences and Climate (CAT-ESSC) was established during the mid-term stage of the XI plan and has been functioning from ESSO-IITM, Pune since then. The main objective of the Centre is to create a large pool of trained and dedicated earth system and climate system scientists for the country with in-depth hands-on expertise on individual physical processes of the land, ocean, atmosphere, biosphere and cryosphere with special emphasis on modeling. During the current year, following training Programmes/Workshops have been conducted.

- IITM's regular PhD program training for IITM Junior Research Fellow (JRF) 2015-16 batch as well as for 2016-17 batch of 14 students each has been conducted.
- A workshop on "Eddy Covariance and GHG Flux Estimation" was organized at IITM during 7-12 November 2016 to train young researchers in different aspects of Green House Gases (GHGs) research in India.
- A workshop on “NWP and probabilistic forecasts” has been conducted from 6-8 Dec 2016 for the benefit of field forecasters of IMD.

During Feb-March 2017, CAT- ESS is conducting two workshops, viz., (i) an international event called INTROSPECT-2017 which will focus on “Model Physical Parameterization Schemes” (ii) Climate Resilience workshop in collaboration with NASA, United States.

6.2 Training In Operational Meteorology

The Training School in Operational Meteorology approved in 2013-14 is being implemented at ESSO-IMD, Pune. One year training of 61 new Meteorologist Gr II (Scientist-B) in 2 batches has been completed along with Advance Meteorological Training Course (AMTC). The 1 year training of fresh batch of Meteorologist Gr II trainees is currently going on. Two intermediate training courses, WMO Group course on Instrument Maintenance & Calibration, Integrated Met Training Course and a refresher course in Aviation Meteorology have been also conducted. Six-month Forecasters training course was also conducted during 2016-17.

International Student hostel to be jointly shared between by ESSO-IMD and ESSO-IITM for the activities of the two training schools was completed and was inaugurated on 23 June 2016 (Fig 6.1). The International Students hostel "PRITHVI" is a 10-story building comprising of 215 single occupancy rooms for students and researchers and 12 guest rooms and is well-equipped with essential facilities.

6.3 International Training Centre for Operational Oceanography

The International Training School for Operational Oceanography (ITCOOcean) established at ESSO-INCOIS in 2012 supports capacity building activities in the field of operational oceanography for the Indian Ocean Rim (IOR) and islands region countries 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 2016-17, the Centre conducted the following international training programmes :

- Indian Ocean Currents: Data, Processing and Applications during 7-11 Nov 2016 for 27 participants.
- International Winter School on Operational Oceanography: Indian Ocean Circulation and Sea Level Variation during 16 - 21 Oct 2016 for 28 participants out of which 13 were foreigners.

Fig 6.1: Prithvi-The hall of Residence

- Regional Training for Capacity Development in Multi-Hazard Early Warning Systems during 19-23 Sep 2016 for 12 participants involving 6 foreigners.
- Emerging Trends in Ocean Observations and Ocean Data Analysis during 04-15 July 2016 for 55 participants.
- Tides and Tidal Data Analysis during 13-17 June 2016 with 25 participants.

A joint training programme of Ocean Teacher Global Academy (OTGA) of IODE-IOC and ITCOocean on 'Discovery and Use of Operational Ocean Data Products and Services' is scheduled to be held during 16-20 Jan 2017.

6.4 BIMSTEC-Center for Weather and Climate

Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) Center for Weather and Climate (BCWC) established at ESSO-NCMRWF has been providing forecast products including extreme rainfall forecasts for the BIMSTEC countries. These are disseminated through ESSO-NCMRWF website. Research work to further improve the forecast products are being carried out. One scientist from Myanmar is currently visiting NCMRWF for training and research.

6.5 R & D Funding in Earth & 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, ESSO-MoES 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 & Resources, (iv) Hydrology & Cryosphere; (v) Earth System Technology.

The Apex committee recommended-in principle the Proposal on *Natural History Park and Museum and Research Institute at Visakhapatnam (NHPM & RI)* by Department of Forests, Govt. of Andhra Pradesh and *Natural History Society of India (NHSI)"*. Another proposal namely "Advanced Research in Hydrology and Knowledge Dissemination" by IISc Bangalore was also recommended.

The following research projects in focused research areas were funded

(i) Atmospheric Research:

- Tropospheric and lower stratospheric processes over the northern Arabian Sea and their influence on the variability of Indian Summer Monsoon by National Institute of Oceanography, Goa.
- Investigation of Aerosol-cloud forced climate changes over India: a multi-satellite approach by University of Pune.
- Environmental Noise mapping for Guwahati City by Indian Institute of Technology, Guwahati .
- Investigation of some alternative atmospheric layer scaling properties over complex terrains of Himalaya by GB Pant Institute of Himalayan Environment & Development.
- Quantification of impact of global warming on changes in precipitation patterns over India by Sathyabama University.
- Improvement in heavy rainfall prediction over Eastern sector of India using high resolution mesoscale modelling system by NIT Rourkela.

(ii) Geoscience:

- Palynoflora, reptilian tetrapods and clay minerals of sediments associated with Deccan Continental Flood Basalts of the Malwa Group, Dhar district, Madhya Pradesh: a biotic response to climatic changes by RTM Nagpur University.
- Development of structural criteria for aquifer mapping in the Precambrian terrains of Ambaji region of North Gujarat, India by IIT, Bombay.
- Geochemistry and C, O, Sr, Nd, Fe, Cr and Mo isotopic compositions of carbonate rocks from greenstone belts of the Dharwar craton: Implications to ocean redox state, oxygenation and carbon burial during Archean by Pondicherry University.

(iii) Hydrology & Cryosphere:

- Estimation of glacier mass balance, glacier dynamics and surface flow using UAV's (Unmanned Aerial Vehicles) in Baspa Basin, Himachal Pradesh - Dept. of Environmental Science, School of Basic Sciences & Research, Sharda University, Greater Noida.
- A scoping proposal to build a two dimensional ice-flow model for basin-scale glacier simulation in the Himalaya-Indian Institute of Science Education and Research Pune.

(iv) Ocean Science:

- Hydrocarbon degrading bacterial emulsifiers from southeast coasts of India.
- Potential impacts of climate change on extreme waves and wave induced sediment transport, coastal erosion/ siltation and shorelines shifts.
- Morbidity, mortality, intensity and impact of ovarian parasitic nematode infection on fecundity of keystone fishes of Bay of Bengal.
- Cyanobacterial biodiversity studies in the regional mangroves.
- Bay of Bengal mesoscale eddies role on rainfall, convection and winds.

(v) Technology Research Board

a. Development of Ka Band Polarimetric Doppler Radar for Cloud Profiling: A project has been approved with funding to Applied Microwave Electronic Engineering and Research (SAMEER), Mumbai to develop a Ka Band Polarimetirc Doppler Radar for cloud profiling. All the sub-systems like 1.8 m dia Cassegrain antenna, antenna drive, exciter, EIKA transmitter, FPGA based transmitter controller and monitoring unit, power distribution unit, DC power supply unit, dual-channel IF receiver have been tested and the system level integration is currently being done. The Ka Band Polarimetric Doppler Radar System would be fully integrated in 2017.

b. Solar Multi-Effect Desalination System: The project for development and setting up of Solar Multi-Effect Desalination (MED) System at Vivekanand Kendra, Kanyakumari is being implemented by IIT, Chennai. The project is sub-divided into four individual sub-systems namely, Multi-Effect Desalination (MED) system, Solar thermal flat plate collector (FPC) water heating systems, Off-grid ground mounted solar photovoltaic (PV) power plant system, Sea water intake and drain system, Distillate Re-mineralization unit and integration of plant subsystems. The detailed design, tendering and ordering, procurement, erection and installation of various subsystems were carried out. The MED system installation work is under progress.

6.6 Earth System Science and Technology Cells (ESTC):

The objectives of ESTC program is to develop theme based network projects involving researchers from various universities, colleges and academic institutions to work together on a specific theme with a Principal Investigator from the lead university acting as ESTC's Principal Coordinator (PC). 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.

Three new ESTCs have been established addressing various aspects of Earth science. The ESTC at NITK, Suratkal, Mangalore, Karnataka is responsible for implementing the network project on "Coastal and Ocean Technology (COT) with initial project entitled "Hydrodynamic performance characteristics of Caisson type breakwater".

The second ESTC on "Satellite Meteorology" established at SRM University, Chennai, Tamil Nadu aims to study Atmospheric Boundary layer using space-borne and ground based techniques, and to study Tropospheric Warming and Stratospheric Cooling using GPSRO.

The third ESTC established at M.K. Bhavnagar University in 2013 on "Marine Coastal Ecology of West Coast of India", involves nine universities/Institutes. The network project comprise of twelve sub projects in marine biodiversity and marine pollution.

An ESTC to set up "Marine Biotechnological Studies" at Sathyabhama University, Chennai will be soon established with an aim to augment marine living resources and biotechnology in collaboration with NIOT and CMLRE; to identify the R & D requirements and to fulfill the gap to develop potent marine bioactive products; to establish collaboration between National and International institutions and to create infrastructure facilities related to advanced research in marine biotechnological studies.

6.7 National Coordinated Program:

The Program, Continental Tropical Convergence Zone (CTCZ) involving multi-institutes is a National coordinated program which was recently successfully completed. The overall objective was to understand the mechanisms leading to space-time variation of the CTCZ and the embedded monsoon disturbances during the summer monsoon. The science foci of the CTCZ programme comprised some important phenomena and process studies. Accordingly, the CTCZ objectives were divided into following three major components. (1) Land-surface processes, atmospheric boundary layer, clouds, aerosols. (2) Ocean Processes, convection over the ocean and air sea interaction. (3) Large scale component. CTCZ involved field experiments, analysis of existing data from conventional platforms as well as satellites, buoys, ARGO floats, and theoretical studies with process models, complex atmospheric general circulation models, as well as coupled ocean-atmosphere models. 17 projects have been executed under the CTCZ programme. CTCZ program could generate large data sets, both atmospheric and oceanic, which will be very useful in the analysis and understanding of monsoon systems and R&D on monsoon.

15 research papers in refereed journals are already published. CTCZ Data Centre has been set up at ESSO-INCOIS., Hyderabad.

6.8 Human Resource Development and Capacity Building

- Five MTech and five PhD students in various fields of Earth Sciences at IIT Delhi under the existing MoU between MoES and IIT Delhi on Atmospheric and Oceanic Sciences have been supported.

ESSO Chairs/Visiting Chairs:

- Prof. J.C.R. Hunt, Cambridge University, UK is presently occupying the Sir Gilbert Walker MoES Chair Professor at IIT Delhi and he will be visiting IIT Delhi during Feb-Mar 2017.
- Prof. V. Chandrasekar, Department of Electrical & Computer Engineering, Colorado State University, Fort Collins CO 80523 has accepted the offer of the position of Samudragupta MoES Chair Professor at IIT Kharagpur.

6.9 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 programme of the Ministry. In addition "Earth Day" and "Ozone Day" are celebrated with the participation of School, College and University students. Ministry also supports the National and International Earth Science Olympiads.

6.9.1 Exhibitions

During the year, the Ministry participated in 18 Exhibitions. The details are as follows:

i. India International Trade Fair-2016, 14-27 November, 2016 at Pragati Maidan, New Delhi.

Fig. 6.2: Ministry's pavilion during India International Trade Fair 2016, New Delhi

ii. India International Science Festival-2016, 07-11 December 2016 at CSIR-NPL, New Delhi.

Fig.6.3: Ministry's pavilion during the India International Science Festival 2016 at CSIR-NPL, New Delhi

Fig. 6.4: Ministry's pavilion during Indian Science Congress-2016

iii. Indian Science Congress-2016, 3-7 January 2016, Mysuru, Karnataka.

6.9.2 Earth Day Celebration-2016

"Earth Day" has been celebrated across the country on 22nd April 2016 and the event was organized at 36 centers across the country including schools, college and universities. The theme for the Earth Day was "Caring Mother Earth". The organizers arranged various competitions like drawing and painting, debate, essay, Tree plantation, 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, prizes at National level was distributed on Ministry's foundation day.

Fig. 6.5: Tree plantation and Painting Competition being organized in different parts of the country.

Fig. 6.6: Children Awarded for painting Competitions for Earth day 2016 at Vigyan Bhawan, New Delhi

6.9.3 Ozone Day Celebration-2016

"Ozone Day" has been celebrated across the country on **September 16th 2016** and the event was organized at 2 centers. About 300 children participated in this event.

6.9.4 Participation in International Earth Science Olympiad

MoES sponsored the 10th International Earth

Science Olympiad (IESO) was conducted at Mie University, Tsu, Honshu, Japan during 20-27 August 2016. Children from 26 Countries participated in the event. The Indian team won three silver medals.

Fig. 6.7: 10th International Earth Science Olympiad (IESO) was conducted at Mie University, Tsu, Honshu, Japan. The Indian team won three silver medals.

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

About 100 events which include seminars, conferences & workshops, field programmes, training activities etc are being supported in area of Earth System Science to provide platform to scientists, engineers, technologists, experts, social scientists and user communities for exchanging information and knowledge. The beneficiaries are National Institutes, CSIR labs, Universities, Non-Governmental organizations, government bodies, etc.

The major areas where the Ministry supported include climate change and impact on health; 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 modelling and simulation; fish development etc.

7. INTERNATIONAL COOPERATION

Research and development is an international endeavour which forms an integral part of the activities of ESSO-MoES. Engaging with the best institutes overseas in the field of Earth system Science, broadens the scope of trans-national research through linking researchers with different skills and expertise in various countries and enriching the experience with overseas partners, introducing them to new skills and ideas. Moreover collaborative research accelerates the growth of new knowledge and enhances scientific deliverables. Therefore ESSO-MoES regularly engages with scientists overseas for furthering its research capabilities for reliable weather and climate services. The progress under various collaborations is as follows.

7.1 Cooperation with NOAA,USA:

Under this Memorandum of Understanding (MOU) originally signed in 2008, ten joint research and development activities have been undertaken with identified Principal Investigators 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. The Statement of Intent (SoI) on a research project "Development of predictive capabilities on Marine Fisheries and Harmful Algal Blooms in Indian seas" between National Oceanic and Atmospheric Administration (NOAA), USA and MoES was signed in August 2013. Under this SoI, four workshops were held at ESSO-INCOIS and ESSO-CMLRE which provided a platform for exchange of ideas and capacity development. In order to continue our efforts in expansion of capacity building and training in the field of modeling namely habitat model for improving dwindling fishery stocks, fisheries model, radiative-transfer-models etc, the SoI is extended for another 3 years till 15 August 2019. Another Statement of Intent (SoI) on "Development of an ocean wave modelling and assimilation system for the Indian Ocean Region" between NOAA, USA and MoES was signed in Nov. 2014 under which the Multi-grid WAVEWATCH III has been upgraded to WAVEWATCH III version 4.10 to provide 10 days global wave forecast on daily basis. The development of a wave surge forecast system for the Indian coastal region using WAVEWATCH III+SWAN+ADCIRC has been initiated at INCOIS. In order to continue for improvement of wave forecast especially during North East monsoon season, the SoI is now extended for further 2 years till 14 Nov 2018.

The fourth meeting of Indo-US Joint S&T Commission was held during 29-30 September, 2016 in Washington, DC. The current activities under Atmospheric, Environmental and Earth Sciences Working Group were reviewed and new areas of opportunity have been identified.

7.2 Cooperation with International Seabed Authority (ISA):

The Ministry of Earth Sciences (MoES) signed a 15 years contract on September 26, 2016 with the International Seabed Authority (ISA) (an Institution set up under the Convention on Law of the Sea to which India is a Party) for exploration of Poly-Metallic Sulphides (PMS). The ISA had earlier approved an application submitted by the MoES for allotment of 10,000 sq. km. area along with 15 years work plan for exploration of Polymetallic Sulphide (PMS) along Central Indian Ridge (CIR) & Southwest Indian Ridge (SWIR) region of the Indian Ocean. By signing the 15 year contract, India's exclusive rights for exploration of Polymetallic Sulphides in the allotted Area in the aforesaid region will be formalized. Further, it will enhance India's presence in the Indian Ocean where other players like China, Korea and Germany are active.

7.3 Cooperation with UK Met Office (UKMO)

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 was undertaken. MoES has joined the consortium with the U. K. Met Office (UKMO), Korea Meteorological Administration (KMA), the Commonwealth Scientific Industrial and Research Organization (CSIRO) and National Institute of Water and Atmospheric Research Limited, New Zealand at an Annual Contribution of £ 100,000. The state-of-art global, regional and convective scale model with horizontal resolutions of 17, 4 and 1.5 km respectively have been implemented along with a global data assimilation system using observations from Indian/International Satellites. Regional version of the UM model at horizontal resolutions of 4 km, 1.5 km and 330 m were implemented for various applications like severe weather, fog and thunderstorm predictions for all India domain as well as city domains.

7.4 Cooperation with NERC (Natural Environmental Regional Council), United Kingdom:

7.4.1 MoU for undertaking joint research initiative on 'The Changing Water Cycle':

The joint NERC-MoES Changing Water Cycle programme was launched in 2010 with an aim to improve understanding of how the water cycle in India is changing and the likely impacts. Five projects supported under this program have been now completed.

7.4.2 MoU on Cooperation in Earth Sciences:

Under this MoU, signed in 2013, three implementing agreements (IA) have been signed

- ***Implementing Agreement (IA) on Predicting the Variability of the South Asian Monsoon*** Monsoon research is an initiative undertaken under the MoES-NERC MoU under which a commitment of about 3 million euro from UK side with matching funding from MoES has been made. Under this IA, three projects involving Indian and UK scientists will study different aspects of physical processes affecting the monsoon. To address the issue of better *measurement and understanding of small-scale processes* that drive the variability, seasonality and predictability in the South Asian Monsoon, a large-scale joint observational campaign was carried out during the period June-July 2016 involving the deployment of UK's BAe-146-301 atmospheric research aircraft with sophisticated scientific instruments and India's Sagar Nidhi and Sindhu Sadhna research ships. Subsequent to obtaining all permissions to fly the aircraft on Indian airspace, the campaign successfully completed on 12th July 2016. The data, vetted by the Ministry of Defence is now being used by the scientists for scientific understandings of the monsoon variability.

- ***IA on Atmospheric Pollution and Human Health in an Indian Megacity:*** Following a workshop on Atmospheric Pollution and health, in May 2015, an IA was signed between ESSO-MOES and Department for Biotechnology (DBT), Govt of India and UK's Natural Environment Research Council (NERC) and the Medical Research Council (MRC) on *Atmospheric Pollution and Human Health in an Indian Megacity* with an aim to provide new knowledge on air pollution issues and impacts on health in a rapidly urbanising society and the evidence to support cost-effective measures for health improvements related to atmospheric pollutants in Delhi, India. This programme will be delivered by a research partnership between UK and Indian scientists. NERC and MRC have jointly made available £6.5m for this programme (including support from the Newton Fund) and ESSO-MoES and DBT will provide matching funds. In response to a joint call in September 2015, five proposals, have been accepted for funding. Out of these, four proposals will be funded by MoES and one by DBT.
- ***IA on Sustaining Water Resources for Food, Energy & Ecosystem Services in India:*** Three projects covering three main geographic regions of India: the Himalayas, the Indo-Gangetic Plain and Peninsular India are selected for funding. The aim is to develop a framework for integrated basin-wide models that incorporate each of the processes within the basin at a temporal and spatial resolution that enables informed decision-making about the management of water resources.
- ***India-UK Virtual Joint Centre on Water Security:*** MoES and the NERC have set up a "India-UK Virtual Joint Centre on Water Security". The Centre is hosted by IITM, Pune and Centre for Ecology and Hydrology, UK. The centre will provide a platform for joint hydrological research and greater dialogue, engagement and knowledge transfer between researchers, policymakers and business. The centre will fund and co-ordinate a diverse programme of workshops and exchange visits of scientists.

7.5 Cooperation with Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan:

India signed an MoU with JAMSTEC, Japan in November 2016 for advancement of academic research in the field of Earth Sciences for the benefit of the peace and human welfare.

7.6 Cooperation with Belmont Forum Countries:

Under an MoU signed in February 2013, between MoES and the Belmont forum Countries MoES is participating in 4 Collaborative Research Areas (CRA) namely Coastal Vulnerability, Food Security, Biodiversity and Ecosystem Services, and Climate Predictability and Inter-regional linkages. Under the CRA on Climate Predictability and Inter-regional linkages, four projects with Indian PIs have been funded during 2016-17 which are as follows :

- PAlaeo-Constraints on Monsoon Evolution and Dynamics (PACMEDY) by IITM Pune.
- High Impact Weather Events in EurAsia Selected, Simulated and Storified (HIWAVES3) by IIT Gandhinagar.
- Globally Observed Teleconnections and their role and representation in Hierarchies of Atmospheric Models (GOTHAM) by IITM, Pune.
- Better understanding of Interregional Teleconnections for prediction in the Monsoon And Poles (BITMAP) by NCMRWF.

Under the CRA on Biodiversity and Ecosystem Services, one project on "Biodiversity and Ecosystem Service Scenarios Network (ScenNet) by Centre for Economic and Social Studies (CESS), Hyderabad has been funded. The projects, working in collaboration with 9 countries focuses on networking and capacity building in all nine countries participating in this network and will substantially contribute to the newly initiated Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and Future Earth.

7.7 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. Following two workshops on Geo-hazards and polar research in India, a joint call inviting proposal with Indian and Norwegian participants side was launched in February 2015. Subsequent to a joint review mechanism, three proposals in Geohazards and five proposals in Climate Systems in Polar regions were recommended for funding.

7.8 Cooperation with RIMES:

The Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) is an international and intergovernmental institution, owned and managed by its Member States (12 Member States and 19 Collaborating Countries), for the generation and application of early warning information. With an aim to strengthen African and Asian countries by placing observation networks and proving advisory services on Ocean Forecast and Tsunami information, INCOIS under MoES has funded the Development and Implementation of an Integrated Ocean Information System for four Indian Ocean Countries namely: Comoros, Mozambique, Seychelles and Sri Lanka. The data from the wave rider buoy is used to validate the forecast for Seychelles coast.

7.9 Cooperation with UNESCO/IOC:

Following the agreement signed in 2013, on activities related to capacity building through International Training Centre for Operational Oceanography (ITCOocean), 17 training programmes were conducted for capacity development in the areas of operational oceanography. The training was imparted to about 490 trainees from India and 73 trainees from 23 countries mainly from the Indian Ocean rim countries and Africa were conducted. Between April 2016 – Nov. 2016, 3 National and 2 International training courses were conducted and 147 trainees including 18 foreign participants were trained. A joint training programme of Ocean Teacher Global Academy (OTGA) of IODE-IOC and ITCOocean on 'Discovery and Use of Operational Ocean Data Products and Services' is scheduled to be held during 16-20 Jan 2017.

Implementing Agreement for membership

of India in the International Energy Agency – Ocean Energy Systems (IEA-OES). India became a member of the IEA-OES through signing of the Implementing Agreement. By becoming a member of the IEA-OES, India will have access to advanced R&D teams and technologies across the world. The International Energy Agency (IEA) is an intergovernmental organization with a broad role of promoting alternate energy sources (including renewable energy).

7.10 South Asia Co-operative Environment Programme (SACEP):

MoES is nodal agency for South Asian Seas Programme (SASP), where a regional oil spill contingency plan is being developed by SACEP to promote and support protection, management and enhancement of the environment in the SACEP region. A national workshop was organised during 02-03 Feb 2015 by ICMAM with all national stake holders to discuss the draft regional Oil Spill Contingency plan. Plan has been updated and finalised by member states through regional workshops held in Colombo (Sri Lanka) during 02-06 Nov 2015 and in Male (Maldives) during 23-25 August, 2016.

7.11 Collaboration with State Oceanic Administration (SOA), China

The first joint committee meeting (JCM) between SOA, China and MoES, India on Marine Science and Technology was held in Beijing on May 17, 2016. Based on the discussion between Chinese scientists and a team led by Secretary, MoES, JCM identified 9 proposals to build collaboration between the two countries on monsoon research, ARGO deployment, Tsunami warning, ocean state forecasting, climate research and polar research. A total of 4 institutes from SOA and 5 institutes from MoES are participating in developing these proposals. It is proposed to evaluate the joint proposals to review and subsequently fund in house by the institutions under ESSO/MoES or as extramural research by MoES.

7.12 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 was established at National Center for Medium Range Weather forecasting (ESSO-NCMRWF), Noida. The forecast products from the NCMRWF global models for the BIMSTEC region are prepared in real time and disseminated through the NCMRWF website. Probabilistic predictions for the BIMSTEC region from the NCMRWF GEFS system are being evaluated.

7.13 43rd Session of WMO/ESCAP Panel on tropical Cyclones:

The 43rd Session of the World Meteorological Organisation/Economic and Social Commission for Asia and the Pacific (WMO/ESCAP) Panel on tropical Cyclones was organized in New Delhi during 2-6 May, 2016. The session reviewed and adopted various actions of Panel including Tropical Cyclone Operational Plan (TCP) for 2016-19, Co-ordinated Technical Plan for 2016-19 and Annual Operational Plan for 2016. The session inaugurated by Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences (MoES) was attended by 65 delegates including 25 International participants.

7.14 WMO's Regional Stakeholder Consultation on Climate Services for the Third Pole Region:

A regional consultation meeting was organized during 9-11 March, 2016 in Jaipur on the development of climate services for the mountainous Hindu-Kush-Himalayan region, known as the Third Pole, with a special focus on agriculture and food security, water management, health, disaster risk reduction and renewable energy. The meeting attended by more than 50 participants from countries in the region as well as experts from around the world, was inaugurated by Dr. M. Rajeevan, Secretary Ministry of Earth Sciences.

7.15 Regional Committee of Intergovernmental Oceanographic Commission for the Central Indian Ocean (IOCINDIO):

The objective of the IOCINDIO is to promote co-operation in the field of Ocean Science and Services among the countries in the region. The are 21 participants representing 19 countries of the central Indian Ocean. The 5th IOCINDIO was hosted in Chennai during 25th-27th April 2016 to promote cooperation in the Indian Ocean region.

8. PUBLICATIONS, AWARDS AND HONOURS

Publications

A total of 387 research papers were published in 2016 by MoES centres and under various programs of MoES, the details of which are given below.

Total Publications:	387
Publications with Impact Factor:	329
Publications without Impact Factor:	58
Cumulative Impact Factor:	785.6
Average Impact Factor :	2.03

Atmospheric and Climate Research, Observations Science Services (ACROSS)

1. Amudha B., Y. E. A. Raj, R. Asokan and S. B.Thampi, 2016, Spatial rainfall patterns associated with Indian northeast monsoon derived from high resolution rainfall estimates of Chennai DWR, **MAUSAM**, 67, 4, 767-788.
2. Amudha, B. Y. E. A. Raj and R. Asokan, 2016, Characteristics of movement of low level clouds associated with onset / wet spells of northeast monsoon of Indian sub-continent as derived from high resolution INSAT OLR data, **MAUSAM**, 67, 2, 357-376.
3. Amudha, B. Y. E. A. Raj. and R. Asokan, 2016, Spatial variation of clouding / rainfall over southeast Indian peninsula and adjoining Bay of Bengal associated with active and dry spells of northeast monsoon as derived from INSAT OLR data, **MAUSAM**, 67, 3, 559-570.
4. Anil Kumar V., G. Pandithurai, P.P. Leena, K.K.Dani, P. Murugavel, S. M.Sonbawne., R.D. Patil and R.S. Maheskumar, 2016, Investigation of aerosol indirect effects on monsoon clouds using ground-based measurements over a high-altitude site in Western Ghats, **Atmospheric Chemistry and Physics**, 16, DOI:10.5194/acp-16-8423-2016, 8423-8430.
5. Arora A., Suryachandra A. Rao, R. Chattopadhyay, T. Goswami, G. George and C.T. Sabeerali, Role of Indian Ocean SST variability on the recent global warming hiatus, **Global and Planetary Change**, 143, August 2016, DOI:10.1016/j.jhydrol.2016.08.040, 21-30.
6. Attri S. D., V. K. Soni, S. Tiwari, A. K. Srivastava, Shani Tiwari and Kanika Taneja, 2016, High aerosol loading over mega city Delhi in the western Indo-Gangetic plain: Optical characteristics, **MAUSAM**, 67, 3, 609-618.
7. Azad S., M. Rajeevan, 2016, Possible shift in the ENSO-Indian monsoon rainfall relationship under future global warming, **Scientific Reports**, 6:20145, DOI:10.1038/srep20145, 1-6.
8. Babu C. A., P. R. Jayakrishnan , H. Varikoden, 2016, Characteristics of precipitation pattern in the Arabian Peninsula and its variability associated with ENSO, **Arabian Journal of Geosciences**, online, DOI:10.1007/s12517-015-2265-x, 1-12.
9. Bera S., G. Pandithurai, and T. V. Prabha, 2016, Entrainment and droplet spectral characteristics in convective clouds during transition to monsoon, **Atmospheric Science Letters**, 17, DOI:10.1002/asl.657, 286-293.

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11. Bhan S. C., Surender Paul, Kalyan Chakravarthy, Rahul Saxena, Kamaljit Ray and Neetha K. Gopal, 2016, Climatology of Tornadoes over northwest India and Pakistan; and Meteorological Analysis of recent Tornadoes over the Region, **J. Ind. Geophys. Union**, 20, 1, 75-88.
12. Bhatla R., A. K. Singh, B. Mandal, S. Ghose, S. N. Pandey and Abhijit Sarkar, 2016, Influence of North Atlantic Oscillation on Indian Summer Monsoon Rainfall in relation to Quasi-Binneal Oscillation, **Pure and Applied Geophysics (PAGEOPH)**, 173(8), 2959-2970.
13. Bhatla R., A.K. Singh, B. Mandal, S.N. Ghosh, S. N. Pandey and Abhijit Sarkar, 2016, Influence of North Atlantic Oscillation on Indian Summer Monsoon Rainfall in Relation to Quasi-Binneal Oscillation, **Pure and Applied Geophysics**, 173(8), 2959-2970.
14. Bhatla R., Madhu Singh and D. R. Pattanaik, 2016, Impact of Madden-Julian oscillation on onset of summer monsoon over India, **Theoretical and Applied Climatology**, DOI:10.1007/s00704-015-1715-4.
15. Bhawar R.L., W-S Lee , R.P.C. Rahul, 2016, Aerosol types and radiative forcing estimates over East Asia, **Atmospheric Environment**, 141, DOI:10.1016/j.atmosenv.2016.07.028, 532-541.
16. Bisht D.S., Suresh Tiwari , U.C. Dumka, A.K. Srivastava, P.D. Safai , S.D. Ghude, D.M. Chate, P.S.P. Rao , K. Ali , T.V. Prabha, A.S. Panickar, V.K. Soni, S.D. Attri, P. Tunved, R.K. Chakrabarty, P.K. Hopke, 2016, Tethered balloon-born and ground-based measurements of black carbon and particulate profiles within the lower troposphere during the foggy period in Delhi, India, **Science of the Total Environment**, 573, DOI:10.1016/j.scitotenv.2016.08.185, 894-905.
17. Budhavant K.B., P.S.P. Rao, P.D. Safai, C. Leck, H. Rodhw, 2016, Black carbon in cloud-water and rain water during monsoon season at a high altitude station in India, **Atmospheric Environment**, 129, DOI:10.1016/j.atmosenv.2016.01.028, 256-264.
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21. Charan Singh, B. P. Yadav, Virendra Singh and Naresh Kumar, 2016, Unusual snowfall and thunder squalls over western Himalayan region during 2012, **MAUSAM**, 67, 4, 945-951.
22. Chate D.M., M.I.R. Tinmaker, M.Y. Aslam,

S.D. Ghude, 2016, Climate indicators for lightning over sea, sea-land mixed and land-only surfaces in India, **International Journal of Climatology**, online, DOI:10.1002/joc.4802, 1-8.

23. Chattopadhyay N., K. Ghosh and S. V. Chandras, 2016, Agrometeorological Advisory to assist the farmers in meeting the challenges of extreme weather events, **MAUSAM**, 67, 1, 277-288.
24. Chattopadhyay N., S. K. Roy Bhowmik, K. K. Singh, K. Ghosh and K. Malathi, 2016, Verification of district level weather forecast, **MAUSAM**, 67, 4, 829-840.
25. Chattopadhyay N., S. S. Vyas, B. K. Bhattacharya and S. V. Chandras, 2016, Evaluating the potential of rainfall product from Indian geostationary satellite for operational agromet advisory services in India, **Journal of Agrometeorology**, 1, 29-33.
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Patents:

Patent Number Granted to NIOT by the Patent office, Govt. of India: 278301 dated 20th December 2016 for a term of 20 years from 22/02/2008: A patent is awarded to National Institute of Ocean technology, Chennai for the invention of a broad band underwater transducer for Marine applications. The important features include operation over a wide band width from 4.5 to 11 kHz with a Transmitting Voltage Response (TVR) of 161 - 164 dB for a linear array. The innovative transceiver has the same size and weight of an existing technology. The Power output of the transducer can be regulated by the user for different marine applications like Echo sounding, Sub-bottom profiling and underwater imaging in addition to long range acoustic telemetry and surveillance for defense applications.

Awards and Honours:

- Ms. B. Amudha, Scientist 'D', RMC Chennai was awarded the prestigious WMO-Professor VilhoVaisala Award-2016 for the Development and Implementation of the Instruments and Methods of Observation in Developing Countries. She has been awarded for the work on the technical document WMO – IOM - 117 entitled "Survey on alternatives for dangerous and obsolete instruments: evaluation of the questionnaire and recommendations for alternatives". She is the first from India Meteorological Department and the second Indian to receive the Vaisala award from WMO.

Ms. B. Amudha, Scientist 'D' receiving the WMO-Professor Vilho Vaisala Award-2016 in TECO-2016 conference at Madrid, Spain

- Dr M. Rajeevan, Secretary has been elected as a Fellow of the Indian National Science Academy (INSA) and National Science Academy of India (NASI) in 2016. He has also been elected as a member of the International Academy of Astronautics and a Fellow of the Indian Meteorological Society.
- Dr R. Krishnan, Scientist-G, IITM Pune has been elected as a Fellow of the Indian Academy of Sciences (IASc).
- Dr. Vinu Valsala was elected as Indian National Young Academy of Science (INYAS) Member of Indian National Science Academy (INSA) for the period of 2016-2021.
- Dr. Gufran Beig became a member of WCRP Core-Project for Stratosphere-Troposphere Processes and their Role in Climate (SPARC) for an initial term of three years.
- Dr. Thara Prabhakaran was selected as a member of 'WMO Expert Team on Weather Modification' since January 2016.
- Dr. J. Sanjay was selected as a Member, WCRP Coordinated Regional Climate Downscaling Experiment (CORDEX) Science Advisory Team (SAT) for the period of 3 years from 01 January 2017.
- Dr. P. Mukhopadhyay was selected as a Member, International CLIVAR-GEWEX Working Group on Asian-Australian Monsoon (WG-AAM).
- Dr. Swapna Panickal was selected as a Member of the Working Group on Coupled Modeling (WGNE) of the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO).
- Dr. Roxy Mathew Koll was selected as a Member of the WCRP/CLIVAR Indian Ocean Region Panel for the period 2016-2018.
- The ESSO-INCOIS Website was awarded the Special Jury Award by Public Relations Society of India.
- The ESSO-INCOIS Annual Report was awarded the 3rd Prize by Public Relations Society of India.
- Dr. T. M. Balakrishnan Nair, Head-ISG, INCOIS was elected as a Fellow of

Telangana Academy of Sciences on 23 June 2016.

- Dr. Kunal Chakraborty, Scientist-D was awarded Young Researcher Award for his outstanding scientific contributions in the field of Bio-Pyhsical Coupling Process in Indian Ocean by Ministry of Earth Sciences (MoES) on 27 July 2016.
- Ms. M. Vijaya Sunanda, Scientist-C, received the Young Achiever Award from Indian Society of Remote Sensing (ISRS) at ISPRS Congress, Prague during 12-19 July 2016.
- Shri K.K.V. Chary, Dy. Chief Administrative Officer and Chairman, Official Language Implementation Committee, received Special Award for implementation of Official Language Hindi at the All India Rajbhasha Hindi Conference and Workshop, Kerala during 26-28 May 2016.
- Ocean Observation System (OOS) team, Dr. R. Venkatesan, S. Ramasundaram, G. Vengatesan, C. Muthukumar, S. SundarJesuraj was awarded with "Societal Innovation Award" for the indigenous development of “Integrated Marine Surveillance System (IMSS)” by "National Research Development Corporation (NRDC), Department of Science and Technology, Government of India.

9. ADMINISTRATIVE SUPPORT

9.1 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 total.

9.2 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.

9.3 Budget and Accounts

(Rs. In crore)

S. No.	Major Head of Account	2014-15 Actuals			2015-16 Budget Estimates			2015-16 Actuals		
REVENUE SECTION		Plan	Non-Plan	Total	Plan	Non-Plan	Total	Plan	Non-Plan	Total
1	3403- Oceanographic Research	423.84	43.74	467.58	659.00	50.00	709.00	444.24	36.58	480.82
2	3425- Other Scientific Research	249.08	27.66	276.74	85.00	34.57	119.57	59.94	34.17	94.11
3	3451- Secretariat Expenditure	0.00	25.04	25.04	0.00	29.70	29.70	0.00	24.96	24.96
4	3455- Meteorology	159.16	297.14	456.30	310.00	326.41	636.41	304.51	295.14	599.65
CAPITAL SECTION										
1	5403- Capital Outlay on Oceanographic Research	0.26	0.00	0.26	10.00	0.00	10.00	1.90	0.00	1.90
2	5425- Capital Outlay on other Scientific & Environmental Research	16.23	0.00	16.23	0.00	0.00	0.00	0.00	0.00	0.00
3	5455- Capital Outlay on Meteorology	51.71	0.01	51.72	115.00	0.02	115.02	91.02	0.00	91.02
	Grand Total	**900.28**	**393.59**	**1293.87**	**1179.00**	**440.70**	**1619.70**	**901.61**	**390.85**	**1292.46**

9.4 Report of the Controller and Auditor General of India

The number of Action Taken Notes (ATNs) pending for Ministry of Earth Sciences taken from various C&AG reports are given in the following 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/PAC reports on which ATNs are pending			No. of ATNs with Audit
			No. of ATNs not sent by the Ministry even for the first time	No. of ATNs sent but returned with observations and audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by Audit but have not been submitted by the Ministry to PAC	
1	2007	NIL	NIL	Para No. 5.1 Report No. 2 of 2007 on "Unfruitful Expenditure of Rs. 33.08 Lakh by IMD for Procurement of Precision Ni-Span 'C'."	NIL	NIL
2	2008			Para No. 7.1 Report No. CA-3 of 2008 on "Non achievement of the objective of Modernizing the accounting and personnel management functions."		
3	2013			Para No. 8.1 Report No. 22 of 2013 on "Irregular introduction of pension scheme and diversion of funds."		
4	2014		Para No. 5.1 of Report No. 27 of 2014 on "National Data Buoy Project"	NIL		
5	2014		Para No. 5.2 of Report No. 27 of 2014 on "Irregular Payment of Gratuity"			
6	2015		Para No. 6.1 of Report No. 30 of 2015 on "Unfruitful expenditure due to non-functional website"			
7	2015		Para No. 6.2 of Report No. 30 of 2015 on "Installation and upkeep of Meteorological Observatories by Regional Meteorological Centre, Kolkata"			
8	2016		Para No. 6.1 of Report No. 12 of 2016 on "Non Establishment of Desalination plants and wasteful expenditure"			

9.5 Staff Strength

The sanctioned strength of the Ministry of Earth Sciences including subordinate and attached offices and autonomous institutions is 8170 during the year 2016-2017. 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	17	4	15	36
Integrated Coastal and Marine Area Management (ICMAM), Chennai	16	3	6	25
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**

9.6 Official Language Implementation

Efforts are made constantly for the promotion of Official Language. The existing *Prithvi Vigyan 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. Under *Prithvi Vigyan Maulik Pustak Lekhan Yojna*, five books have been received. During the year, Hindi Fortnight was organized in two sessions from 5.9.2016 to 14.9.2016 and 20.9.2016 to 23.9.2016. During this fortnight 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 are being awarded to ten employees. An Incentive Scheme for officers for giving dictation in Hindi is in operation. In the year, the Committee of Parliament on Official Language has inspected six offices under IMD. The year also saw organization of two Hindi workshops in terms of the stipulation from Department of Official Language. One Official Language inspection of NCESS was carried out on 20th to 24th August, 2016.

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

9.7 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.

9.8 Parliament Matters

The Parliament Section, which caters to the correspondence with the Parliament Secretariats, replied Lok Sabha (104 questions) and Rajya Sabha (50 questions) last year.

9.9 Vigilance Activities and Achievements

Dr. M.P. Wakdikar, Sc. 'G' continues to be CVO of the Ministry w.e.f. 31.12.2014. Senior level officers have been appointed as VOs in attached/ subordinate offices and autonomous bodies of the Ministry. A preventive as well as punitive vigilance monitoring is rigorously pursued through the CVO and VOs.

Internal complaints committee to deal with cases of Sexual Harassment at workplace in line with extant instructions is in existence. One complaint of Sexual Harassment has been reported this year. The internal complaints committee has carried out during last six months, six meetings to consider the live case. The case continues to be live at present.

9.10 Significant Audit Points Printed in Audit Reports of 2016

No significant audit points have appeared in the audit reports of 2016.

10. 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 MoES. The Ministry extends its gratitude to all those who have provided their enormous support in both administrative and scientific matters. 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 chaired by Prof. J. Srinivasan, IISc, Bengaluru.
2. PAMC on Hydrology and Cryosphere chaired by Prof V.K. Gaur, CMMACS, Bengaluru.
3. PAMC on Geosciences, chaired by Prof. Ashok Singhvi, PRL, Ahmedabad.
4. PAMC on Ocean Science and Resources chaired by Dr. Shailesh Nayak, Former Secretary, MoES
5. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, DRDO, Hyderabad.
6. The Governing Council and Finance Committee of IITM chaired by Prof V.K. Gaur, CMMACS, Bengaluru and Research Advisory Committee of IITM chaired by Prof. J. Srinivasan, IISc, Bengaluru.
7. Research Advisory Committee of Integrated Coastal and Marine Area Management Project (ICMAM) – chaired by Dr. M Baba, former Director, Centre for Earth Science Studies (CESS).
8. Research Advisory Committee of the Centre for Marine Living Resources and Ecology (CMLRE) – chaired by Dr. Dileep Deobagkar, former VC, Goa University.
9. Research Advisory Committee of the Indian National Centre for Ocean Information Services(INCOIS) – chaired by Prof. G. S. Bhat, IISc, Bengaluru
10. Scientific Advisory Council of ESSO-NIOT chaired by Dr. P.S. Nair, Emeritus Scientist, ISRO, Bangalore.
11. Research Advisory Council of NCAOR, chaired by Prof. Harsh Gupta, President Geological Society of India & IUGG.
12. Research Advisory Council of NCESS chaired by Dr. Somnath Dasgupta, Chair Professor, Jamia Millia Islamia (JMI).
13. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof. B. N. Goswami.
14. 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.
15. The Indian Panel of Changing Water Cycle Programme and Integrated Ocean Drilling

Program (IODP) chaired by Prof V.K. Gaur, CMMACS, Bangalore.

16. **Review of the Autonomous Bodies:** In accordance with the recommendations of the Expenditure Management Committee constituted by the Department of Expenditure, Ministry of Finance, five independent Peer Review Committees (PRC) were constituted to review the five autonomous bodies under the MoES.

The PRCs for IITM, INCOIS, NIOT, NCAOR and NCESS were headed by Prof Roddam Narasimha, Honorary Professor, JNCASR; Prof Goverdhan Mehta, National Research Professor; Dr. K. Kasturirangan, Former Chairman, ISRO and Member (Science) Planning Commission; Prof J. Srinivasan, Emeritus Professor, Divecha Centre, IISc Bangalore and Prof R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO respectively.

सत्यमेव जयते

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