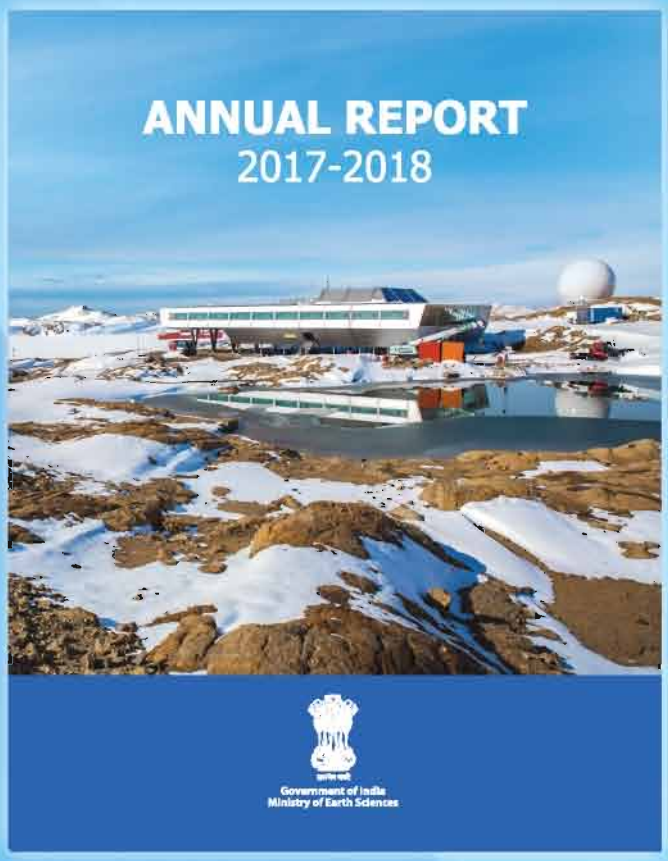
ANNUAL REPORT
2017-2018

सत्यमेव जयते

Government of India
Ministry of Earth Sciences

Front Cover



India's Bharati Station in Antarctica.

Back Cover

LiDAR

India's fastest and first multi-petaflops super computer 'Pratyush' at IITM, Pune

Puducherry beach before and after the restoration work carried out by NIOT.

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ESSO

Earth System Science Organization
Ministry of Earth Sciences
Government of India

CONTENTS

Chapter 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 the Earth System Science for providing weather, climate, ocean, coastal state, hydrological and seismological services. The services include forecasts and warnings for various natural disasters. In addition, the ministry has the mandate of making ocean survey for living and non-living resources and exploration of all the three poles (Arctic, Antarctic and Himalayas). The services provided by the ministry are being effectively used by different agencies and state governments for saving human lives and minimizing damages due to natural disasters.

The Ministry has the following organizations under its administrative control through which the above listed services are being rendered to the country :

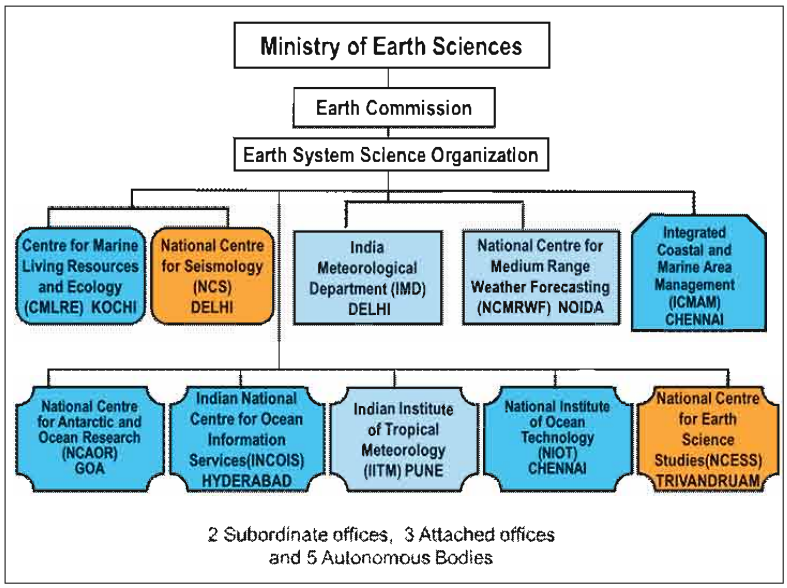

Fig 1.1: MoES organizational structure.

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 and Services (ACROSS)

An integrated early warning System of Air Quality and Weather Forecasting And Research (SAFAR) was dedicated to the nation by Dr Harsh Vardhan, Hon'ble Union Minister Science and Technology and Earth Sciences on 12th May 2017 in Ahmedabad. With the advent of SAFAR, a new health action plan "Ahmedabad-AIR (Air Information and Response)" was launched with a lead from Ahmedabad Municipal Corporation and other research organizations which will connect SAFAR products with health related mitigation options.

A new cutting-edge Cosmic-ray Soil Moisture Observation System (COSMOS) was launched. A network of fieldscale soil moisture monitoring stations is being developed across India (COSMOS-India) under the NERC-MoES program using cosmic-ray soil moisture sensors (CRS). The IITM CRS is the latest addition to the COSMOS India network. The cloud physics laboratory was re-established by NCESS in Braemore, Thiruvananthapuram on 12 May, 2017. The instruments installed at the new site include Micro rain radar, Disdrometer, Ceilometer and an Automatic weather station.

An observational campaign to understand different physical features of Fog and factors responsible for its genesis, intensity and duration was also

continued during December 2017 at the Indira Gandhi International Airport (IGIA) and at ICAR-IARI in New Delhi. These observations will be used for improving model forecasts of Fog.

The first phase of the National Monsoon Mission was completed by setting up high resolution coupled dynamical prediction system with reasonable prediction skill for seasonal and extended range time scales and very high resolution atmospheric model for weather prediction. For the first time, India Meteorological Department used the Monsoon Mission dynamical model to prepare operational seasonal forecast of 2017 monsoon rainfall over India. MoES has now launched the Monsoon Mission Phase II program, for next 3 years (2017-2020) with emphasis on predicting extremes and development of applications based on monsoon forecasts.

IMD implemented Global Ensemble Forecasting System (GEFS) for ensemble forecasts in the medium range time scale. NEPS (NCMRWF Ensemble Prediction System) products are now available operationally on TIGGE (THORPEX Interactive Grand Global Ensemble) site (hosted by ECMWF) along with similar forecast products from all leading NWP centres of the world.

The quality of weather services saw noticeable improvements in skills of Heavy Rainfall Forecasts and tropical cyclone forecasts. Presently, around 22 million farmers are directly benefitted by the agro-meteorological services of IMD. For the recent cyclone Ockhi, accurate predictions were provided almost 2 days in advance, helping the state governments in mitigating damages caused by the cyclone.

The new High Power Computing (HPC) system with a capacity of 6.8 PF computational power is being installed at two MoES Institutes: 4.0 Peta Flops HPC facility at IITM, Pune and 2.8 Peta Flops facility at NCMRWF, Noida. The 4.0 peta flops HPC system has already been inaugurated at IITM by Dr. Harsh Vardhan, Hon'ble Minister for Science & Technology, Earth Sciences and Environment, Forests and Climate Change. This facility is part of Ministry's continuous endeavor to provide world class forecast services to the citizens of India through upgrading various operational and research activities and the needed infrastructure. Country's need for better forecasts of Weather and Climate conditions like monsoon, extreme events, Tsunamis, Cyclones, earthquakes, air quality, lightning, fishing, hot/cold waves, flood/drought, etc will be met by this HPC facility.

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

INCOIS continued to provide forecasts on the state of the oceans, the PFZ advisories and species specific advisories for a wide spectrum of users. The State-of-the-art Ocean State Forecast Laboratory was set up at the Indian National Centre for Ocean Information Services (INCOIS), Hyderabad. It consists of a video wall with control unit for display along with a Decision Support System comprising of Forecast Assessment and Support Tool (FAST) for better decision making from a range of model outputs and observations.

The Indian Tsunami Early Warning Centre (ITEWC) monitored 31 earthquakes of magnitude greater than 6.5, during the period 1 January - 31 December 2017. These earthquakes could not generate any Tsunami and hence no threat bulletins were issued for India. An open sea trial of India's first wave powered navigational buoy developed indigenously by National Institute of Ocean Technology was successfully carried out

off Ennore port. A shallow water Remotely operated Vehicle developed by National Institute of Ocean Technology (NIOT) was deployed. Sonar and underwater visuals were collected for sunken barge and the report was submitted to Chennai Port.

A Foundation Stone for the Marine Finfish Hatchery and Test Facility for Ballast Water Treatment Technologies was laid on April 8, 2017 by Shri Y.S. Chowdary, Honourable Minister for State for Science & Technology and Earth Sciences at Nellore sea front. These facilities will be developed by National Institute of Ocean Technology.

A deep sea ankler fish, Lophiusgracilimanus (one single Female specimen, 270mm Standard Length) has been rediscovered and redescribed after a gap of almost a century from off Andaman Coast of India, 7°5' N, 93° 4' E at a depth of 650 m. Further, a species of worm eel of genus Neenchelys has been discovered as new from South eastern Arabian sea off Kollam from 450 m depth during the exploratory survey. Presently, there are only 2 species *viz.* Neenchelysbuitendijki Weber & de Beaufort 1916 and N. cheni among 12 species in this genus, reported from Indian waters.

Ministry of Earth Sciences (MoES) has set up a dedicated Seabed Minerals Laboratory with state-of art facilities at CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar for metallurgical research on seabed minerals for Polymetallic Nodules.

An agreement has been signed by Secretary, MoES and Lakhadweep administration to establish 6 more desalination plants at six islands in Lakshadweep. These desalination plants are funded by the Lakshadweep Administration, but will be implemented by MoES.

1.3 Polar and Cryosphere Research (PACER)

A total of 116 persons including 54 scientists and 62 logistic support staff from 28 different national organizations were deployed in Antarctica during 36th Antarctic Expedition. In addition, 04 Norwegian scientists were also deployed at Maitri under the Mass balance, dynamics, and climate of the central Dronning Maud Land coast, East Antarctica (MADICE) project, a collaborative project between India and Norway.

The first joint Indo-Norwegian field campaign was undertaken during the 36th Indian Scientific expedition to Antarctica (2016-17). As part of this, the MADICE team had conducted various geophysical, glaciological studies and retrieved ice cores from Djupranen (D) and Leningrad (L) ice rises of Nivlisen ice shelf from the central DML region.

The 37th Indian Scientific Expedition to Antarctica (37-ISEA) was launched in November 2017. A total number of 41 projects were recommended for the 37-ISEA. Indian Expedition to Southern Ocean/Antarctic Waters in 2016-17 was launched from Port Louis, Mauritius on 6th January 2017 with 24 scientists onboard from various organizations and institutions across the country. Continuous observations for various atmospheric and oceanic parameters were carried out in the entire cruise track.

1.4 Seismology and Geoscience Research (SAGE)

The national seismological network consisting of 84 observatories has been functioning smoothly and a total of 232 earthquake events occurred in and around India (Latitude 0-40° N, Longitude 60-100° E) were detected and auto-located during the period January to October, 2017. Of these, 201 earthquakes were of magnitude range 3.2 to 4.9, while 31 were of magnitude 5.0 and above.

Information pertaining to significant events was provided to all concerned state and central government agencies, dealing with relief and rescue operations in the region and also posted at website. For automatic earthquake parameter dissemination, "India Quake", a mobile App was developed and launched. Seismic microzonation studies of 30 selected cities, falling in seismic zone V, IV, III and State Capitals has been initiated.

Scientific drilling of the Koyna pilot borehole KFD1 to a depth of 3 km and the acquisition of downhole geophysical data were completed. Passing through ~1.25 km - thick succession of Deccan basalt flows and ~1.75 km into the underlying granite-gneiss basement rocks, the borehole is the deepest drilled through crystalline rock formations in the country. Cuttings were collected at 5 m intervals in basalt and 3 m intervals in basement rock. Additionally, limited cores were collected from discrete depths in the 1500-3000 m section. To keep pace with the drilling, three field laboratories were functional on site: (i) geological lab., (ii) mud-logging lab., (iii) online gas and fluid sampling lab.

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 the 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. A total of 21 new research projects in focused research areas were approved for funding in 2017. Under the Outreach and Awareness Program, MoES participated in 17 exhibitions and supported about 90 Seminar, Symposia, Conference, and Workshop etc. Around 5% of the annual budget of the Ministry is allocated for extramural support.

1.6 International Interface

MoES extensively engages with the best institutes overseas in the field of Earth system Sciences by bringing together the best researchers and facilities wherever they are placed in the world and working together to solve some of the key challenges in weather and climate related to the Indian region. The Council of the International Seabed Authority (ISA) on 10th August 2017 approved the extension of contract between Ministry of Earth Sciences (MoES), Government of India and the ISA (an Institution set up under the Convention on Law of the Sea to which India is a Party) for exploration of Polymetallic Nodules (PMN) for a further period of 5 years (2017-22).The ministry has been actively working with the Intergovernmental Oceanographic Commission of UNESCO towards establishment of a Category-2 Centre(C2C) of UNESCO for Operational Oceanography at INCOIS, Hyderabad. ITC Oocean hosted at the INCOIS (Indian National Centre for Ocean Information Services) campus in Hyderabad will be established as a Category-2 Centre (C2C). This has been approved by the 39th Session of UNESCO General Conference held on 7th November 2017. On 15th December 2017, the Cabinet Committee accorded approval for the same.

1.7 Scientific Publications

There has been an exponential growth in number of research publications by the scientists of the Ministry during the past few years. A total number of 398 research papers (with a cumulative impact factor of 862) were published during 2017 by MoES scientists under various scientific programs of the Ministry (Fig. 1.2).

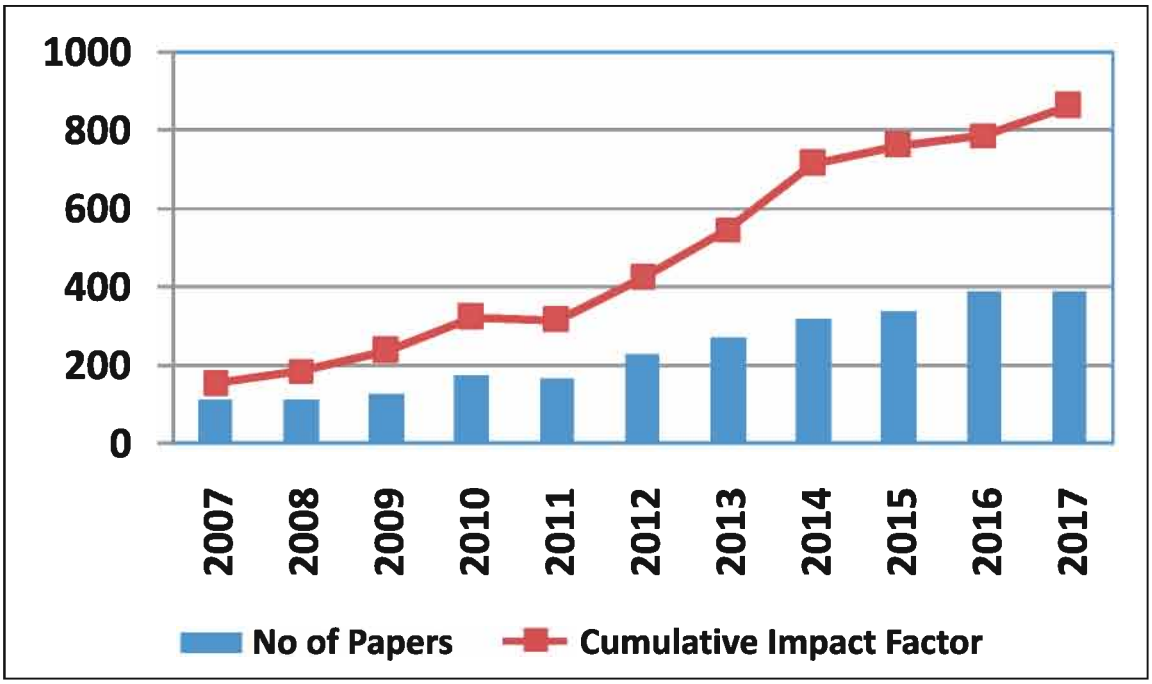

Fig. 1.2: Number of research papers and cumulative impact factor year wise.

1.8 Budget Expenditure

The total outlay for the Ministry for the year 2017-18 was Rs.1719 crores which has been reduced to Rs. 1596.10 crores at the RE stage. The expenditure profile for the last 10 years is shown in the table below.

Year	BE	RE	Actual Expenditure
2007-08	887.95	655.85	562.03
2008-09	972.90	820.00	751.69
2009-10	1213.20	1137.20	1080.51
2010-11	1305.25	1281.06	1098.07
2011-12	1569.12	1227.01	1174.58
2012-13	1672.29	1198.66	1177.14
2013-14	1693.73	1311.12	1248.15
2014-15	1702.23	1336.88	1294.35
2015-16	1622.68	1420.98	1296.80
2016-17	1672.45	1579.11	1459.76
2017-18	1719.48	1596.10	1256.17*

(*) Expenditure as on 15.01.2018

Chapter 2

Atmosphere and Climate Research, Observations Science and Services (ACROSS)

Introduction

Ministry provides Weather, Climate and Hydro-meteorological Services to various users round the clock and throughout the year. Both operational and research aspects for these services are implemented through the programme, ACROSS.

During 2017, many significant achievements have been made on providing weather and climate services. Many major improvements also have been made in data assimilation in numerical models. The first phase of the Monsoon Mission was completed successfully in this year, with significant achievements, including setting up of very advanced prediction systems for Seasonal prediction; Extended range prediction (for next 20 days) and Very high resolution Short range prediction (up to 8 days). All the above model developments have been transferred to the India Meteorological Department (IMD) for generating operational products. For the first time, IMD used the Monsoon Mission dynamical model to prepare operational seasonal forecast of 2017 monsoon rainfall over India. Many observational campaigns also have been taken up as special atmospheric observations help us to understand model deficiencies and to improve the accuracy of 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. IMD has been augmenting its observing system networks over the past years. During 2017, the following upgradation of the network has been made.

- The S-Band Polarimetric Doppler Weather Radar at Kochi was inaugurated by Hon'ble Minister of Earth Sciences, Science & Technology and Environment, Forests & Climate Change Dr. Harsh Vardhan. In July 2017
- Indigenously developed integrated Automated Weather Observing System (AWOS) which was developed jointly by NAL and IMD has been successfully commissioned at Mangalore Airport in July, 2017. This measures current weather and Runway Visual Range (RVR).
- New Aeronautical Met. Station has been commissioned at Rohini (Delhi), Shirdi (Maharashtra) and Kishangarh (Rajasthan) during the year 2017.

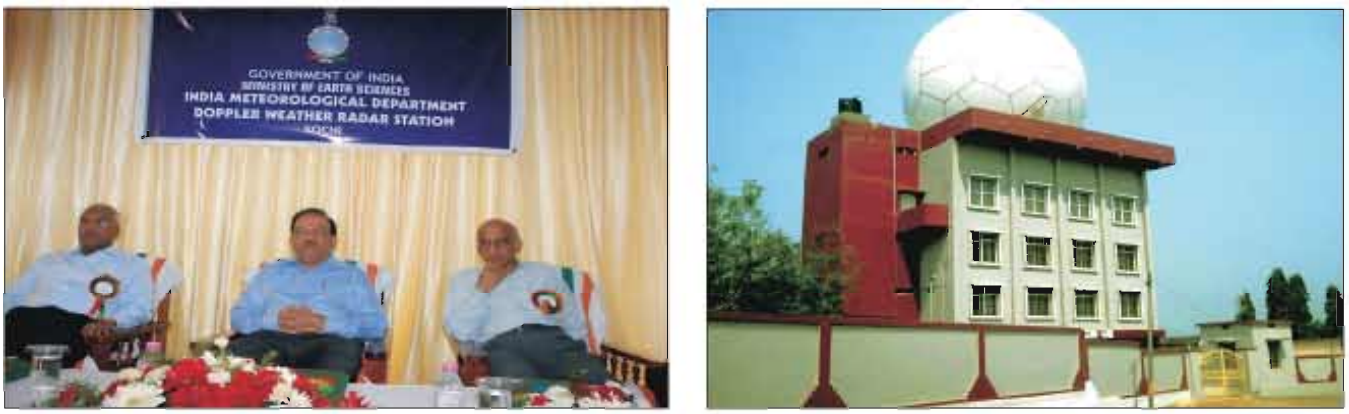

Fig. 2.1: Inauguration of the S-Band Polarimetric Doppler Weather Radar at Kochi.

- Two numbers of transmissometers were commissioned in Kolkata and one in Mangalore during the year 2017.
- Three hundred (300) Automated Weather Stations (AWS) have been upgraded with new version Data logger with dual communication- Satellite and GPRS. AWS data are sent to server with GPRS communication.
- Electronic Sunshine recorders were installed at Twelve WRDC (World Radiation Data Centre) network stations viz. Ahmedabad Chennai, Delhi, Goa, Jodhpur, Kodiakanal, Mumbai, Nagpur, Pune, Shillong, Thiruananthapuram and Visakhapatnam.
- A FTP link was established with JMA Tokyo for exchange of "WMO RARS radiance Data", "MTSAT Clear Sky Radiance (CSR)" and "IMD's RARS data" between RTH New Delhi and Tokyo and routing all the radiance data to NCMRWF/NWP centre as well as on GTS.
- A new link was established with DHMS Bhutan for the first time for successful data exchange of Bhutan over GTS via RTH New Delhi.
- A VPN tunnel was established over internet with Myanmar, Naval Met Kochi, AWS (SI Pune), Mirror RTH Pune, UK Met office and DWD Germany.
- A network of 25 nos. Global Navigation Satellite System (GNSS) stations for "Earth and Atmospheric studies" has been Installed and commissioned to derive Integrated Precipitable Water Vapor (IPWV).
- An impact disdrometer was installed at Cherrapunji (Meghalaya), in collocation with ISRO's C-band Radar for better understanding on raindrop size distribution.
- The high altitude cloud physics observatory at Rajamallay in Munnar, Kerala was inaugurated by Dr. M. Rajeevan, Secretary, MoES on 9th June 2017. This observatory is established by National Centre for Earth Science Studies (NCESS), Thiruvananthapuram, in the premises of Kannan Devan Hill Plantation Pvt Limited (KDHP) in Rajamallay. The observatory is situated at an altitude of 1820 *m* above mean sea level. ***This observatory is the highest elevation cloud physics observatory in the Tropical region over the south Asia.***

Satellite Products for Forecasting

IMD is in the process of establishing Multi-Mission Meteorological Data Receiving and Processing System(MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS in collaboration with M/s Antrix Corporation Ltd, ISRO for which an MOU has been signed between IMD and ISRO on 6th March, 2017. Modified scan strategy of INSAT-3D and INSAT-3DR sounder payload has been implemented with effect from 12th August, 2017. INDIAN region sector data is now available on hourly basis and Ocean region data is available on one and half hourly basis.

To improve navigation accuracy, Fixed Grid Navigation and Automatic Template Based Registration package for INSAT-3D Imager was developed and operationalized at Space Application Centre, Ahmedabad and IMD, New Delhi.

High Altitude Cloud Physics Laboratory (HACPL), Mahabaleshwar

Particle into Liquid Sampler with Ion Chromotography (PILS-IC) was installed at HACPL for studying aerosol chemical composition and its influence on CCN activation. Ice Nuclei measurements were implemented at HACPL to quantify the fraction of aerosols that act as Ice Nuclei.

Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)

Fig. 2.2: Different types of Observations under CAIPEEX.

CAIPEEX Phase-IV ground campaign is started in May 2017. Various ground based instruments are installed in Singhad College of Engineering, Solapur at the core of rain shadow region. The background data have been collected with ground based instrumentation. About 157 radiosonde measurements have been completed so far. A Dual polarimetric C-band radar was installed as part of the campaign. As part of the campaign, 26 rain gauges have been installed in the proposed seeding evaluation area. The Flare testing laboratory is under development, which will be used to characterize the size distribution and chemistry of aerosols used as seed material.

Winter Fog Experiment (WIFEX) over the Indo-Gangetic plains of India

The WIFEX was started during the winter of 2015-16. The observational campaign for the winter season 2016-17 were conducted at IGI Airport New Delhi and Agricultural University, Hisar, Haryana during November 2016 to February 2017. WIFEX (2017-18 started on 10th November 2017 and will continue till 20th February 2018. The objectives of the Winter Fog Experiment (WIFEX) over the Indo-Gangetic Plains of India are to develop better now-casting and forecasting of winter fog on various time and spatial scales.During WIFEX(2017-18), the following new instruments have been installed at IGIA, Delhi: (i) MARGA -2S (Chemical analysis of PM1, PM2.5 and gases) which provides online measurement of water soluble chemical constituents (Cl, SO4, NO3, NH4, Na, K, Ca and Mg ions) of PM1 and PM2.5 particulates and some atmospheric trace gases (HCl, HNO2, HNO3, SO2 and NH3) on hourly time scales, (ii) Ceilometer, (iii) Fog droplet monitor: Fog droplet size distributions during fog events and (iv) Fog dispersal set up (experimental mode Ion generator).

2.2 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. Further developments on data assimilation during the year are as follows:

Continuous efforts were made at NCMRWF to maximize its data reception capabilities as well as utilization of all kinds of data from various observational platforms in its data assimilation system. From August 2017, NCMRWF has started downloading satellite observations from NOAA Production Distribution and Access (PDA) server instead of Data Distribution Server (DSS). This new system enhanced data reception capabilities of NCMRWF, with sharp increase in the reception volume of satellite observations during 2017. Further, an MOU was signed with EUMETSAT for setting up EUMETSAT Terrestrial Broadcast Reception System at NCMRWF. This system has been recently installed and tested at NCMRWF. Observations received through this system will further enhance the observation reception capabilities of NCMRWF. Thus, NCMRWF is connected to main international and national satellite data producing centres, e.g. ISRO, NOAA, EUMETSAT through NKN and JAXA/JMA through GTS network.

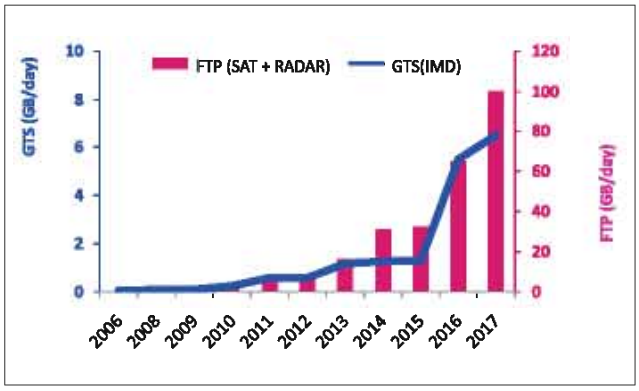

Fig. 2.3: Growth of data reception at NCMRWF over the years.

NGFS Data Assimilation System:

NCMRWF's GFS analysis system (NGFS) was upgraded to 4D-EnsVar system in April 2017. NCMRWF has started working as core data assimilation centre for various institutions of the Ministry. NCMRWF is regularly upgrading its NGFS data assimilation system to handle new Satellite datasets with special focus on Indian satellites. NCMRWF has validated recent ScatSat-1 ocean wind observations against buoy observations and found good correlation between these two datasets. Assimilation of Indian satellite observations viz. ScatSat-1, MT-SAPHIR & ROSA, INSAT 3D & 3DR sounder was started in NGFS data assimilation system.

NCUM Data AssimilationSystem:

NCMRWF Unified Model (NCUM) assimilation-forecast system has been upgraded periodically to adapt the new developments. A hybrid 4D-Var data assimilation system at 40 km horizontal resolution (N320L70) produces the analysis increments for the model. Indian satellite observations viz., INSAT-3D sounder radiances and Megha-Tropiques SAPHIR radiances are operationally used in the NCUM system in addition to other conventional and satellite observations. Data assimilation capability for INSAT-3DR sounder data and SCATSAT ocean surface winds have been recently developed and tested.

The impact of all types of observations used in the data assimilation system on the forecast were studied in detail through adjoint-based Forecast Sensitivity to Observations (FSO) and Observing System Experiments (OSE) during monsoon, 2017. The study clearly shows that satellite observations are very important in the global domain for improving the forecast, however over

Indian region conventional observations are equally important (Fig. 2.4). The study also indicates that Megha-TropiquesSAPHIR radiances have significant beneficial impact on the forecast both globally and over Indian region. The beneficial impact of low altitude peaking channel of SAPHIR is more than any other similar instruments in any International satellite.

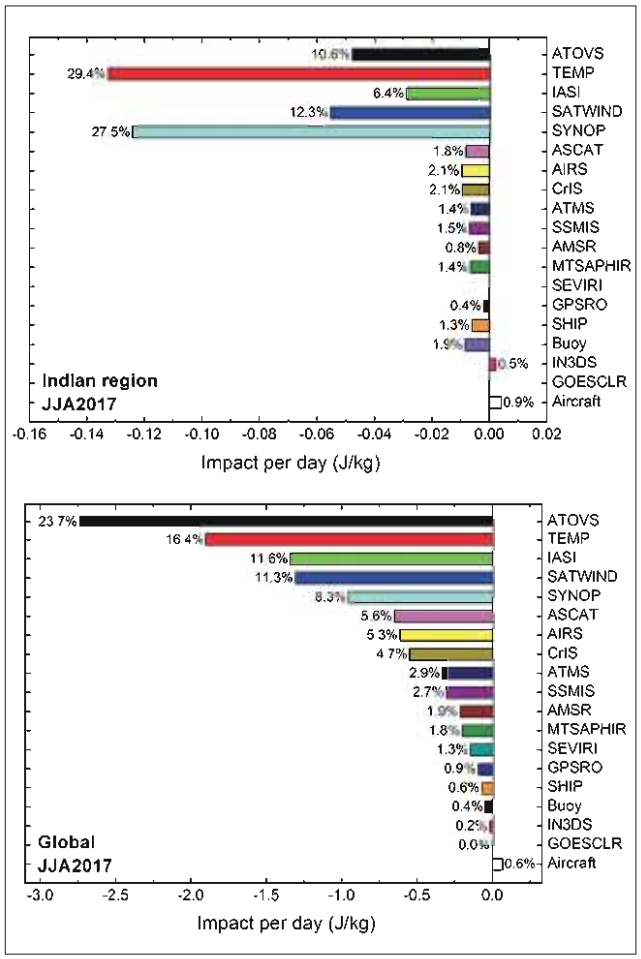

Fig. 2.4: Mean impact of various types of observations on 24 hr forecast of NCUM during June-July-August, 2017 (JJA2017) over Global and Indian domains.

Utilization of Indian DWR Observations

NCMRWF receives data from all the Indian Doppler Weather Radar on a continuous basis. These data are archived at NCMRWF for real-time and also for any hindcast requirements. A DWR data monitoring system has been developed at NCMRWF which checks for continuity of the data both spatially and temporally on a real-time basis. The radial winds from Doppler Weather Radar is being assimilated in the 4 km UM regional model using the 3D-Variational Assimilation system.A fully automated gridded radar rainfall product was generated at 4 km resolution. These products are used for the validation of high resolution UM regional model.

2.3 Global and Regional Modelling

The Global Forecast System (GFS) 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 1 December, 2016. During 2017 IMD implemented Global Ensemble Forecasting System (GEFS SL) for ensemble forecasts in the medium range time scale. The GEFS SL at semi-Lagrangian resolution T574 in horizontal resolution (~ 25 km) with 64 hybrid sigma-pressure layers with the top layer centred at 0.27 hPa (approximately 55 km) was made operational on 1 May, 2017. It is run once in a day (0000 UTC) with 20 members (and 1 control) to give ensemble mean and probabilistic 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 "OCKHI" reasonably well. The spatial observed and forecast rainfall band associated with TC "OCKHI" is shown in the in Fig.2.5. The model forecast with 30 November, 2017 initial conditions is able to demonstrate the inner core of heavy rainfall and the outer rain bands as seen in the observations.

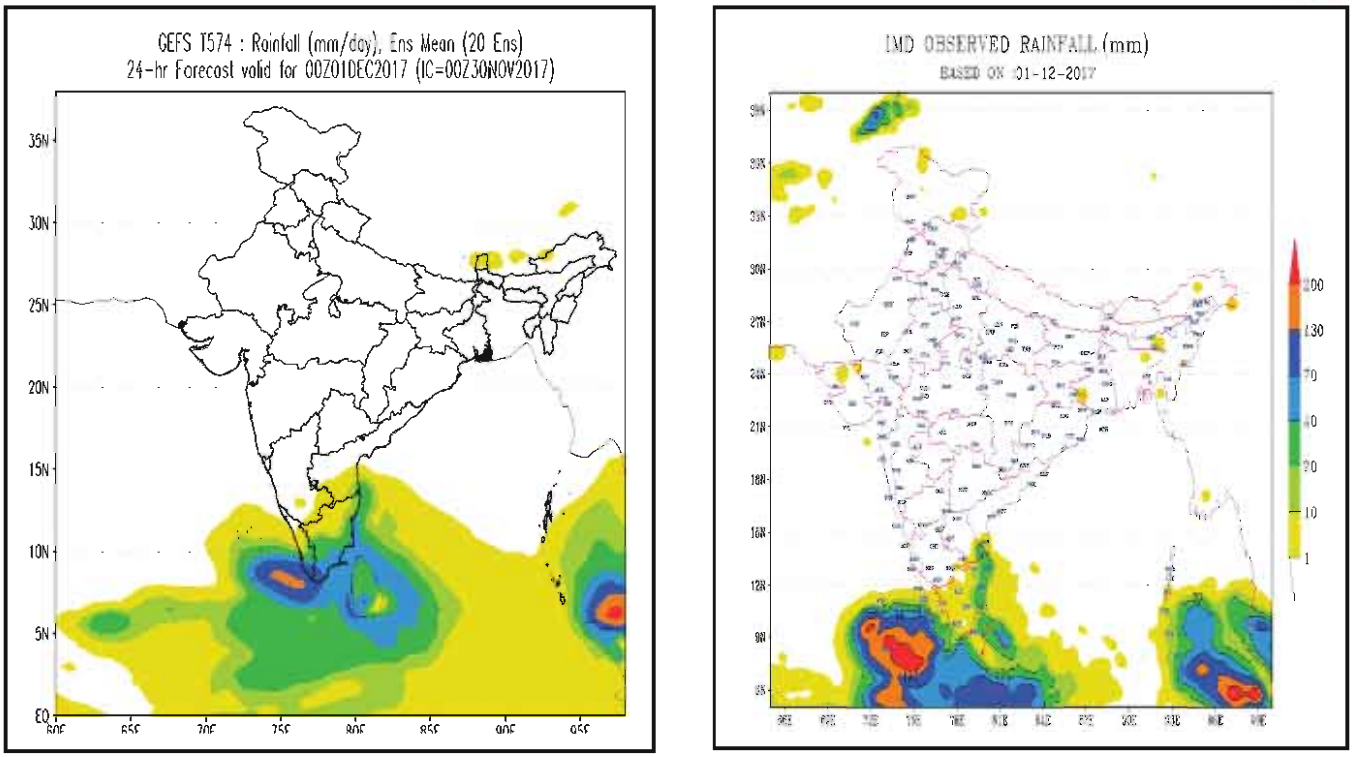

Fig. 2.5: The observed (right) and 24 hr forecast rainfall (left) associated with tropical cyclone "OCKHI" valid for 1st December, 2017.

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 (ERF) 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 days 2-8 (week1; Friday to Thursday), days 9-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday). The extended range forecast of monsoon rainfall and extreme temperatures are being used by various user agencies during the year 2017. It is proposed to run these models for ERF twice a week in place of once in a week from 2018 monsoon season

During the southwest monsoon season from June to September 2017 there were many transitions phases (active to weak and weak to active) as shown from the standardized rainfall anomalies over the core monsoon region (Fig. 2.6). A verification of prediction of transition of active to weak phase of monsoon during the period from 4-10 August, 2017 based on the different lead time is given below. The weak phase of monsoon rainfall during 4-10 August, 2017 was predicted well in the extended range forecast with lead time of one week (IC of 2nd August), two week (IC of 26 July) and three week (IC of 19 July).

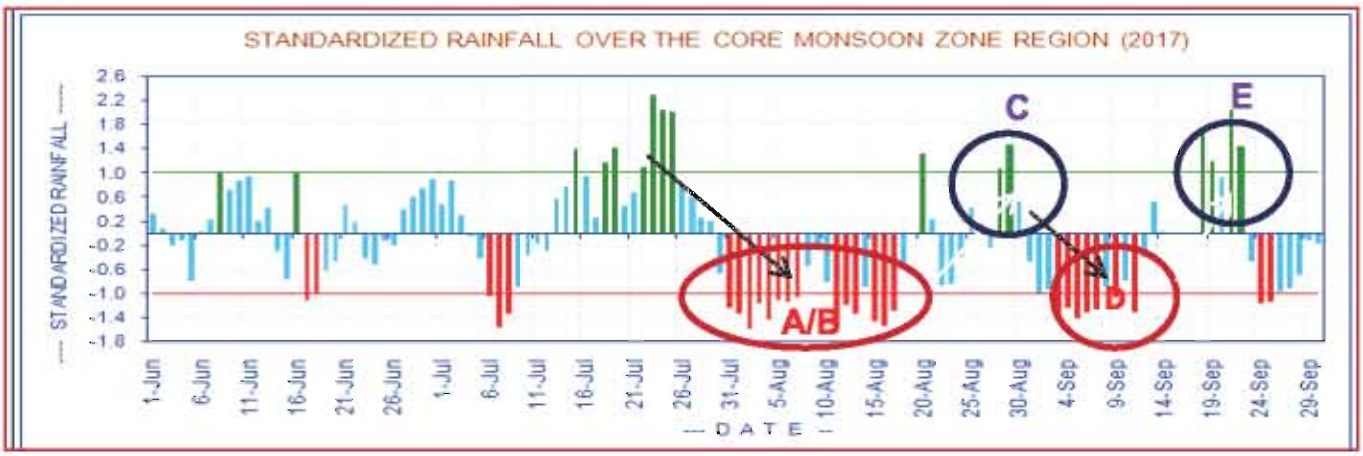

Fig. 2.6: Standardized rainfall anomalies over the core monsoon region during June to September, 2017.

The triple nested (18, 6 and 2 km) version (v3.8a) of Hurricane WRF (HWRF) model has been run operationally implemented with three dimensional ensemble variational assimilation in 6 hourly cyclic-mode for the forecasting of cyclone over North Indian Ocean. The regional model (NCUM-R) was upgraded with latest tropical science settings and tested at 4 km and 1.5 km resolutions. A number of sensitivity experiments were conducted with NCUM-R over Indian region to test the sensitivity of various science changes in the tropics and the results were presented in UM collaborative forums.

The science settings were developed for the Delhi fog model (DM) at 330 m resolution with fixed aerosol distribution and operationalised the Delhi Fog forecasting system for the winter season of 2016 (Fig. 2.7). Enhanced orographic features at 330 m resolution, along with other surface boundary conditions lead to improvements in the simulation of spatio-temporal variability of visibility. The impact of the urban heat island on visibility prediction is also investigated using recent high resolution land use/land cover data from ISRO in the model.

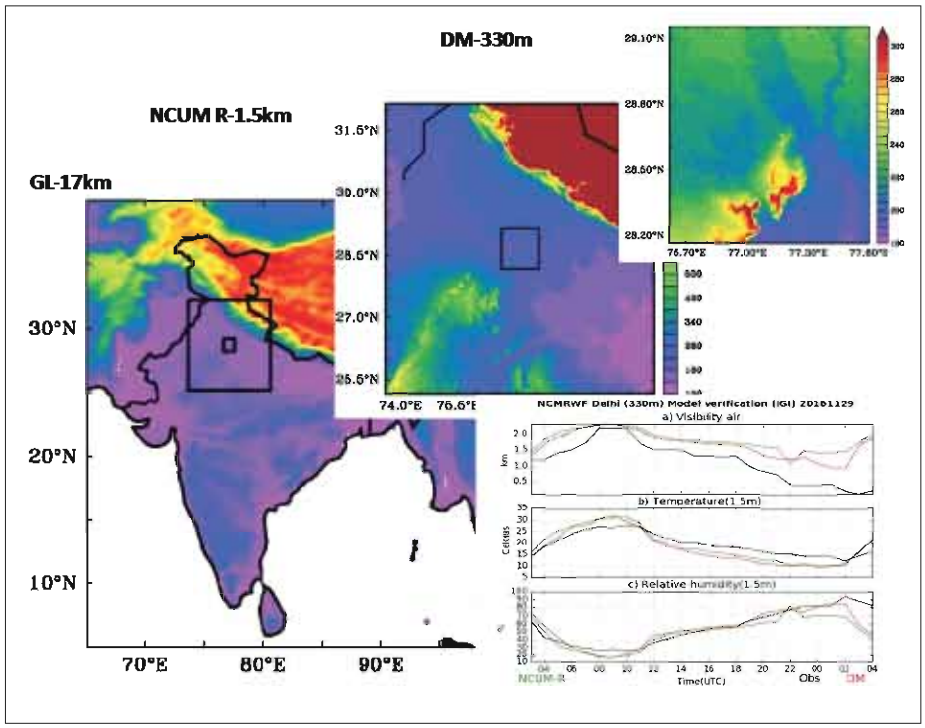

Fig. 2.7: Delhi Model setup and the verification of visibility, temperature and Relative Humidity for 29 November 2016 against METAR observations at IGI airport.

NCMRWF Ensemble Prediction System (NEPS):

In order to address the uncertainties in the surface forcing, improvements are made in the NEPS system for preparation of perturbations of sea surface temperature (SST) and soil moisture content (SMC). The SST and SMC perturbations are included operationally in the NEPS. NEPS based on an improved software framework was also implemented.

One of the six Departmental Action Plans of MoES is the development of a very high resolution Ensemble Prediction System (EPS) at NCMRWF. The horizontal resolution of EPS was increased to 17 km and tested successfully. Impact of SST and SMC perturbations along with increased resolution is demonstrated. The strike probabilities and member tracks of tropical cyclone MORA predicted by the 22 member EPS of 17 km resolution without and with SST and SMC perturbations along with 44 members and 33 km NEPS without SST and SMC perturbation are shown in Fig. 2.8.

TIGGE (THORPEX Interactive Grand Global Ensemble)is a focal point for a range of research, including research on ensemble forecasting, predictability and the development of products to improve the prediction of severe weather. NEPS products are now available operationally on TIGGE site (hosted by ECMWF) along with similar forecast products from all leading NWP centres of the world. NEPS products will also be available to international community for operational use via TIGGE.

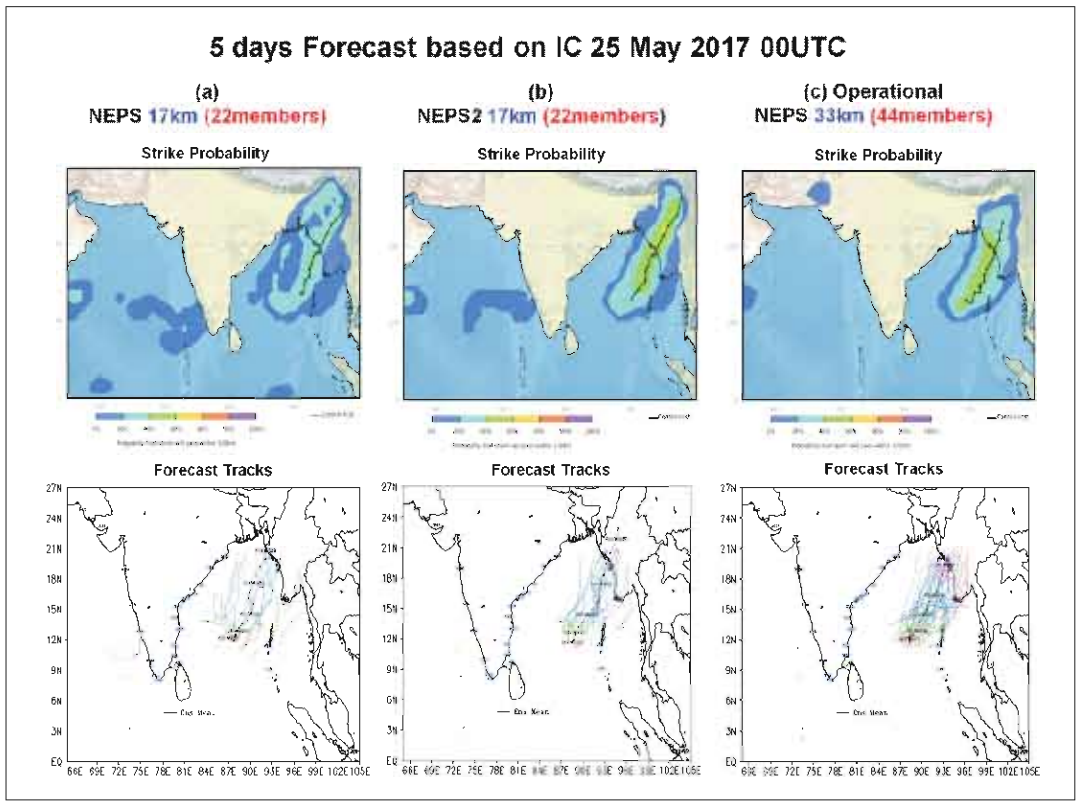

Fig. 2.8: (a) Strike probability and member forecast tracks predicted by 22 member EPS of 17 km horizontal resolution without SST and SMC perturbations; (b) Same as (a) but with SST and SMC perturbations and (c) Same as (a) but for 44 member EPS of 33 km horizontal resolution.

2.4 Verification of Model forecasts

NCMRWF rigorously validates its NWP forecasts against various ground truths for improvement in its modelling system. Root Mean Square Error (RMSE) in the 850 hPa predicted winds computed against the radiosonde observations show a long record of decreasing trend (Fig. 2.9). The improved forecast performance in the NCMRWF models can be attributed to increased volume of input observational data, improved data assimilation methods and increased model grid resolution in recent years.

Detailed quantitative rainfall forecast verification were carried out against the IMD-NCMRWF daily high resolution rainfall analysis. Categorical verification results are summarized in Fig 2.10 for different rainfall thresholds using the BIAS score.The BIAS score examined for different rainfall thresholds (Fig. 2.10) shows both models overestimate light rains and underestimate higher rainfall amounts.

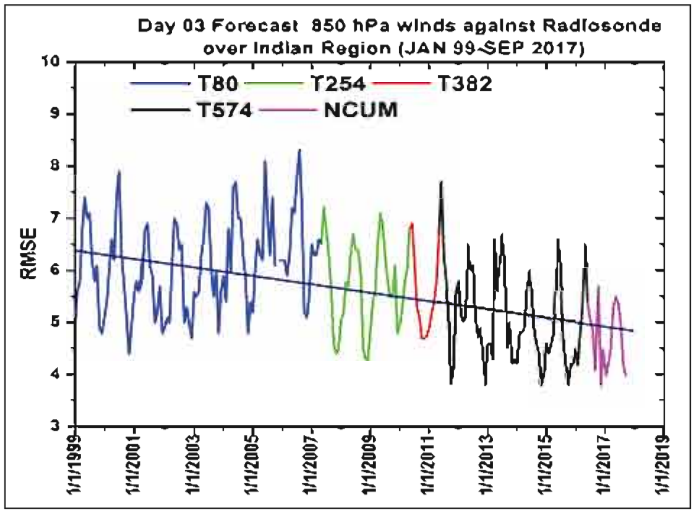

Fig. 2.9: RMSE of the 850 hPa winds against the Radiosondes over the Indian region, showing errors are consistently decreasing.

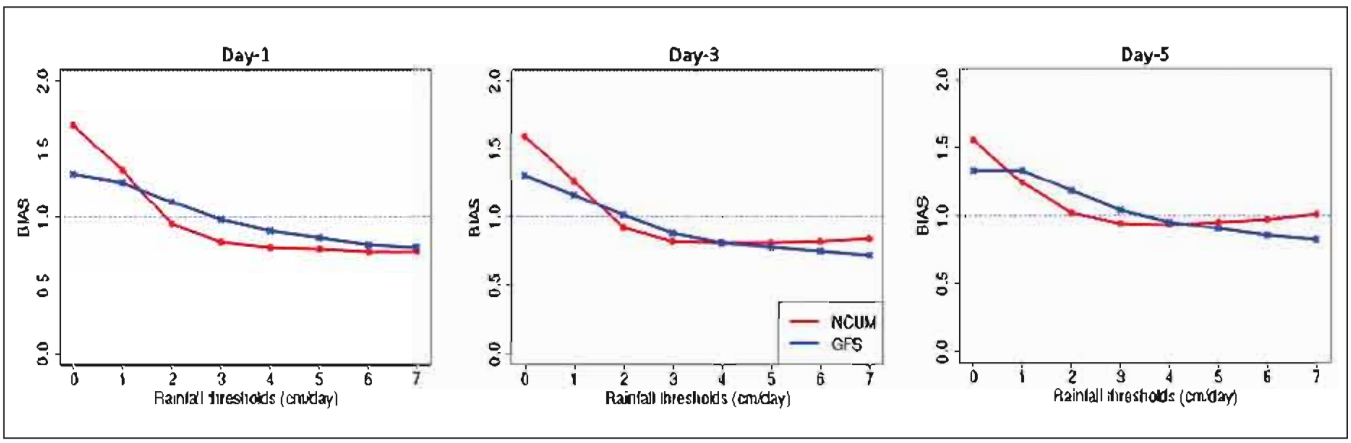

Fig. 2.10: Frequency Bias or Bias Score (BIAS) for forecast rainfall exceeding different threshold during Jun-Sept 2017. Panels (a), (b) and (c) correspond to Day-1, Day-3 and Day-5 forecasts.

IMD's real-time daily gridded surface temperature (TMAX) data were used to verify and bias correct the deterministic 2m maximum temperature forecasts from NCUM and GFS for a period of MAM 2017 over the Indian land area.The verification of Tmax forecasts is carried out during hot weather season MAM 2017 using the raw (DMO) and bias corrected (BC) NCUM and GFS forecasts (Fig. 2.11).

The performance of the model forecasts is indicated by Pears's Skill Score (PSS). High values of PSS indicate better forecasting capability. PSS values (<0.4) indicate moderate skill in the forecasts. After bias correction, the PSS values are higher (>0.4), particularly for high temperature thresholds. Thus post-processing methods are used to improve the forecasts.

2.5 Climate Modelling

Atmospheric observations show accurate reporting and little growth in India's methane emissions

A combination of satellite, aircraft and surface observations during 2010-2015 were used to quantify Methane (CH_4) emissions from India and to investigate sources of discrepancies between the 'top-down' derived emissions and the two inventories, EDGAR-2010 and India's National Communication (NATCOM). Results suggest little growth in Indian emissions during the period 2010-2015, in contrast to positive growth suggested by inventories. Results also show that the magnitude of top-down emissions is

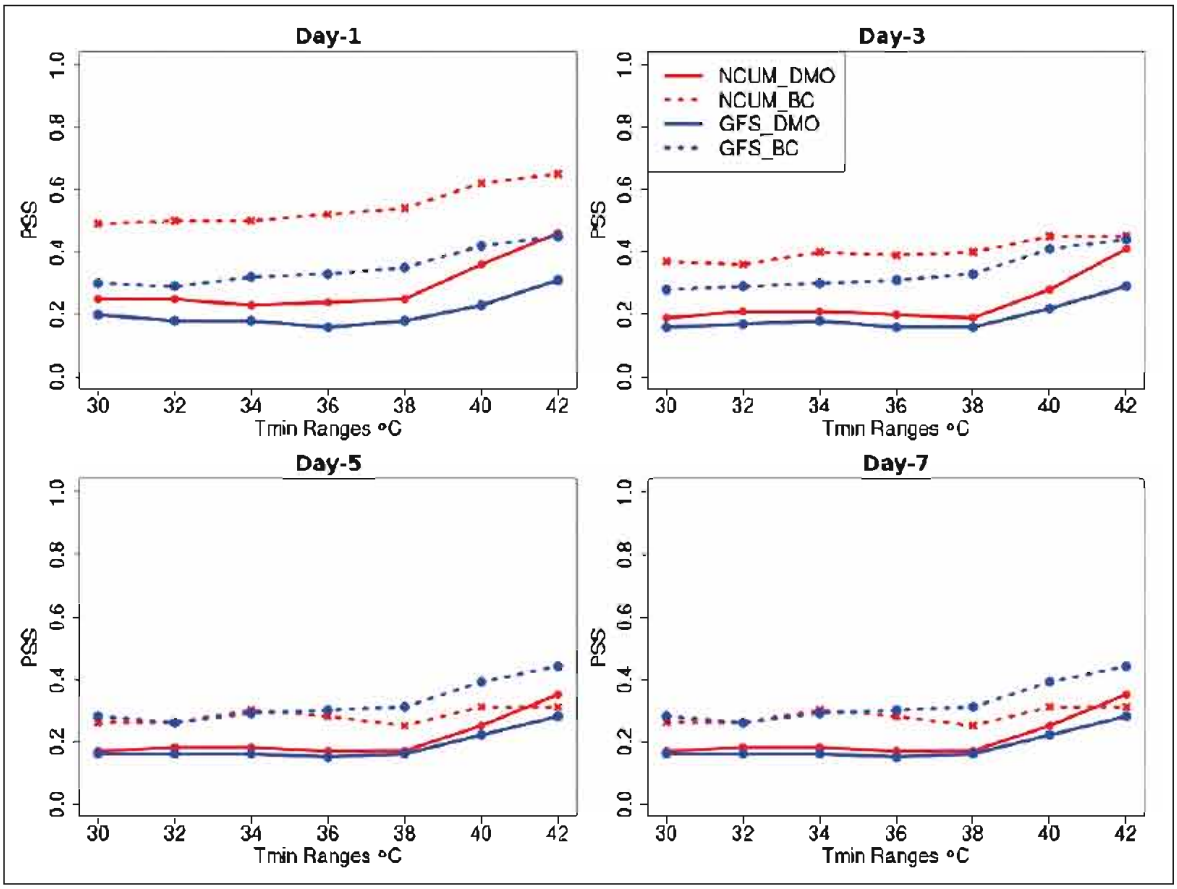

Fig 2.11: PSS in the raw and bias corrected Day-1 to Day-7 forecast of TMAX during Mar-May 2017.

consistent with the emissions reported by India in its Biennial Update Report (BUR) and is 30% smaller than global inventories. These findings demonstrate the need for more robust bottom-up accounting, using country-specific data and more advanced accounting methodologies.

A three-fold rise in widespread extreme rains over India

Global economic losses from floods exceeded 30$ billion per year in the past decade, with some of the largest losses linked to extreme rainfall events in Asia. Floods attributed to extreme rain events in India alone accounted to losses of about 3$ billion per year, which is 10% of the global economic losses. These floods are demonstrated to be on a rise due to the occurrence of "widespread extreme rains". A three-fold increase is found in these widespread extreme events during 1950-2015. These severe weather events result in large scale floods and catastrophic loss for life and property across central and northern India – Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, Telangana, Odisha, Jharkhand, Assam and parts of Western Ghats – Goa, north Karnataka and South Kerala. There have been 268 reported flooding events in India over 1950-2015 affecting about 825 million people, leaving 17 million homeless and killing about 69,000 people.

Ocean Data Assimilation and Modelling

NEMO Ocean model based global ocean initialization system NEMOVar has been implemented and in real-time is producing global ocean analysis of all standard ocean parameters once a day. The NEMOVar is one of the best ocean data assimilation (ODA) systems which assimilate a variety of in-situ and satellite data as input on daily basis. This ODA system implemented at NCMRWF is very similar to what is being used in leading centres like ECMWF. The best part of this system is that it has 75 layers in the vertical, out of which 35 layers are in top 300 metres. The top layer in Upper Ocean is 0.5 m, and due to this fine vertical layers the system resolves the shallow mixed layer to capture the diurnal cycle realistically. The horizontal resolution of the global system is 25 km. The global data assimilation system NEMOVar is capturing well the ocean temperature structure compared to in-situ Buoy data.

2.6 Environmental Meteorology Services

SAFAR-Ahmedabad & Ahmedabad-AIR plan dedicated to the Nation

SAFAR-Ahmedabad an integrated early warning System of Air Quality, Weather and Health was dedicated to the Nation by Dr. Harsh Vardhan, Hon'ble Union Minister for Science & Technology and Earth Sciences along with several State Ministers and dignitaries on 12 May 2017 in Ahmedabad. With the advent of SAFAR, a new health action plan "Ahmedabad-AIR (Air Information and Response)" was launched with a lead from Ahmedabad Municipal Corporation and other research organizations which will connect SAFAR products with health related mitigation options. During the occasion, a booklet for common citizen to know about SAFAR services "Ashavali-Tarang" - an introduction to SAFAR-Ahmedabad; Emission Inventory (statement of account of pollution sources); Unified SAFAR web-Portal; "SAFAR-Air" Mobile App for Ahmedabad were released.

Fig.2.12: Inauguration of the SAFAR-Ahmedabad.

IMD is expanding the skyradiometer network SKYNET-India by installing eight more skyradiometers in different geographic regions. High Volume Samplers for collecting PM10, PM2.5 and Total Suspended Particulate Matter have been installed at Delhi, Ranichauri, Pune and Varanasi.Environment Monitoring and Research Centre (EMRC) has evaluated more than 1500 Environmental Impact Assessment Reports of Thermal Power, Industrial, Coal Mine and Non-coal Mine projects referred to IMD by the Ministry of Environment & Forests and Climate Change during 2017.

2.7. Cyclone Forecasting Services

In this year, there were 10 cyclonic disturbances (depressions and cyclones) over the north Indian Ocean (NIO) and adjoining land regions against the long period average (LPA) of 12 disturbances per year based on data of 1961-2015. Out of 10 CDs, 3 intensified into tropical cyclones against the normal frequency of 4.5 cyclones per year over north Indian Ocean (NIO) based on LPA. It included 1 cyclonic storm (CS), Maarutha, one severe cyclonic storm (SCS), Mora and one very severe cyclonic storm, Ockhi. These cyclones are:

- Cyclonic storm, Maarutha over Bay of Bengal (15-17 April)
- Cyclonic storm, Mora over Bay of Bengal (28-31 May)
- Very Severe Cyclonic Storm, Ockhi over Bay of Bengal (29 November to 06 December)

The cyclonic activity over the NIO was near normal during pre-monsoon season, 2017 with formation of two cyclones. The activity during the post-monsoon was below normal with formation of one cyclone by the end of November. No cyclone crossed the Indian coast during 2017 against the normal of about 2 such cyclones per year.

Cyclone Forecast Verification

The annual average track forecast errors in 2017 have been 61 km, 108 km and 190 km, respectively for 24, 48 and 72hrs against the past five year average error of 97, 149 and 183 km based on data of 2012-2016. The errors have been significantly lower during this year as compared to long period average (2012-16). The track forest skills compared to climatology and persistence forecast are 68%, 77% and 76% respectively for the 24, 48 and 72 hrs lead period which is much higher than long period average of 2012-2016 (54%, 67% & 69% respectively). The annual average landfall forecast errors for the year 2017 have been 19 km, 50 km and 59 km for 12, 24 and 48 hrs lead period during 2017 against the average of past five years of 37 km, 56 km and 94 km during 2012-2016. The landfall time forecast errors have been 1, 0.5 and 3.5 hrs for 12, 24 and 48 hrs lead period during 2017 against the average of past five years of 2.5, 4.2 and 4.7 hrs during 2012-2016. It can be seen from Fig. 2.13 that there has been continuous improvement in forecast accuracy with decrease in landfall and track forecast errors and increase in skill over the years.

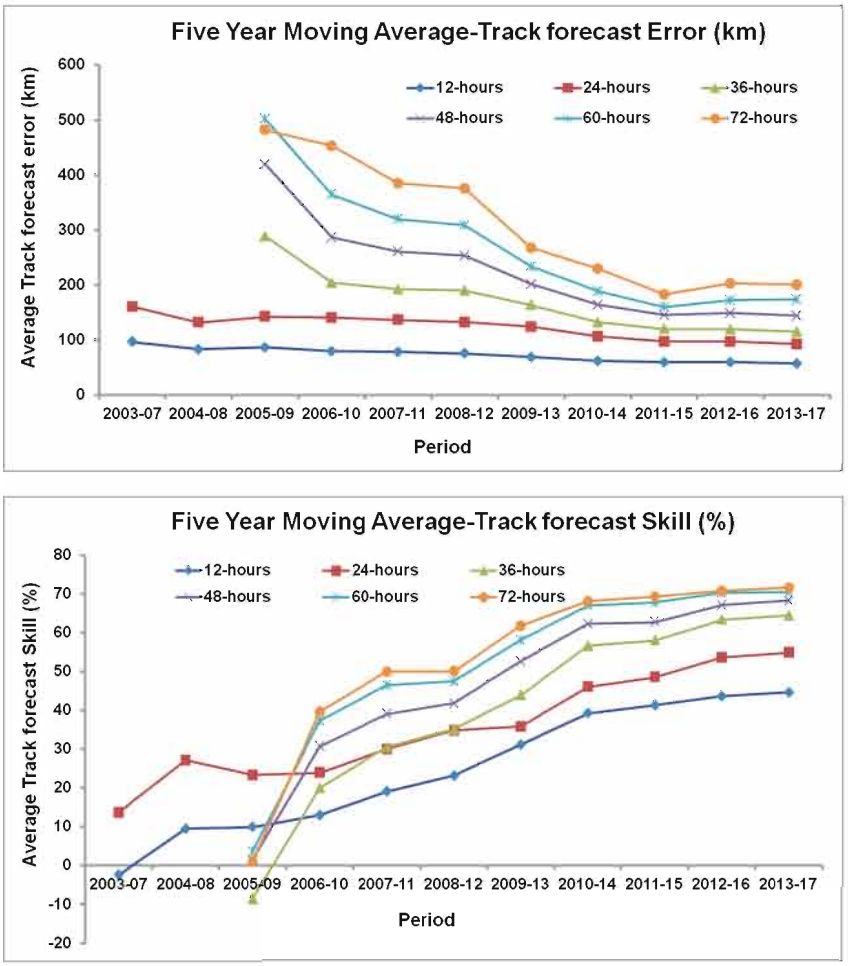

Fig. 2.13: Five Year Moving Average (a) Track Forecast Error (km) and (b) Track Forecast Skill (%) of RSMC, New Delhi over North Indian Ocean.

2.8 Southwest Monsoon and Northeast Monsoon 2017

The first stage long-range forecast for 2017 South-west monsoon rainfall for the country as a whole was issued on 18th April. IMD's Long range forecasts for the 2017 south-west monsoon season (June to September) had indicated:

(i) Quantitatively, the monsoon seasonal rainfall is likely to be 96% of the Long Period Average (LPA) with an error of ±5%.

(ii) Forecast assessment suggests 38% of probability for near normal Monsoon rainfall.

Consensus forecast for the 2017 southwest monsoon season (June to September) Rainfall over South Asia was issued in 10th Session of the South Asian Climate Outlook Forum (SASCOF-10) from 24th to 26th April at Thimpu Bhutan. Summary of forecast statement was: Normal rainfall is most likely during the 2017southwest monsoon season (June-September) over much of South Asia.

Long range forecast update for 2017 southwest monsoon rainfall was issued on 6th June which indicated that the season rainfall for the country as a whole is likely to be 98% of the long period average (LPA) with a model error of ±4%. The seasonal rainfall is likely to be 96% of LPA over North-West India, 100% of LPA over Central India, 99% of LPA over South Peninsula, and 96% of LPA over North-East India all with a model error of ±8 %.

The observed rainfall over the country as a whole during the monsoon season (June-September) 2017 was 95% of its LPA. Seasonal rainfall over Northwest India, Central India, south Peninsula and Northeast (NE) India was 90%, 94%, 100% and 96% of respective LPAs. Out of the total 36 meteorological subdivisions, 25 subdivisions constituting 65% of the total area of the country received normal seasonal rainfall, 5 subdivisions received excess rainfall (18% of the total area), and 6 subdivisions (17% of the total area) received deficient seasonal rainfall. Monthly rainfall over the country realized as a whole was

104% of LPA in June, 102% of LPA in July, 87% of LPA in August and 88% of LPA in September.

The Table below gives the summary of the verification of the long range forecasts issued for the 2017 Southwest monsoon.

Table: Details of long range forecasts and actual rainfall, 2017

Region	Period	Forecast (% of LPA)		Actual Rainfall (% of LPA)
		18th April	6th June	
All India	June to September	...	98 ± 4	95
Northwest India	June to September		96 ± 8	90
Central India	June to September		100 ± 8	94
Northeast India	June to September		96 ± 8	96
South Peninsula	June to September		99 ± 8	100
All India	July		96 ± 9	102
All India	August		99 ± 9	87
All India	August to September		100 ± 8	87

Thus, the forecasts for the seasonal rainfall over country as whole and the four broad geographical regions and the forecast for July rainfall over the country as whole were within the forecast range.

However, the forecasts for the rainfall during the second half of the monsoon season and the August rainfall were found to be overestimated to the observed rainfall. The forecast for monsoon onset over Kerala for this year was very accurate, as both the forecasted and realized date of onset of monsoon over Kerala was 30th May.

Northeast Monsoon 2017

The south Peninsula consisting of five subdivisions (Tamil Nadu, Coastal Andhra Pradesh, Rayalaseema, Kerala and south interior Karnataka) receives about 30% of its annual rainfall during the North-East monsoon season (October to December). Tamil Nadu in particular receives about 48% of its annual rainfall during this season. IMD issued the long range forecast for NE monsoon in the last week of September 2017. The details of long range forecast for the northeast monsoon season rainfall over South Peninsula and Tamil Nadu are shown in the table below:

Table: Details of long range forecast and actual rainfall for northeast monsoon 2017

Region	Long Range Forecast	Actual
South Peninsula	The 2017 NE monsoon (Oct-Dec) rainfall is most likely to be **normal**(89% -111% of LPA).	The actual rainfall (285.8 mm) was **86%** of LPA (332.1 mm).
Tamil Nadu	The 2017 NE monsoon (Oct-Dec) rainfall is most likely to be **normal**(88% - 112% of LPA).	The actual rainfall (394 mm) was **90%** of LPA (438.2 mm).

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

At present 636 Agromet Advisory Service (AAS) districts bulletins are being prepared and issued to cater to the needs of farmers in the country. Also, IMD in collaboration with CRIDA, Hyderabad issued Operational Agromet advisory Service Bulletin based on Extended Range Weather Forecast during the monsoon season to help farmers to cope with climate risks and uncertainties and effectively use seasonal to inter-annual climate forecasts. At present agromet advisories are disseminated under PPP mode and through Kisan Portal to 21.69 million farmers. Also, weather forecast and advisories under alerts and warnings through SMS enable farmers in planning farming operations effectively to minimise/ control damage of crops under adverse weather conditions. In addition to above Crop Specific Weather based Agromet Advisories` for the country on daily basis are being telecasted through DD Kisan Channel, on real time in programs like 'Kisan Samachar' and 'Mausam Khabar' in Hindi and Marathi. Farmers' awareness programmes were organised at 41 AMFUs across the country during the year. Besides, the Nodal Officers/Technical Officers participated in number of awareness programme and taken active initiatives in popularizing the GKMS. AMFUs also arranged field visits, field demonstration, farmers' interaction and also participated in Kisan Mela.

2.10 Hydro-meteorological Services

The Hydro-meteorological Division of IMD is providing the necessary technical and operational support to various Central/State Govt. organization and other agencies in the field of Hydromet design, flood forecasting, rainfall monitoring for water management and agricultural planning purposes etc. During the year 2017, design storm studies of thirty seven (37) projects have been completed and results communicated to the concerned project authorities. An amount of Rs.10,43,623/- (Rupees ten lakh forty three thousand six hundred twenty three only) has been collected for carrying out the design storm studies in respect of projects received from private/profit earning agencies.

2.11. Dissemination of forecasts and warnings

Global / National Data Collection Network of IMD including internet and other infrastructure for fast, reliable, secured and un-interrupted information and communication services at all the stations of the department including HQ have been enhanced, to meet the operational requirements.

SMS/ web based timely dissemination of Cyclone warning, Weather alerts, agriculture forecast etc. to public (including Chardham yatra, Mata Vaishno Devi & Shri Amarnathji yatra) and authorities engaged in disaster mitigation/ evacuation/relief etc. were done under "Digital India Programme" for safety of life and property. Automation of city weather/ seven day forecast uploads for about 310 important cities of India on IMD website as well as WMO website, which has been very much appreciated by WMO. New data sets received from INCOIS, INSAT, DWR, MTSAT Clear Sky Radiance (CSR) data from Japan, AWOS METAR data through SMS have been successfully ingested into RTH for dissemination to NCMRWF, NWP, other national centres as well as GTS. 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). The Facebook and Twitter accounts for different divisions of IMD have been created for wider outreach of forecast.

IMD has implemented ambitious project "Severe Weather Forecast Demonstration Project (SWFDP)" taken up with the joint initiative of IMD and WMO is to monitor, predict and warn the public and the Disaster Managers against the Severe Weather namely heavy rain, strong wind, storm surge and high waves. RSMC New Delhi is 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. Every day, regional guidance is being provided to member countries on dedicated webpage http://nwp.imd.gov.in/mme/fdp-bob.

All the works done have resulted in a better information collection and dissemination system for the operational forecasters, disaster managers and other related services resulting into better image of IMD/ MoES among the public and global meteorological community.

2.12 High Performance Computing (HPC)

India's first Multi Petaflop Supercomputer "PRATYUSH" High Power Computing (HPC) System was inaugurated and dedicated to Nation by Dr Harsh Vardhan, Hon'ble Union Minister for Science & Technology, Earth Sciences and Environment, Forest and Climate Change, on 8th January 2018 at IITM Pune. The new IITM HPC facility with a peak capacity of 4 Peta Flop (PF) from M/s. CRAY Inc. USA will help in improving the weather and climate prediction and forecast systems.

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

3.1 Ocean Services

The ministry has been delivering a suite of ocean information services to the stakeholders to meet the operational requirements in various sectors. These ocean information services have been provided successfully on operational basis to the benefit of various seafaring communities, coastal residents, defence forces and ocean scientists.

3.1.1 Tsunami Early Warning Services:

As a part of tsunami early earning services, a new TUNAMI F2(Tohoku University's Numerical Analysis Model for Investigation)model was set up for the Indian Ocean region to generate Open Ocean Propagation Scenario Database (OOPS SB) in spherical coordinates. We have upgraded the new domain (Fig. 3.1) for the Indian Ocean setup with 3.2 million grid points and have optimized the Database of Scenarios covering both Makran and Sunda Tsunamigenic Zones.

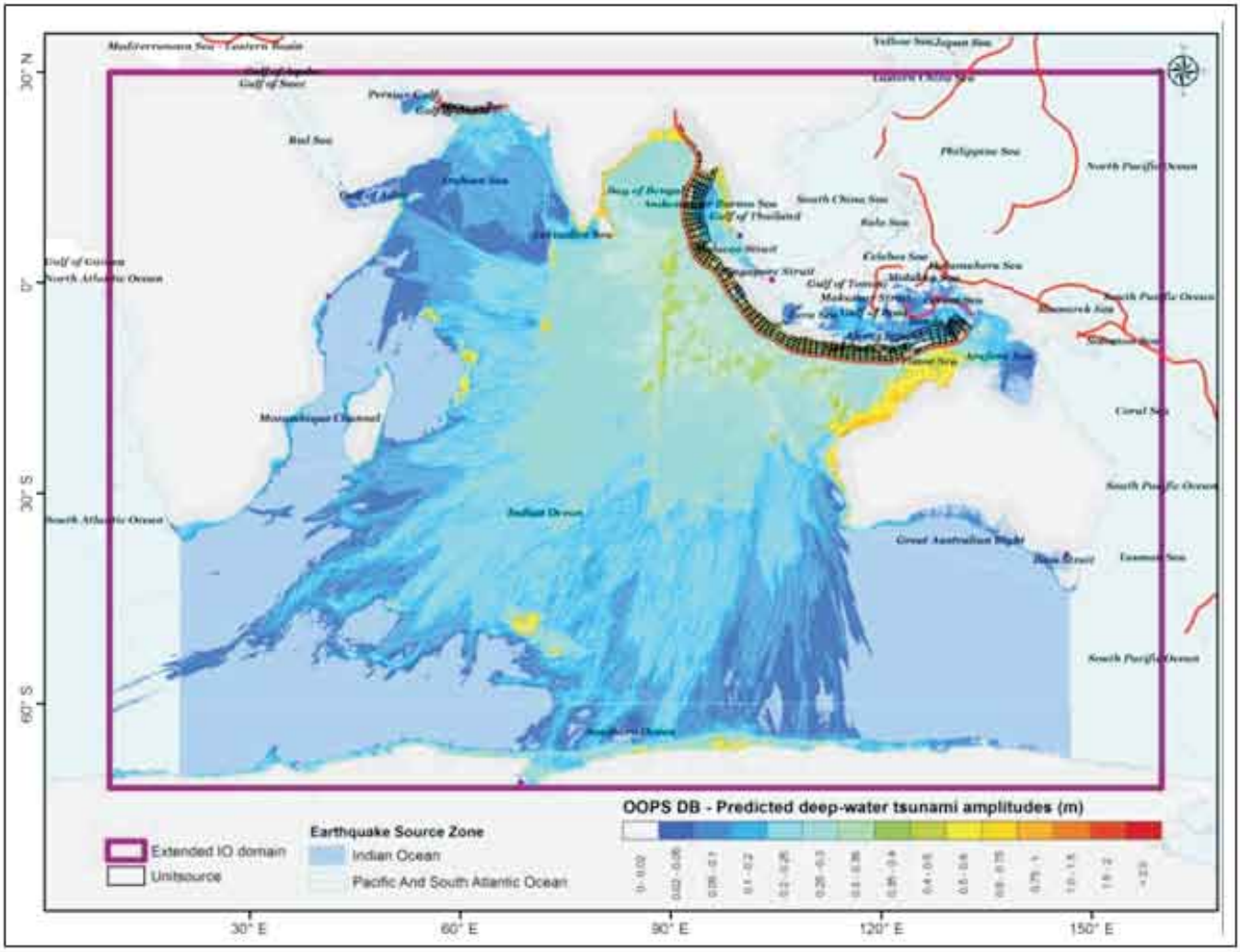

Fig.3.1: Upgraded new domain for the Indian Ocean setup with 3.2 million grid points.

INCOIS continued to monitor the seismic activities close to the tsunamigenic source regions in the Bay of Bengal and the Arabian Sea. During this period INCOIS monitored 20 earthquakes that occurred in the Global Ocean (Fig. 3.2). However, no major earthquakes were detected in the Indian Ocean and hence there was no occasion to issue any kind of tsunami warning.

3.1.2 Enhancements in Storm Surge Warning System:

Improving on our effort to provide inundation advisories, a module has been developed in-house at INCOIS that uses open source tools (GMT-Generic Mapping Tools) for generation of Inundation Raster from ADvancedCIRCulation (ADCIRC) model. The same is integrated in Storm Surge Decision Support System (DSS) which helps provide advisories during such events.The updated system was used during two cyclonic events, namely, Marutha (April, 2017) and More (May, 2017).

3.1.3 Coastal MVHM (Multi-hazard Vulnerability Mapping)

INCOIS has taken up the Multi Hazard Vulnerability Mapping (MHVM) project. The 3D GIS Mapping of 520 sq. km. has been completed for vulnerable areas such as Cuddalore, Pondicherry, parts of Machalipatnam and Rameshwaram. 3D GIS Mapping along the selected areas are in progress.

Socio-economic data, collected from door-to-door survey, pertaining to individual buildings were further used to develop methodology to generate building level risk assessment for tsunami like disaster. The building-wise risk assessment during a disaster has been evaluated based on the tsunami run-up height at each building which in-turn is derived from tsunami inundation model and corresponding building socio-economic data.

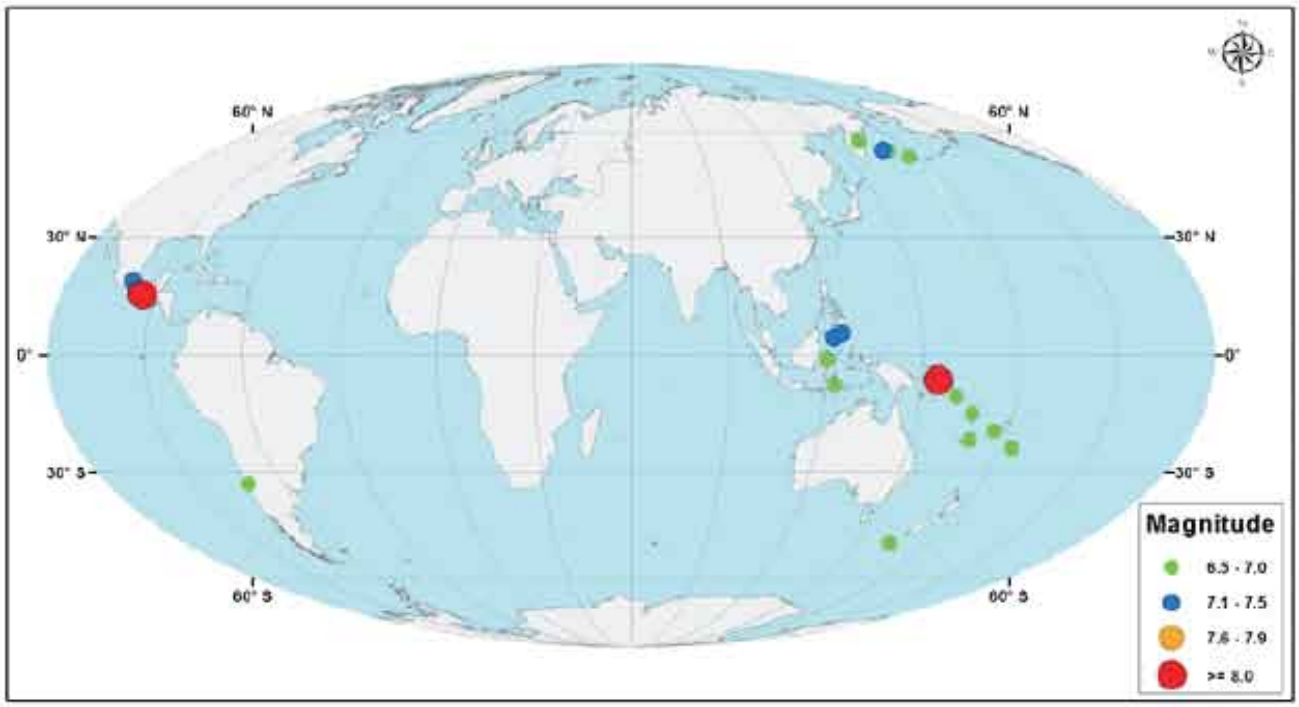

Fig.3.2: Epicentres of earthquakes in the world Ocean that occurred during Jan-Dec 2017.

3.2 Ocean State Forecast (OSF) Services

INCOIS continued to provide forecasts on the state of the oceans for a wide spectrum of users. A State-of-the-art Ocean State Forecast Laboratory at INCOIS (Fig. 3.3) was inaugurated by Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences, Government of India on 3 March 2017. The laboratory has a Decision Support System (DSS) consisting of Forecast Assessment and Support Tool (FAST). This tool will help better analyse model outputs in conjunction with observations (in-situ as well as satellite) and fine tune OSF advisories. Real-time acquisition of data and health of the instruments deployed in the deep sea can also be monitored continuously.

Joint INCOIS-IMD Bulletins were issued during Cyclone *Maarutha* (east central Bay of Bengal) during April 15-17, 2017. Kondalkattu Alert (high wind condition off and along the coast of Tamil Nadu) was also issued on 18th May 2017. Positive feedbacks on these bulletins were received from fisherfolk through MSSRF. INCOIS also issued rough weather warning for Allappuzha, Ernakulam and Thrissur (Kerala coast) for March 20, 2017 which was validated by user reports.

An Android Mobile App (in multilingual mode) on Search And Rescue Aid Tool (SARAT) developed by INCOIS was launched by Shri Rajendra Singh, Chairman, National Maritime Search and Rescue (NMSAR) Board and Director General, Indian Coast Guard during the XVI National Maritime Search And Rescue Board Meeting held at Vigyan Bhavan, New Delhi on 10 July 2017. The App can assist the searching for over 64 types of missing 'objects' in the ocean including boats, ships, man-over-board etc. App is available for download from Google Play Store under the name "SARAT".

INCOIS also started providing OSF services to various countries including Comoros, Mozambique and Madagascar. Dr M. Rajeevan, Secretary, Ministry of Earth Sciences, and Chair,

Fig. 3.3: Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences, Government of India inaugurating the state-of-the-art Ocean State Forecast Lab and (right panel) QR code-based dissemination of Ocean state forecasts on 3 March 2017 at INCOIS, Hyderabad.

RIMES Council, launched the system for operational use in the presence of David Grimms, President of World Meteorological Organization (WMO) and other dignitaries from the 48 countries of Indian and Pacific Ocean region at the 3rd RIMES Ministerial conference held at Port Moresby, Papua New Guinea during 23-25 August 2017.

3.3 Oil Spill advisory

Trajectory predictions (indicating the movement of oil spill) of the Ennore (Chennai) oil spill were disseminated as Bulletins to the Indian Coast Guard. Four Bulletins were issued from 28.01.2017 to 08.02.2017. The oil spill occurred off Ennore port, due to the collision of vessels MAPLE and DAWN on 28.01.2017 at 04.00 hrs.

3.4 Marine Fishery Advisory Services (MFAS)

The Potential Fishing Zone (PFZ) advisory service is one of the flagship programmes of INCOIS, which directly benefits lakhs of fishermen in the country. The information on the potential regions of fish availability is derived from satellite measurements of sea surface temperature and chlorophyll. The advisories were disseminated in smart map and text form on daily basis, except during fishing-ban period and adverse sea conditions. During January-October 2017, multilingual Potential Fishing Zones (PFZ) advisories were issued (at least for a sector) for all the 290 days (except 14 days' marine fishing ban across the coasts), against the annual target of 300 advisories. Similarly, a total of 188 Tuna PFZ

Fig. 3.4: Inauguration of Ocean State Forecast and Information System for Comoros, Madagascar and Mozambique on 25-08-2017 at Papua, New Guinea.

advisories were also provided. The user-base of MFAS has witnessed a significant increase in recent years, mainly due to dissemination via mobile as shown in Fig. 3.5. With the support of Ministry of Home Affairs and Ministry of Agriculture, INCOIS is coordinating with the state fisheries departments to obtain the mobile numbers of all the sea-going fishermen. So far, 98,922 mobile numbers have been added to the user-database. These fishermen will directly receive PFZ advisories on their mobile phones. Efforts are underway to include more fishermen in the network.

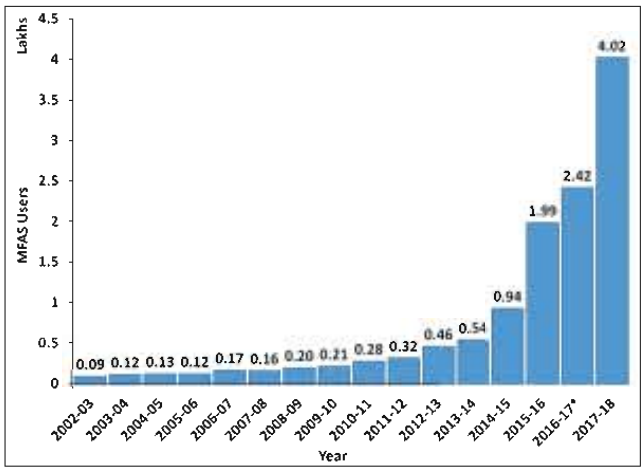

Fig. 3.5: Total registered users reached by INCOIS and its partners.

Harnessing the geostationary satellite data for PFZ

Since development of the methodology for generating Potential Fishing Zones (PFZ) advisories at ISRO centres, and its establishment as an operational service at INCOIS, only Polar-Orbiting Satellites' (POS) data have been used. Initial attempts made at INCOIS to use geostationary satellite (GS) SST (Sea Surface Temperature) data (e.g. Kalpana-1) faced difficulties due to coarse (8 km) spatial resolution. Another opportunity has arisen after the launch of INSAT-3DR mission in September, 2016. Along with its predecessor INSAT-3D mission, SST data at 4 km spatial resolution is now being made available every 15 minutes – for the full Indian Ocean region. Efforts are underway to harness these data and establish a Standard Operating Procedure (SOP) for utilising them in PFZ advisory services. The INCOIS team has already tested PFZ generation with the help of these data. The GS data can not only help filling gaps in the POS data, but also provides opportunities for value-added services such as PFZ NOWcast – and hence, paving the way for future scope of using GS SST and ocean colour data.

3.4.1 Species specific research efforts

3.4.1.1 SATTUNA (Satellite Telemetry of Tuna)

Under the SATTUNA (Satellite Telemetry studies on migration patterns of Tunas in Indian Seas) project, during year 2017, additional sixteen yellowfin tuna were tagged with Pop-up Satellite Archival Tags (PSATs) in collaboration with CMFRI and FSI. Data collected by PSATs were used to analyze and understand the Tuna habitat. From the results, it is observed that Tagged fish did not exhibit significant deep diving or diurnal behaviour, and preferred ambient temperatures of 26-30°C and 25-29°C in the Arabian Sea (AS) and the Bay of Bengal (BoB), respectively. In general, tuna spent 60% and 70% time in the regions with Sea Surface Temperature of 26-29°C and Sea Surface Height-anomaly of ±6 cm, respectively.

3.4.1.2 Indian Oil Sardine

Development of the predictive capabilities for the Indian oil sardine (Sardinellalongiceps) stock off

the southwest coast of India is being pursued under the ongoing technical cooperation between NOAA, USA and MoES institutions INCOIS and CMLRE. The sixth workshop under this collaboration was held at INCOIS in September, 2017 during which a statistical forecast model was developed and tested. Such outputs are envisaged to be provided in future, in the form of outlook bulletins.

3.4.1.3 Hilsa Shad

A new small-pelagic fish habitat-suitability model focusing especially the Northwest Bay of Bengal was pursued for Hilsa shad (Tenualosailisha). An in-house, validated coupled biophysical Regional Ocean Model System (ROMS) simulated sea surface temperature (SST), chlorophyll concentration (CC), dissolved oxygen (DO), salinity and remotely sensed rainfall were used as predictor variables for hilsa catches, into a Generalized Additive Model (GAM) and Geographic Information System (GIS). Several GAMs were constructed with Hilsa shad Catch per Unit Effort (kg h−1) as a response variable for the period of 2009-2016. Best-fit model was selected based on the significance of model terms, reduction in Akaike's Information Criterion and increase in cumulative deviance explained; to predict Catch Per Unit Effort (CPUE) and was validated using a linear model.

3.5 Data Services

INCOIS, designated as the National Oceanographic Data Centre (NODC) by the International Oceanographic Data Exchange (IODE) Programme of the Intergovernmental Oceanographic Commission, continued serving 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 from a wide variety of ocean observing system such as Argo floats, moored buoys, drifting buoys, wave rider buoys, tide gauges, wave height meter, ship mounted autonomous weather stations and HF radars. The data centre at INCOIS obtained and archived the real time in situ data from the various ocean observing systems.

3.5.1 Ocean Remote sensing data products

The remote sensing data from various sensors flown on board Oceansat-2, NOAA series of satellites, METOP, Terra and Aqua satellites are received in real-time at the ground stations established at INCOIS. A notable addition this year was the availability of direct broadcast data from Suomi-NPP satellite (having VIIRS, CrIS& ATMS sensors) for operational activities of INCOIS. The data are processed and made available to in-house operational activities as well as to other operational agencies in the country in the near-real time. INCOIS had also served request based off-line data products to many research organizations.

- **Digital Ocean:** Digital Ocean is a dynamic framework of a set of applications to efficiently integrate and manage heterogeneous ocean data and to provide advanced visualization and analysis tools. The Digital Ocean project is in advanced stage and significant progress have been made.
- **MoES metadata portal:** A metadata portal for the ease of search and discovery of various geo-spatial datasets collected and maintained under the various MoES programmes was developed by INCOIS. The Meta data portal includes a metadata editor based on ISO-

19115 standards relevant to the basic geographic information and extensions for imagery andgridded data.

- **Services to the Indian Navy:** INCOIS data centre continued to support Indian Navy by providing oceanographic data. Data centre also developed a software for visual quality control of XBT profiles for Naval Operations Data Processing and Analysis Centre (NODPAC).

INCOIS data centre also developed "MaMeAt" - a tool for visualizing marine meteorological data for Naval applications. The data for this tool is obtained from the Indian Meteorological Department (IMD), NODPAC and individual records of International Comprehensive Ocean-Atmosphere Dataset (ICOADS).

3.6 Ocean Observation Network(OON)

The primary purpose of acquiring a suite of accurate measurements of ocean parameters is to cater research and a wide range of operational services including issue of early warnings. These observation systems are broadly classified into two categories viz., moored and drifters. The moored systems include moored buoys, HF Radar, tide gauges, current meters, whereas the drafter encompass drifting buoys, Argo floats, gliders etc. The details of observations systems deployed, operated, maintained and supported by India and their current status are shown in the table below.

3.6.1 Moored Buoys

Ocean observation systems group of National Institute of Ocean Technology has been systematically maintaining the sixteen buoy systems with surface & subsurface sensors, four coastal buoys, one calval buoy and two tsunami buoy systems for continuous data collection. During the reporting period 11 cruises were conducted to carry out 48 deployments/retrieval operations. These buoy systems are providing continuous real time uninterrupted data, which have been disseminated to INCOIS. OOS fulfilled the objectives envisaged in the Administrative Order. Indian Buoy programme successfully completed 20 years of service to the Nation and the event was celebrated on 22nd April 2017.

Type of Platform	Target for XII Plan period 2012-17	Commissioned till October, 2017	Data received during October, 2017
Argo Floats *	200	298	136
Drifters*	150	103	2
Moored Buoys	16	19	18
Tide Gauges	36	34	26
High Frequency(HF) Radars	10	10	9
Current Meter Array	10	11	2
Acoustic Doppler Current Profiler(ADCP)	20	20	18
Tsunami Buoys	7	9	9
Wave Rider Buoy	16	17	10

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

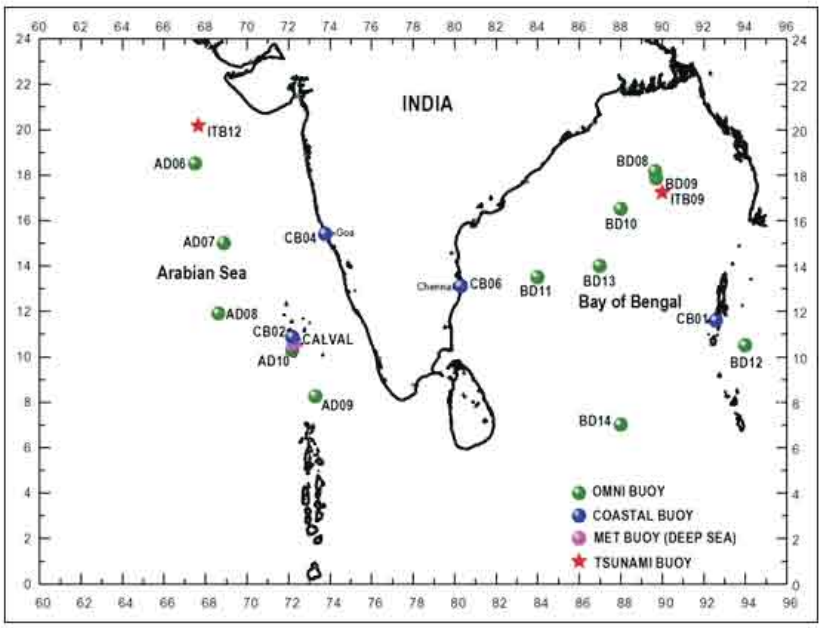

Fig. 3.6: Locations of Moored Buoys deployed in the Indian Ocean.

OOS Group sustains and maintains OMNI, Met, Tsunami buoy network in Indian seas and the data are being shared with NOAA NDBC through INCOIS.

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

The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) was designed to study the Indian Ocean's role in the monsoons. To augment and maintain the RAMA array, two cruises are conducted in the equatorial Indian Ocean on board SagarNidhi during 05th August – 03rd September, 2017 (30 days) and 19th October –18th November, 2016 (31 days). A total of 7 RAMA moorings, 2 Tropflux, 5 ADCP moorings were serviced and also deployed 19 drifters and 8 ARGO floats. At present 78% (36 out of 46) of the RAMA mooring array sites are occupied. One more cruise is expected to be conducted in the February – March 2018 (35 days cruise). 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 98 research publications were emerged from this project.

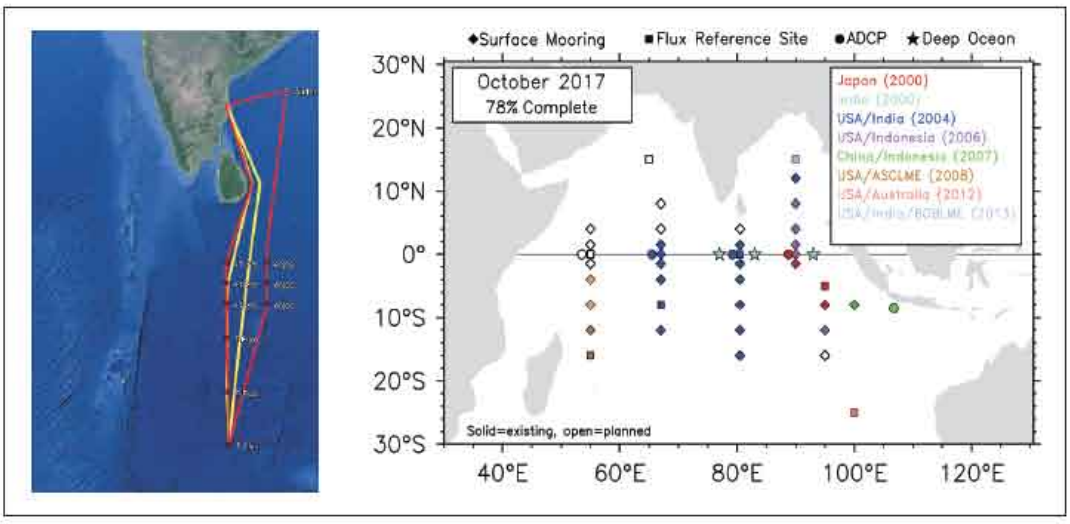

Fig.3.7: Cruise track and present status of the RAMA array in the Indian Ocean.

3.6.3 Indian XBT Project

CSIR – National Institute of Oceanography has been executing the Indian XBT project supported by the MoES through (INCOIS) since the last two and half decades. Under this project, temperature / salinity data are collected by deploying XBTs / XCTDs using ships of opportunity (cargo ships). During this period, 4 transects were achieved between Chennai-Portblair and Portblair-Kolkata and 1 transect between Kochi-Lakshadweep with collection of 52 profiles from XBT and 32 profiles from XCTD and 184 samples of Sea surface salinity (SSS).

3.7 Ocean Modelling and Research

INCOIS completed setting up the High-resolution Operational Ocean Forecast System (HOOFS) at a resolution of 2.25 km x 2.25 km for entire coastal waters around the country. Validation of the forecasts generated using the HOOFS setups showed significant improvements in the quality of operational ocean forecasts provided by INCOIS. Global Modular Ocean Model (MOM5) is being setup for studying the Indian Ocean response to the global warming.

Ocean data assimilation based on Local Ensemble Transform Kalman Filter (LETKF)is now setup for the Regional Ocean Modeling System (ROMS). This setup can assimilate in-situ profiles of temperature and salinity and satellite observations of SST and SSH. The ROMS setup with LETKF data assimilation system will be made operational very soon. INCOIS has also setup LETKF data assimilation system in Modular Ocean Model (MOM4p1d) as part of Monsoon Mission.

INCOIS continued to provide ocean analysis based on Global Ocean Data Assimilation System (GODAS). This has been extensively used by IITM and IMD for initializing the CFS model for seasonal prediction of monsoon. INCOIS also provided the information on the evolution of climate indices such as ENSO, IOD and MJO based on GODAS analysis. Ocean Reanalysis also is generated for the period 2003-present using GODAS.

Observation System Evaluation Experiment using GODAS has shown that the ocean analysis and reanalysis before the Argo era may be significantly affected sparse spatial coverage of moored buoys. Through controlled experiments, using real and simulated observations in two different ocean models and assimilation systems, it has been shown that shocks are generated in the ocean at the lateral boundaries of the moored buoy network. They thrive and propagate westward as Rossby waves along these boundaries.

3.8 Coastal Research

The coastal research a multi-disciplinary endeavour encompassing four specific fields namely coastal pollution, coastal processes, coastal vulnerability and coastal ecosystems are being carried out through various projects to provide scientifically-informed inputs to the decision makers and public for the better utilization and management of coastal areas.

3.8.1 Coastal pollution - Sea Water Quality Monitoring along Indian Coast

Towards periodical assessment of the health of our coastal waters, systematic multi temporal and spatial data on coastal water quality are being collected across the Indian coastline (started as the COMAPS programme in 1991) which is probably the only dataset available in the country to study the long term water quality and pollution trends of the coastal waters of India. The

data are being provided to the all the coastal States and Central Pollution Control Board (CPCB) and has also been posted on the website for public use. Presently, data on more than 25 environmental parameters are being collected at 24 locations (transects), with the help of R & D institutes which is useful for assessing the health of Indian marine waters and help prioritize areas that need immediate and long-term action.

Prediction of seawater quality (PWQ) program is implemented for Chennai coast using a water quality model coupled with physical transport and biogeochemical processes on a spatio-temporal scale to provide 5-day forecast of SST, salinity, DO, BOD, ammonia (NH_4), nitrite (NO_2), nitrate (NO_3), phosphates (PO_4) and faecalindicator bacteria (FIB). A web-based user interface and a mobile App *(Clean Coast)* is developed to disseminate the forecast to the beach goers and coastal stake holders. The program is proposed to be extended to other beaches along east coast in next three years.

3.8.2 Monitoring and mapping the Shoreline change along Indian coast; Hydrodynamics and sediment transport studies along South Maharashtra

(i) Monitoring and mapping the Shoreline change along Indian coast

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. A GIS based interactive database was created and 517 maps depicting cumulative shoreline changes for the years 1990-2016 were generated. The shoreline changes vulnerability was classified in 7 classes i.e. 3 each for accretion and erosion and 1 for stable. The analysis of last 26 years data suggests that about 33%, 38% and 29% coast is

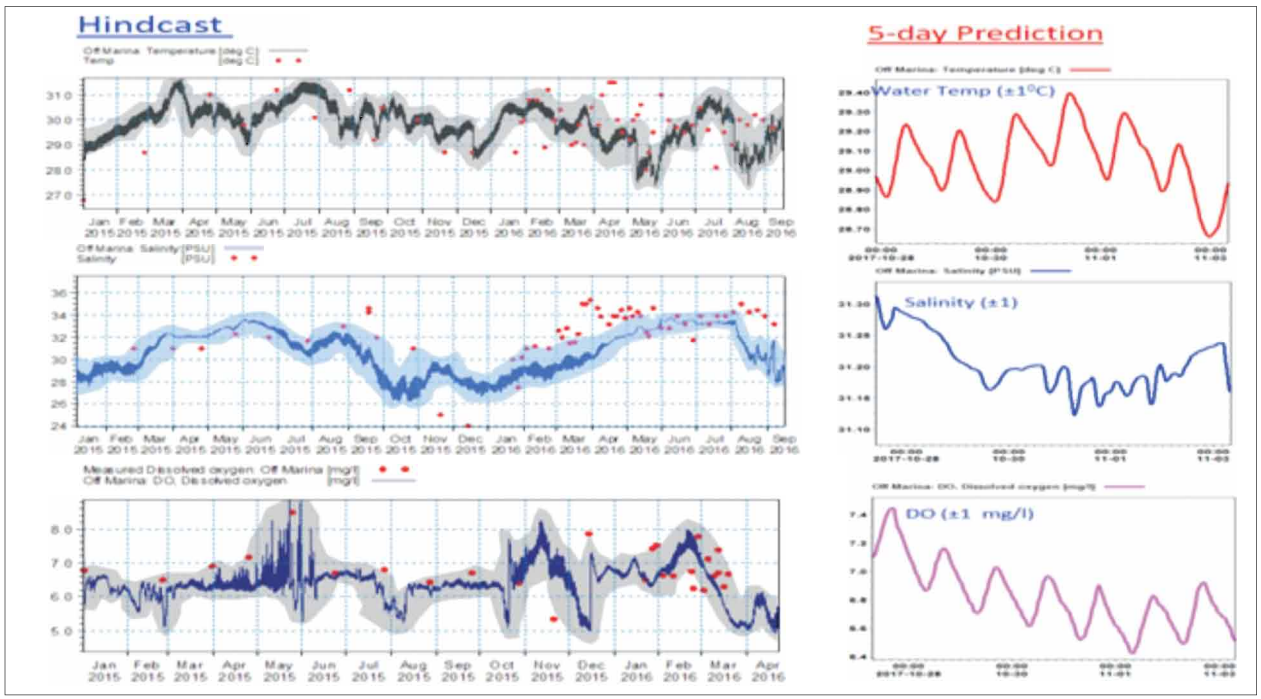

Fig. 3.8: Hindcast and 5-day forecast of water temperature, salinity and dissolved oxygen at Marina beach, Chennai.

eroding, accreting and is stable in nature respectively. During 2017-18, a field survey was carried along Kerala, Maharashtra and South Gujarat coast to assess the annual shoreline changes, sediment sample collection, GCP's collection and for result validation. A database for beach sediment containing the grain size, compositionetc is developed. It has geo-tagged information for more than 1100 sediment samples collected at 371 beach locations spreading along Indian coast and along with field photographs depicting erosion / accretion. A web based coastal service on shoreline change is developed to disseminate the information to all stakeholders. The overall shoreline changes of Indian coast are given in Table 1.

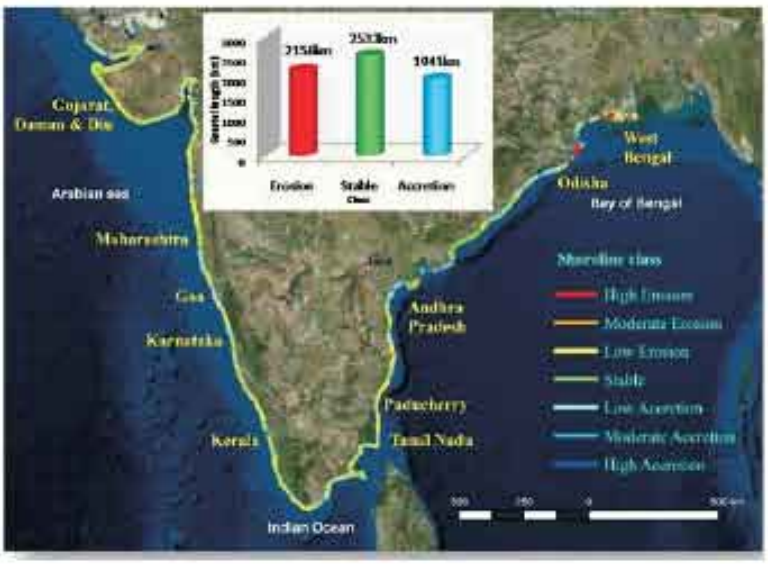

Fig.3.9: Shoreline Vulnerability along the Indian Coast.

(ii) Coastline Vulnerability Index (CVI)

In 2017-18, a pilot study on Coastal Vulnerability Index (CVI) for 125 km long stretch along Nagapattinam coast was carried out using physical parameters such as slope, elevation, geomorphology, significant wave height, tide, shoreline Change, sea level change, tsunami and storm surge. The analysis suggested that 19% coast falls in low, 64% medium and 17% is highly vulnerable. Similar work is in progress for Chennai and Cuddalore coast.

Table 1: Status of state-wise Shoreline changes along Indian coast (1990-2016)

Sl No	State		Coast Length (in Km)	Coast length (in Km)					
				Erosion		Stable		Accretion	
				km	%	km	%	km	%
1	West Coast	Gujarat	1701.78	524.84	31	741.98	43	434.96	26
2		Maharashtra	739.57	178.26	24	472.67	64	88.64	12
3		Goa	139.64	16.82	12	95.58	68	27.24	20
4		Karnataka	313.02	70.02	22	151.16	48	91.84	30
5		Kerala	592.96	263.04	45	201.52	34	128.40	21
6	East Coast	Tamil Nadu	991.47	407.05	41	353.56	36	230.86	23
7		Puducherry	41.66	23.80	57	14.63	35	3.23	8
8		Andhra Pradesh	1027.58	272.34	27	320.98	31	434.26	42
9		Odisha	549.50	153.80	28	113.52	21	282.18	51
10		West Bengal	534.35	336.52	63	68.78	13	129.05	24
Total			6631.53	2156.43		2533.86		1941.24	
%				33		38		29	

(iii) Impact of sea level rise on Shoreline

In 2017-18, a pilot study on shoreline retreat with sea level rise was carried out for Chennai coast using RCP-2.6, RCP-4.5, RCP-6 and RCP-8.5 scenario (Fig. 3.10). The impact of Sea Level Rise (SLR) for 50 and 100 years was estimated using Bruun rule. Long term analysis trend suggest that more than 60% of the region falls in stable to low accretion. Using different time frames and scenarios of projected SLR for Chennai, the area of horizontal inundation is estimated for 100 years as ~1.6km (Bruun rule) and ~1.1 km (Modified Bruun rule). Similar work is being carried out for Cuddalore (Tamil Nadu) coast, Sundarbans (West Bengal) and Vengurla coast (Maharashtra).

3.8.3 Ecosystem Modelling for SW coastal waters of India

Periodic sampling was conducted in the Kochi coastal waters along five transects with 25 locations within the 50m depth contour to understand the biogeochemical processes and to develop an ecosystem model. The field data was utilized in both analytical and numerical models for the simulation of hydrodynamics, water quality, nutrients and chlorophyll through a processes response physical-biogeochemical coupled model. Our findings indicated a large difference between total nitrogen (TN) and dissolved inorganic nitrogen (DIN) concentrations suggesting that organic nitrogen was the major form of nitrogen in the coastal waters of Kochi. The coastal waters of Kochi were within the oligotrophic to mesotrophic conditions during the study period. The mean N: P ratios were low (<10) during all the seasons suggesting that nitrogen is a limiting nutrient for primary production in the coastal waters of Kochi. High chlorophyll-a and primary production was observed during the southwest monsoon season as compared to the other seasons.

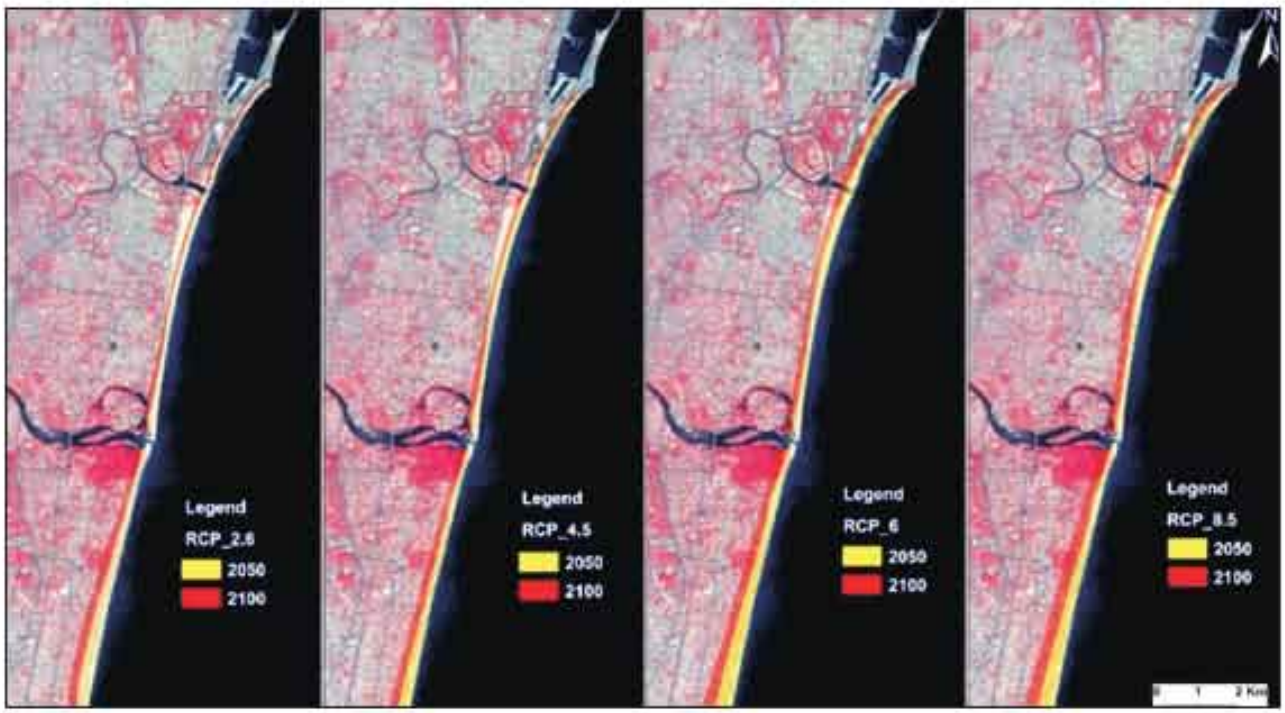

Fig. 3.10: Estimation of potential impact of Sea level rise for various RCP scenarios.

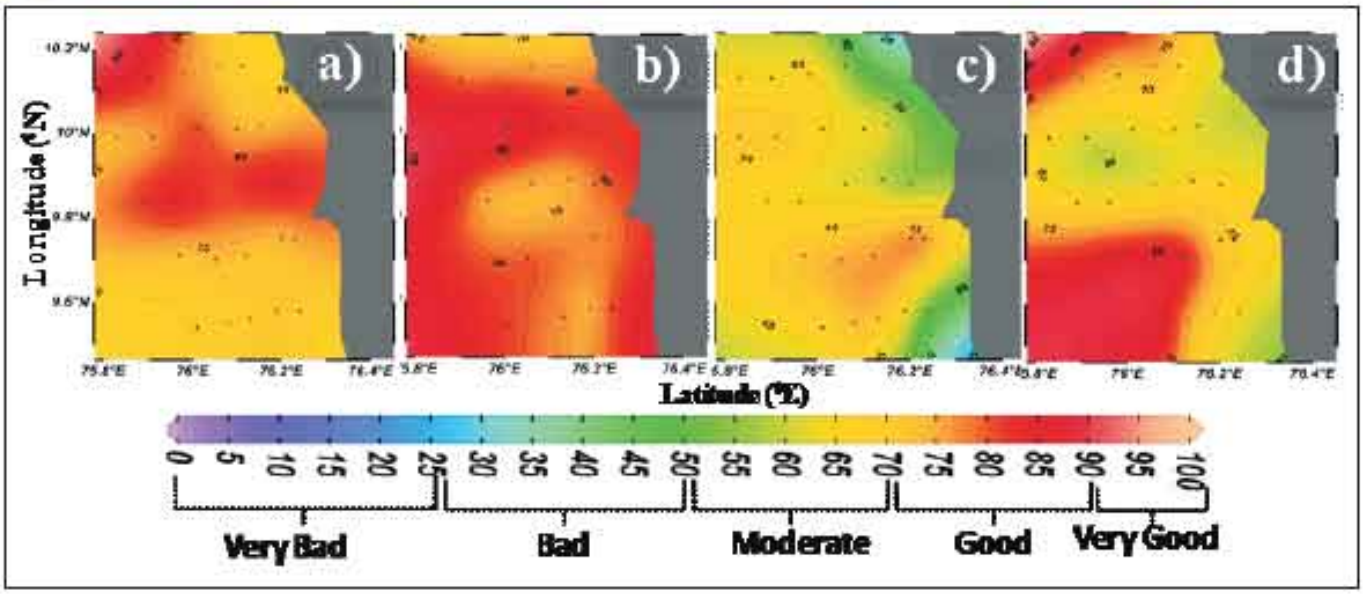

Fig. 3.11: CWQI of the coastal waters of Kochi during a) winter monsoon, b) spring inter monsoon, c) southwest monsoon and d) fall inter monsoon season.

3.9 Marine Living Resources (MLR)

Under the continning MLR programme of CMLRE, the following two projects are proposed during 2017-20.

I. Marine Ecosystem Dynamics of eastern Arabian Sea (MEDAS) and

II. Resource Exploration and Inventorization System (REIS).

3.9.1 Marine Ecosystem Dynamics of eastern Arabian Sea (MEDAS)

Six cruises were taken onboard FORV Sagar Sampada to understand the ecosystem dynamics in the South East Arabian Sea. Multi-scale processes associated with the Arabian Sea Warm Pool (ASWP), during the peak and weak phases and the Coastal Upwelling (CU) onset was addressed based on the FORV Sagar Sampada cruise data, satellite and climatological data. Warm pool associated with peak temperature was observed to be on the higher side than the normal records during 2003-2017 span. The strongest was during 2010 (30.84°C) followed by 2016 (30.79°C), 2005 (30.72°C) and 2017 (30.55°C). Studies on hydrodynamics and current structure along the shelf edge of South East Arabian Sea(SEAS) observed a vertically homogeneous thermal structure in the upper 80m with evidence of intrusion of Bay of Bengal waters up to 14°N. Sector wise comparison of ADCP and Ekman current showed less influence of wind on the current field throughout the sector except at south (7-8°N). The huge mass of Oil Sardine eggs collected from the upwelling fronts indicate active breeding of the fishes during the season especially in pockets which favor concentration, retention and production processes important to recruitment success.

3.9.2 Resource Exploration and Inventorization System (REIS)

Four cruises were taken onboard FORV Sagar Sampada to harness the living resources of the

Indian EEZ. Three fishing operations were made along the Terrace of Trivandrum (ToT) along the south west coast of India and one of the trawling operations was the deepest (1425m) which has ever been made onboard. Two deep sea fishes, *Lophiusgracilimanus* (one single Female specimen, 270mm Standard Length) and *Diretmoidesverginae* Kotlyar, 1987, has been redescribed from off Andaman Coast of India, 7°5'N, 93° 4' E at a depth of 650 m and Great Nicobar Waters at a depth of 576m respectively. A species of worm eel of genus *Neanchelys* has been described as a new species from the South eastern Arabian sea off Kollam from 450 m depth. A new species of deep sea angler fish belonging to the genus *Chaunax*, 196 mm has been described from the southwest coast of India, 8.28° N, 76.20° E at a depth of 1050-1100 m.

3.9.3 IndOBIS

An additional record of about 3750 belonging to 23 major groups of deep sea organisms from northern Indian Ocean has been added to the IndOBIS during the current year.

3.9.4 FORV Sagar Sampada

During the period, FORV Sagar Sampada undertook 15 cruises in the Arabian Sea, the Andaman Water and the Bay of Bengal with a total of 286 days out at sea. The vessel was utilized by PRL, INCOIS, NIO-RC-Mumbai, NIO-Goa, Kerala University for Fisheries and Ocean Studies (KUFOS), Pondicherry University,

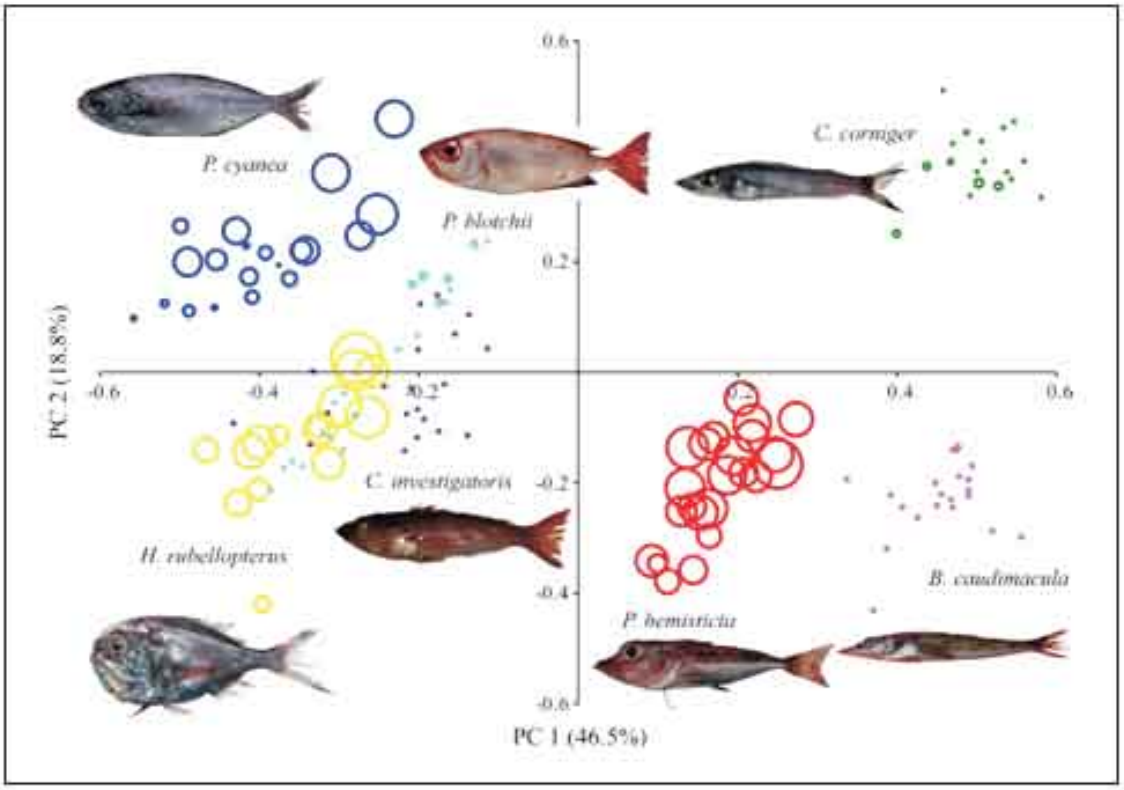

Fig. 3.12: The MANOVA analysis showed the existence of significant differences among species (Wilk's Lambda= $3.025*10^{-4}$, $F_{36,288}$=261.5, $P< 0.0001$), hence functional niches were not overlapping. The species *P. cyanea* showed the lowest values of overlap and *P. blochii* the highest degree of overlapping.

Fig. 3.13: Visit of the Parliament Standing Committee on Science & Technology and Environment to FORV Sagar Sampada.

NIOT, and CMLRE to undertake the various activities of Marine Living Resources Program (MLRP) carried out by CMLRE.

The Parliament Standing Committee on Science & Technology and Environment chaired by Hon'ble MP Mrs Renuka Chaudhary reviewed the activities of CMLRE onboard the ship FORV Sagar Sampada during May 11th 2017.

3.9.5 New Campus for CMLRE

The construction of new Campus for CMLRE at Puthuvypu, Kochi is progressing and is expected to be completed by March, 2018. 75% of the administrative cum Science block and Transit Hostel work has been completed. An amount of 2 crores has been utilised so far for the building construction work during the current year.

3.10 Ocean Technology

3.10.1 Development of manned and unmanned underwater vehicles

In order to carry out target verification of missing aircraft AN-32, based on the request of the Indian Coast Guard, the deep water remotely operated vehicle, ROSUB 6000, developed at NIOT for exploration of deep sea minerals was deployed at 3400 m water depth on board Sagar Nidhi. The target verification involved a joint team comprising of NIOT, Indian Air force, Indian Navy and Indian Coast Guard.

Fig. 3.14: ROSUB 6000 systems on board Sagar Nidhi for AN32 aircraft target verification.

PROVe is an underwater Remotely Operated Vehicle (ROV) designed and developed indigenously for shallow water applications up to 500 m, and it is capable of operating in the Polar and open ocean environmental conditions. In January 2017, PROVe was used for carrying out underwater inspection of the barge which sank in the Chennai Port during the Vardha cyclone. PROVe SONAR was used for overall spatial mapping of the barge in turbid water conditions. During March 2017, PROVe was also deployed in the open ocean environment for the first time using MoES research vessel FORV Sagar Sampada by the joint team of NIOT and Centre for Marine Living Research and Ecology (CMLRE), Cochin scientists for carrying out biodiversity investigations in the Arabian Sea off-Mangalore at 40, 96 and 200m water depths.

In-house developments are carried out for the manned submersible personnel sphere with view ports and entry hatch, life support system, power budget estimation and underwater battery system design etc. A mock up personal sphere of 2.1m diameter is realized for acclimatization of the personnel. The acrylic view ports are designed, fabricated and tested in the hyperbaric chamber for 600 bar pressure withstand capability.

3.10.2 Development of Integrated deep sea mining system

As part of the development of Integrated Deep Sea Mining system, a reduced experimental undercarriage with involute grousers was developed. The sinkage, traction force and locomotion was studied in a simulated soft soil conditions in a test tank. Experimental studies are done to identify the impact of suspended loads on the power and optical conductors of the electro-optic umbilical cable.

Locomotion trials of the experimental under carriage is planned to be undertaken on the actual soft sea bed soil conditions in the Central Indian Ocean basin so as to validate the efficacy of the designed track system. The system is developed and sea trial readiness is verified. Sea trials are planned at shallow water depths up to 1000m prior to the deployment at the central Indian Ocean basin. The system is augmented with precision instrumentation for measuring the traction forces, cable drag, vehicle attitude underwater and sinkage-pull out forces with regard to soft soil.

An autonomous battery operated in-situ soil tester for 6000 m depth operation is also developed for sea bed soil characterization. Compared to the previous model, this system would have much reduced weight and does not need a dedicated electro-optic umbilical. The system with endurance of 8 hours can log soil parameters locally and can be retrieved later for analysis.

3.10.3 Technology development for exploration and extraction of gas hydrates

An Autonomous Coring System (ACS) capable of collecting 100m core from deep ocean basins based on wire-line technology was qualified for its integrated functionality at about 3000 m water depth successfully during Sep - Oct 2016. The functionality qualification at 3000m water depth includes underwater hydraulic valves for sub system operations using rate and proportional manifolds, subs sea power system, electronics, control software, sensor, luminaries and cameras.

3.11 Coastal Engineering

3.11.1 Seabed engineering investigations and model studies for Gulf of Khambhat development Project

Kalpasar is a major civil engineering work envisaged to capture fresh water draining out from Mahi, Narmada and Sabarmati rivers by constructing a 30km earthen dam across the Gulf of Khambhat from Bhavnagar to Dahej to create a huge fresh water reservoir for irrigation, drinking and industrial purposes. Kalpasar department has entrusted the sea bed engineering investigations and numerical model studies of GoK to NIOT. NIOT is working closely with Design team of Kalpasar to evaluate the impact of the construction works.

3.11.2 Design and Demonstration of Submerged Offshore Reefs for beach restoration at Pondicherry coast

Based on the learning from experimental beach nourishment, process based measurements and numerical studies; proposal for two reefs along with beach nourishment is made. Methodology for implementation of beach nourishment along with design beach profiles was arrived and this indicates an immediate requirement of 0.5 million m3 of sand for nourishment. Implementation of proposed hybrid solution (Beach Nourishment and two Reefs) not only protects the coast but also restores the beach, which was lost. The northern Reef will be implemented by MoES and the Southern Reef along with beach Nourishment will be implemented by Puducherry Government. The Bhumi Pooja was performed in the presence of honorable Chief Minister of Puducherry and the project execution has commenced. NIOT is implementing submerged northern reef and the activities are in progress. Puduchchery Govt. has implemented beach nourishment with 3 Lakh Cubic meter of sand. A MoU was Signed with Puducherry Government to provide Technical Services for implementation of Southern reef under Smart City Development Program.

Fig. 3.15: Beach formed during the progress of northern reef implementation.

3.11.3 Establishing desalination plants in UT Lakshadweep Islands

MoES-NIOT is extending technical support for the issues related to the LTTD plants commissioned at Agatti, Minicoy and Kavaratti and proposal to install similar plants in six more islands. Government of India approved the proposal for establishing LTTD plants of 1.5 lakhs liters per day capacity in all 6 Islands of UT Lakshadweep for an amount of at Rs.187.87 crores excluding taxes and asked to complete the project in 2 years' time. Subsequently, an open tender has been floated on 23.09.2017 and Pre-bid meeting was conducted on 12.10.2017. The tender due date is 24.11.2017 and expected to commence the implementation during January 2018.

3.11.4 Sustainable Shoreline Management

Sustainable Shoreline Management (SSM) program aims to design solutions for sustainable management of coastlines with potential stakeholder interests like industry, fishing, tourism etc. Design of shore protection schemes for Kadalurperiyakuppam, Bommayarpalayam, Mahabalipuram and Vishakapatanam are being undertaken upon the request by the stakeholders.

3.11.5 Coastal segment classification – DISSEMINATE ATLAS

A digital database for Tamil Nadu coastline showing engineering structures and their effects on the adjacent shoreline morphology was prepared. Satellite imageries, field monitoring, numerical modeling studies and statistical analysis have been coupled together for preparation of shoreline impact maps. The results of the study are published in the form of an atlas called DISSEMINATE.

3.11.6 Coastal HF Radar network along Indian coast including Andaman island under Ocean Observation Network (OON)

INCOIS is successfully operating 5 pairs of the High Frequency Radar's along the Indian Coast and the data are made available to the Scientific community.

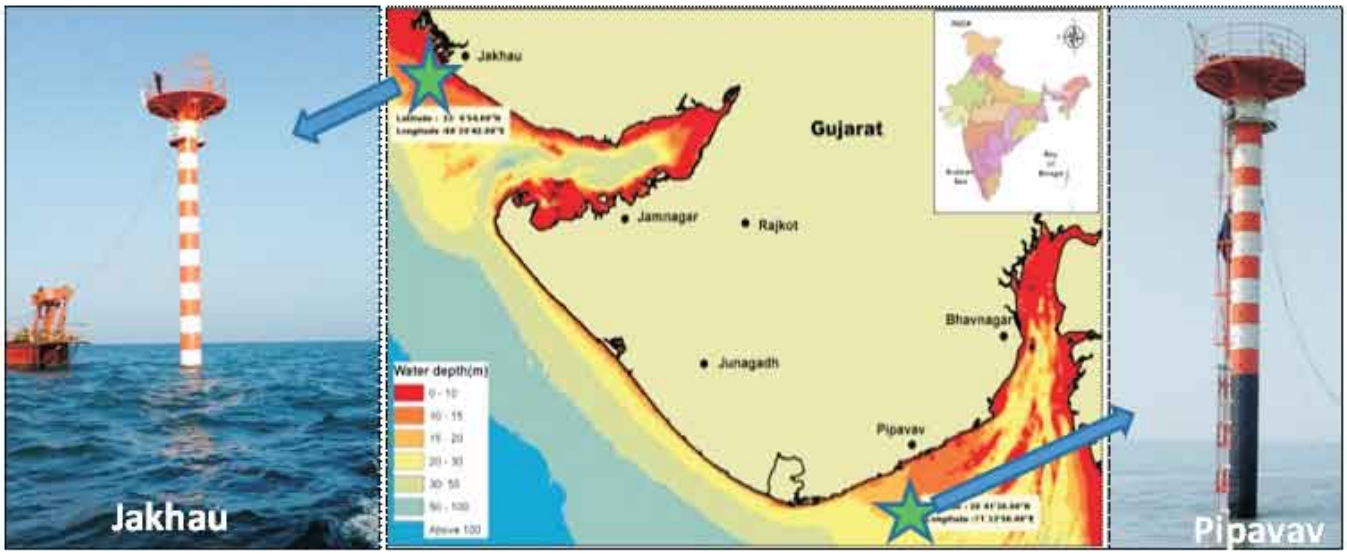

Fig. 3.16: LiDAR based data collection platform.

3.11.7 Prediction and Monitoring of Tides at Ropex Service Jetty, Ghogha, Gujarat

Gujarat Maritime Board requested NIOT to predict the tides and operational window for the construction of link span bridge work from sea side using the crane barge and to provide tides, currents and depths along the navigational channel for the safe navigation of the vessel Island Jade.

Numerical model simulations are carried out for Gulf of Khambhat and extracted the tide, current along the navigational channel. A detailed report on operational window for vessel is submitted to GMB and accordingly Honorable Prime Minister launched the ferry service on 22 October 2017.

3.11.8 Coastal Erosion Mitigation and Shoreline Management Plan for Visakhapatnam

NIOT and Deltares Netherlands has jointly signed an agreement with Greater Visakhapatnam Municipal Corporation (GVMC) to carry out the studies on Coastal Erosion Mitigation and Shoreline Management Plan for Visakhapatnam funded by World Bank.

3.11.9 Feasibility studies on Fixed and Floating platform for Offshore Wind Turbine

Establishment of offshore wind farms requires collection of offshore wind profiles for a continuous period more than a year. So, a LiDAR based data collection platform was developed for MNRE-NIWE at Gulf of Khambhat and M/s Suzlon at Gulf of Kutch. We designed offshore substructure considering high tidal currents and poor soil conditions in Gulfs. This platform being unique and first of its kind in India, suitable installation methodology was developed by modifying the Jack-up barge with state of the art launching and driving mechanism. This helped in reducing the overall project cost to 40% compared to prevailing methodologies. The platform at Gulf of Khambhat and Gulf of Kutch in about 15m water depth was successfully installed.

3.12 Energy and Fresh Water

3.12.1 Wave powered navigational buoy

Indigenously developed wave powered navigational buoy was put to extensive open sea testing in Kamarajar port at Ennore near Chennai. The buoy has performed very well. A strategy is being worked out in consultation with various ports for the proliferation of this device as a navigational aid.

Fig 3.17: Wave powered navigational buoy indigenously developed by NIOT.

3.12.2 OTEC Desalination Test Facility at NIOT

An OTEC desalination test facility was inaugurated at NIOT campus on 13th November 2017. The equipments such as turbine, heat exchangers, flash chamber for both open and

closed cycles have been integrated and the studies commenced. An ultra-low pressure steam turbine developed indigenously will also be tested in this laboratory.

3.12.3 OTEC Powered Desalination Plant at Kavaratti

NIOT is set to install a new self-powered thermal desalination plant of 100m3/day capacity at Kavaratti Island, U.T Lakshadweep as a step towards meeting growing drinking water demand using ocean renewable energy. Oceanographic surveys off Kavaratti Island were conducted using ORV SagarNidhi and SagarManjusha followed by geotechnical investigations. Considering this as an island based plant, where safety and impact on environment is of utmost importance, the open cycle OTEC process was finalized wherein no refrigerant will be used to run the power cycle. Land acquisition for setting up the plant is in progress.

3.13 Ocean Science and Technology for Islands

3.13.1 Marine Algal Biotechnology

A novel process has been developed for the production of pharmaceutically vital lutein and a nutritionally rich, pharmacoactive growth promoter from Chlorella vulgaris and it is filed for patenting. Algal oil rich in polyunsaturated fatty acids and carotenoids, namely, algal PUFA-1 and algal PUFA-2 exhibited promising anti-tuberculosis activity against Multidrug Resistant Strain of Mycobacterium tuberculosis. High value carotenoid and fucoxanthin were extracted from the marine diatom Amphiprorapaludosa and also optimized mass culturing process to develop this species as a commercial fertilizer.

3.13.2 Microbial biotechnology

NIOT has successfully developed High Pressure retainable water Sampler (HPS) with the help of The Royal Netherland Institute for Sea Research (NIOZ). The HPS system was tested on board ORV SagarNidhi and water samples were collected from 3000 m depth. Narrow spectrum antifungal secondary metabolites producing PurpureocilliumlilacinumOC-II2a was isolated from sediment samples collected at a depth of 1495 m in the Arabian Sea was found to inhibit pathogenic fungus Cryptococcus albidus (MTCC 2661) at a minimum inhibitory concentration of 2 µg/mL.

3.13.3 Open sea cage culture

Open sea cage culture of cobia (Rachycentron canadum) was demonstrated at Thupilipalem in collaboration with Andhra Pradesh State Fisheries Department. Fishes were grown to an average weight of 2.37 kg with an average daily

Fig. 3.13: Fish harvest handed over to fishers by Hon'ble Minister of State Shri Y.S.Chowdary.

growth rate of 7.26 g/day. A total of 3,061 kg of cobia were harvested and sold at a farm gate price of Rs. 325/kg, which fetched an amount of Rs.9,95,000/. The cages successfully withstood the fury of cyclone 'Vardha' which made the landfall near the culture site with a wind velocity of 100-120 km/hr. One day training on open sea cage culture was organized for 100 traditional fishers of the Pamanji region. To overcome the shortage for marine finfish seeds a multi species marine finfish hatchery was planned at Pamanji, and the Hon'ble Minister of State (MoES) Shri Y. S. Chowdary laid the foundation stone for the facility on 8th April 2017.

3.13.4 Ballast Water Treatment Technologies - Test Facility

Towards assessment of inlet water quality for establishment of ballast water treatment technologies test facility, baseline studies for 42 months have been completed along Pamanji (Nellore, A.P.) coast. The salinity, total suspended solids, phytoplankton, zooplankton and bacterial load are in accordance with the IMO's G-8 guidelines. A laboratory – scale low cost high voltage pulse system for ballast water treatment was successfully developed and tested in the laboratory.

3.14 Marine Sensors, Electronics and Ocean Acoustics

3.14.1 The indigenously developed Buried Object Scanning Sonar system is configurable and operable through a user friendly GUI in deck. Sonar operational parameters like number of pings/s, transmitting frequency, pulse width, data acquisition duration (depth of operation), gain of programmable gain amplifiers, etc. are configurable in the GUI. Sea trials of the system were conducted during June- July 2017 at shallow waters off Chennai.

3.14.2 Deep Sea Autonomous Underwater Profiling Drifter (D-AUPD)

AUPD technology has been transferred to Indian industry and produced systems were deployed in BoB. End users like INCOIS shall procure systems for operational requirements. Development of spherical shape profiling system suitable for deep ocean measurements up to 4000m is taken up. Buoyancy engine capable of functioning up to 4000m water depth is built and interfaced with spherical profiling system (D-AUPD). The proto type system is tested at Idukki Lake and the performance of the system is observed for few cycles at 110m water depth. D-AUPD will be interfaced with INSAT communication for data telemetry.

3.14.3 Ambient noise measurements in the Arctic region-Kongsfjorden

The Ambient Noise Measurement System (ANMS) deployed in the Arctic along with "IndArc" mooring during July 2016 has been retrieved on 19th July 2017, with 8 months of noise time series measurements. The system has been redeployed on July 21, 2017, which consists of 2 hydrophones acquiring 3 minute data hourly with a sampling frequency of 25 kHz. The Arctic ambient measurements retrieved on 28th July 2016, with 280 days of data, have been analysed and the soundscape in the fjord region has been studied. Predominant noise sources are due to ice melting/bubbling/calving, wind effects and biological origin. Acoustic signatures of ice dependent marine pinniped species such as Walrus and bearded seals have been identified and analysed.

3.15 Seafront Facility Development

Establishment of a Seafront Facility in Nellore has been taken up. Coastal Regulation Zone clearance

has been accorded by Ministry of Environment, Forest and Climate Change, New Delhi for establishing the Sea front Facility. Construction of Compound wall, Security block & Project site office at Chittedu site are in progress. Construction of Race way ponds for Algal culture and fencing is being carried out at Pamanji site.

3.16 Ocean Survey & Mineral Resources

3.16.1 Geoscientific Studies of the Exclusive Economic Zone (EEZ)

NCAOR is entrusted to carry out high-resolution bathymetric mapping of deep-water blocks (more than 500 m water depth) of the EEZ and has so far surveyed 14,12,645 SqKms of area during 50 oceanic cruises, thus covering a total of 75.32% of the deep-water blocks and acquired underway geophysical datasets for 2,86,699 Line kms.

A total of four cruises onboard chartered vessel RV-MGS Sagar were undertaken, thus covering a total area of 97,846Sq Kms and underway geophysical data acquisition of 23,372 Line km. Sediment samples were collected at 14 locations during these cruises.

3.16.2 Delineation of India's Continental Shelf

NCAOR, nodal agency for the Extended Continental Shelf Program of India, has submitted its second partial submission as per the Statement of Understanding (contained in Annex II to the Final Act of the Third United Nations Conference on the Law of the Sea, 1982) to the Ministry of Earth Sciences in March 2017. This succeeds India's first partial submission made in 2009 pursuant to Article 76, UNCLOS, 1982. A high level Mauritian delegation visited NCAOR on 5-7th June 2017 to discuss and explore possible collaboration to their extended continental shelf claim.

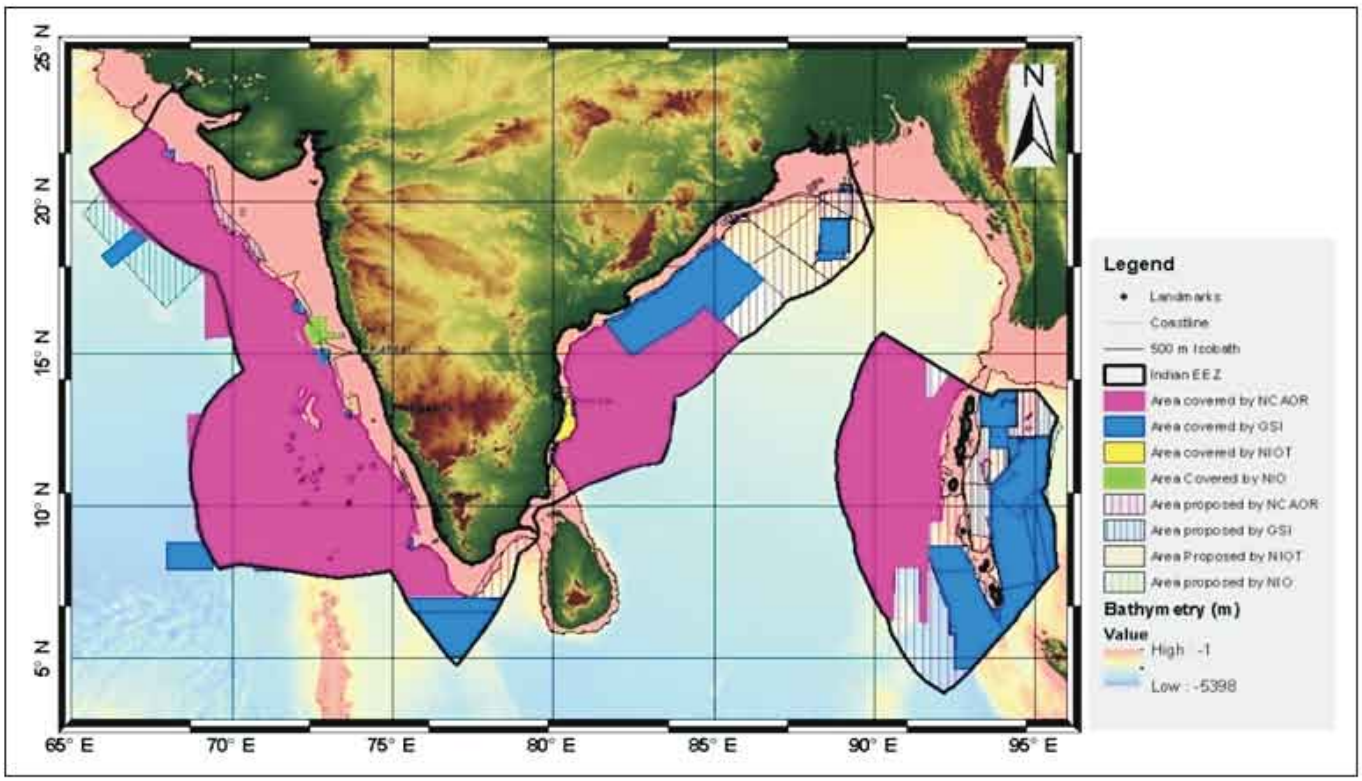

Fig. 3.19: Map showing status of area surveyed so far and priority areas.

3.16.3 Indian Endeavours towards the International Ocean Discovery Program (IODP)

The 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 2017, Indian scientists took part in following IODP expeditions: (1) South China Sea Rifted Margin A [IODP- 367, 8th Feb, 2017 - 9th April, 2017], and (2) South China Sea Rifted Margin B [IODP- 368, 9th April, 2017 - 11th June, 2017]. IODP-India has provided funding support in May 2017 for post cruise research proposal submitted by Indian IODP participants for two years. IODP-India in association with ANZIC and other national IODP offices convened an international workshop on prospective scientific drilling proposals in Indian, Southern oceans and Antarctic Shelf region at Sydney, during June 13-16, 2017. Two Indian scientists from NIO, Goa participated in the meeting.

3.16.4. Studies on Hydrothermal Sulphides

Ministry of Earth Sciences has initiated a mission-mode multi-disciplinary program on exploration and study of hydrothermal sulphide mineralization with emphasis on the South West and Central Indian Ridges. Seafloor Polymetallic hydrothermal sulphide deposits are most commonly formed along Mid-Oceanic ridges and volcanic provinces in water depths from <500 to 5000 m. Two months survey and exploration cruise onboard RV MGS Sagar undertaken from 12th January 2017 to 25th March 2017 in CIR and SWIR utilizing physical, chemical, biological and geological means. The survey included: (i) Physical and Chemical oceanographic studies of water column to identify plume signatures as well as to develop baseline environmental data, (ii) Biological studies in sea water column and sediments samples for baseline environmental studies and (iii) Morphological and structural features identification on high-resolution bathymetric data to identify probable zones of hydrothermal activity.

3.17 MoES Efforts on Sustainable Development Goal-14 (SDG-14)

The Sustainable Development Goal No. 14 aims to conserve sustainable use of oceans, seas and marine resources for sustainable development. Some of the activities during the last one year are as follows:

- A set of 17 voluntary commitments were announced by India during the Ocean Conference, held during 5-9 June 2017 at New York.
- The Ministry through its constituent unit ICMAM coordinated the Coastal Cleanup day, on 16th September 2017 with a view to promote the protection of beaches and the coastal regions.
- For addressing the issue of conservation of Marine Mammals, a multispecies cetacean systematic survey and training was conducted on board Fishery Research Oceanographic Vessel, *FORV SagarSampada*, from December 15 to 18th, 2017, off Kochi, India. The results of this pilot survey are extremely promising and suggest that longer and systematic cetacean surveys in combination with fisheries, oceanographic, and acoustics research could provide us with a comprehensive assessment of the marine ecosystem and advance India's capabilities to protect its unique and rich marine biodiversity that is unparalleled in the world.

4.1 Scientific Studies in Antarctica

4.1.1 Cryosphere& Climate

Mass balance, dynamics, and climate of the central Dronning Maud Land (DML) coast, East Antarctica (MADICE)

The collaborative Indo-Norwegian project MADICE investigates the ice dynamics, current mass balance, and millennial-long evolution in the coastal Antarctica as well as the past changes in atmospheric and sea ice dynamics in this region, using remote sensing data, geophysical field measurements, and ice core based climate reconstruction. The first joint Indo-Norwegian field campaign was undertaken during the 36th Indian Scientific expedition to Antarctica (2016-17). As part of this, the MADICE team conducted various geophysical, glaciological studies and retrieved ice cores from Djupranen (D) and Leningrad (L) ice rises of Nivlisen ice shelf from the central DML region (Fig. 4.1). The major achievements during field campaign were: (i) The geophysical work included extensive static and kinematic GPS surveys (1700 line km), deep and shallow-sounding radars (800 line km) over the two ice rises. Along this survey line, 90 markers were also installed; (ii) Two winter-over APReS to measure basal melting and an automatic weather station were installed in Leningradkollen ice rise; (iii)The team conducted two ice core drillings at the summits of Djupranen (122 m) and Leningradkollen (51 m) ice rises.

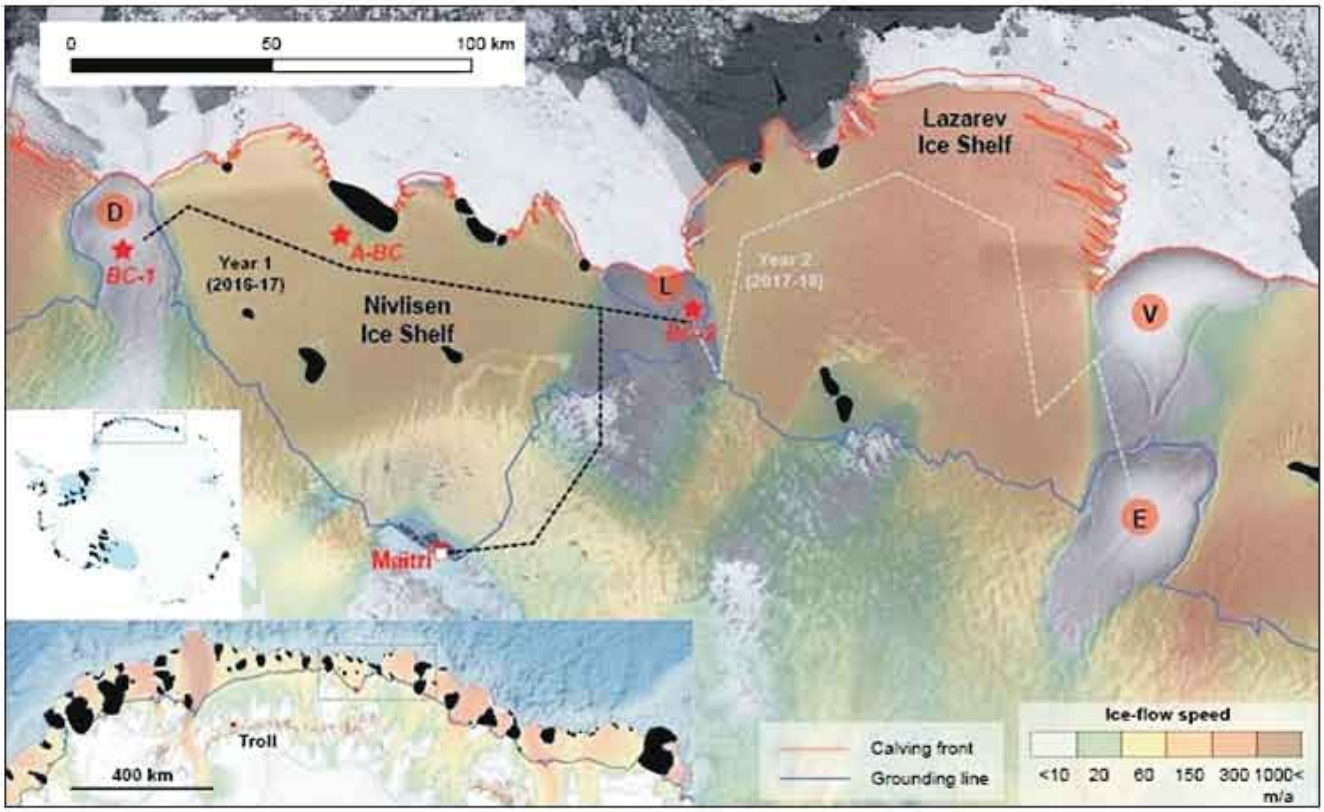

Fig. 4.1: MADICE study area in central DML, including the Nivlisen and Lazarev Ice Shelves, and ice rises Djupranen (D), Leningrad (L), Verblyud (V), and unnamed Eastern (E) ice rises. The background is a composite of the MODIS and LIMA satellite mosaics and the color shows ice flow speeds.

Spatial variability and possible sources of acetate and formate in the surface snow of East Antarctica

Carboxylic acids contribute to total acidity of precipitation and can potentially play an important role in the cloud condensation nuclei activity and influence the radiation budget of the earth's atmosphere. Therefore, understanding the sources and fluxes of these organic acids is important in Antarctic environment. To understand the sources and spatial variability (with respect to distance from the sea and elevation) of monocarboxylic acids, surface snow samples along a coastal-inland transect (180 km) in the ice cap region at Princess Elizabeth Land and a coastal transect in the Amery Ice Shelf (130 km), East Antarctica were analyzed for monocarboxylic acids. Variations in both acetate (Ac−) and formate (Fo−) seem to be unrelated to the acidity of snow. Ionic balance determined for the snow samples indicate the availability of HNO3 that could undergo photolysis to produce hydroxyl radical, one of the major reactants involved in oxidation reactions with organic matter. Interaction of Ac− and Fo− with alkaline minerals could lead to their stability in the snowpack and minimize their loss from the snow surface (Fig. 4.2). Resident microbial communities could also influence the budget of the carboxylic acids in snow.

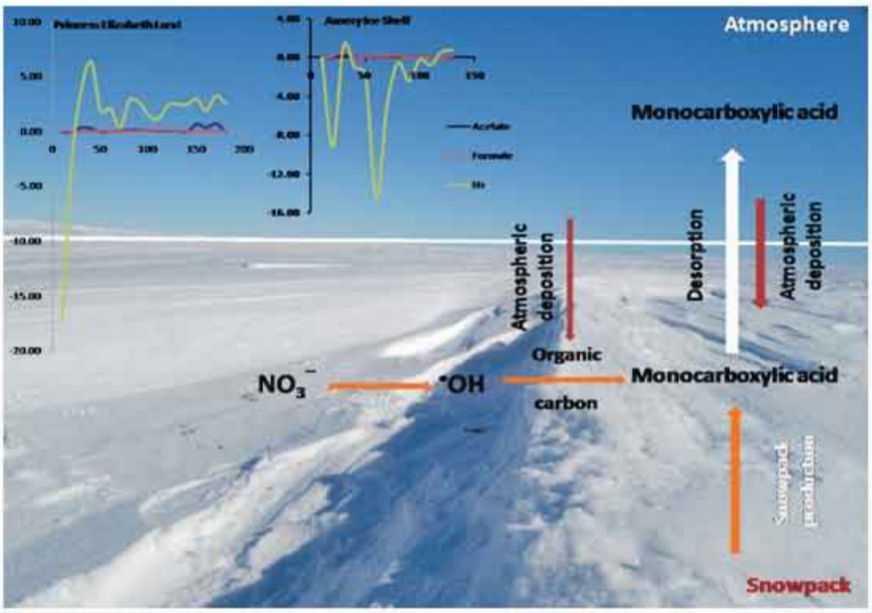

Fig. 4.2: Schematic diagram depicting the chemical process involved in the production of carboxylate in Antarctic snow.

Response of Sandy Lake in Schirmacher Oasis, East Antarctica to the glacial-interglacial climate shift

Freshwater lakes in Antarctica fluctuate from ice-free state (during austral summer) to ice-cover state (during austral winter). The Antarctic seasons respond sharply to the glacial and interglacial climates and these signatures are archived in the lake sediments. A sediment core from Sandy Lake, a periglacial lake located in Schirmacher Oasis of East Antarctica records distinct changes in grain-size, C, N, C/N ratios (atomic), $\delta^{13}C_{OM}$ and $\delta^{15}N_{OM}$ contents during the last 36 ky. The contents of the sedimentary organic matter (OM) proxies (C_{org}~0.3 ± 0.2%, C/N ratios ~9 ± 5 and $\delta^{13}C_{OM}$ ~ 18 ± 6‰) indicate that the OM in this lake sediment is a product of mixing of terrestrial and lacustrine biomass. Such intense winters might have resulted in the lake surface to be ice-covered for most part of the year when the temperatures remained consistently colder than the Holocene temperatures. The denitrification within the lake evident by enriched δ15NOM (>10‰) during Antarctic LGM might have resulted from oxygen-limitation within the lake

environment caused by insulated lake surface (Fig. 4.3). The seasonal opening-up of the Sandy Lake similar to the modern pattern started with the establishment of the optimum temperature conditions (i.e., 0oC anomaly) in the Antarctic, prior to which the lake environment might have remained mostly insulated or closed.

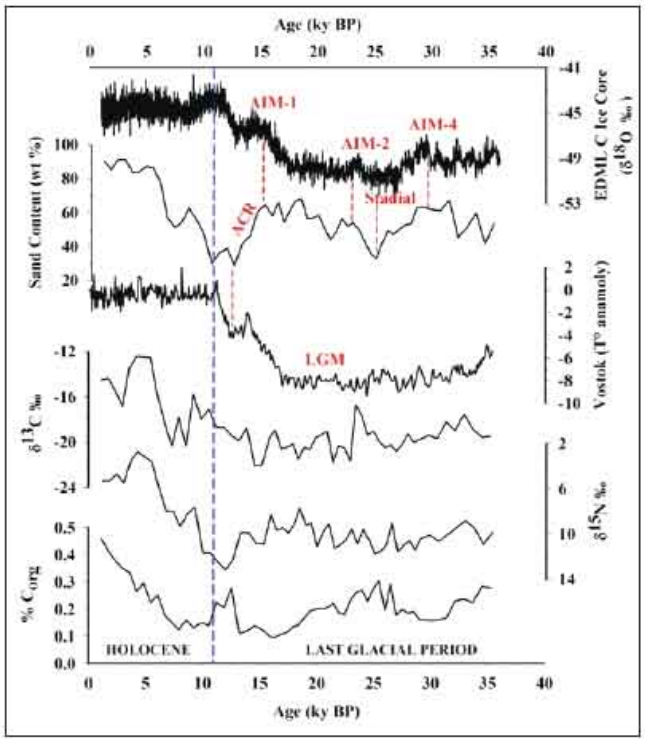

Fig. 4.3: Glacial-interglacial changes in organic carbon, $\delta^{13}C$, $\delta^{15}N$, sand content from Sandy Lake in Schirmacher Oasis, East Antarctica and ice core records.

Moveable Atmospheric Radar for Antarctica (MARA): Turbulence in association with tropopause folds at 68°N, 73°S and 69°S

Observations by VHF radars at Maitri, Antarctica (69°S), Troll, Antarctica (73°S) and Esrange, Sweden (68°N) are used to show the relationship between atmospheric turbulence, winds and static stability in association with tropopause folds passing the respective locations. For individual events, and for averages over 23 - 30 events at each site, the shortest turbulent mixing times are found in the jet stream in the upper troposphere on the equatorward side of the folds. Additional turbulent mixing occurs, some on the poleward side of the fold, in connection with mountain waves but, on average, this is less important that mixing in the jet stream. When strong mountain waves are present, turbulence outside the jet can make a significant contribution and turbulence levels within the jet are increased. An empirical relation between vertical turbulence mixing time, horizontal wind speed and buoyancy frequency is demonstrated.

4.1.2 Polar Remote Sensing Studies

Antarctic iceberg calving events captured via Indian space-borne missions

Antarctic icebergs are tracked using multispectral images from Linear Imaging Self Scanning Sensor (LISS-IV) aboard IRS-P6 satellite in the vicinity of Larsemann hills and environ, Ingrid Christensen coast, Princess Elizabeth land, east Antarctica. The two images captured specifically 384 days apart from LISS-IV, enabled a thorough understanding of the significant changes that have occurred in the study area during this short epoch. The 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 been decreased by 12.51%, suggesting the melting of icebergs in the given time period. This study eventually demonstrates the quantitative analysis of iceberg calving, changes in iceberg numbers, rate of iceberg disintegration, and rate of iceberg drift in the Prydz Bay of the Larsemann hills area.

Antarctic sea ice variability and dynamics

Using satellite-based passive microwave sea ice concentrations for 1979-2015, seasonal trends pre- and post-2000 were studied. The results indicate that post-2000 there is an increasing sea ice trend of 11% for Indian Ocean (IO) and 32% for Pacific Ocean sectors, whereas Ross sea sector experiences a 32% decline. Sea ice extent in Bellingshausen-Amundsen sector has been decreasing since 1979 by -3300 sq. km/year, however post-2000 an increasing trend of 11700 sq. km/year is seen which contributes to an overall Antarctic sea ice increase. The Weddell Sea showed an overall increase in sea ice by 19750 sq. km/year, as compared to a negative trend of -2450 sq. km/year pre-2000 scenario. Post-2000 Antarctica sea ice experiences twice the rate of increase compared to pre-2000 era mainly due to the influence of positive SAM index. The overall increase is 22000 sq. km/year for 1979-2016 period. Further, remote forcing by Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM) also influences the sea-ice seasonal changes on spatial scale.

4.1.3 Operations, Management and Research Support for the Antarctica Expeditions

A total of 116 persons including 54 scientists and 62 logistic support staff from 28 different national organizations were deployed in Antarctica during 36th Antarctic Expedition. In addition, 04 Norwegian scientists were also deployed at Maitri under MADICE project. The chartered expedition vessel MV Ivan Papanin returned to Cape Town along with two helicopters (KAMOV 32C and AS 350B3) and 37 passengers on 02 April 2017 leaving behind a 24 member team at Maitri and 23 member team at Bharati for the over winter period.

Debriefing Function: Over 150 expedition members of the total 207 who participated in the Indian Scientific Expedition to Antarctica from the 34th winter team, 35th winter & summer team and the 36th summer team were felicitated during the debriefing function held at NCAOR on May-15, 2017.

The XXXVII Indian Scientific Expedition to Antarctica: The 37th Indian Scientific Expedition to Antarctica (37-ISEA) was launched in November 2017. The National Workshop on Evaluation of Research Projects for Planning the 37th ISEAwas organized at NCAOR during 18th-19th May, 2017 and 40 projects were shortlisted. Total 41 projects were recommended for the 37-ISEA.

4.2 Scientific Studies in Arctic

A total of 45 Indian scientists participated in Indian Arctic Expedition-2016-17.IndARC-2 was successful retrieved and IndARC-3 was deployed in July, 2016.To concretize the scientific and logistics aspects of the Indian scientific endeavors in the Arctic during the year 2017-18 (Fig.4.4), NCAOR had solicited proposals for initiating scientific research at the Ny-Ålesund research base in Svalbard, Norway for the following aspect:

- Atmospheric Science with special reference to study of aerosols, trace gases and precipitation over the Arctic
- Marine Science: Dynamics and functioning of Arctic fjords (Kongsfjorden)
- Environmental Chemistry: Natural contaminants in food webs and long range pollutants
- Cryospheric studies: Snow and ice chemistry, glaciology.

Fig 4.4: In-situ data collection from Arctic.

4.2.1 Long term monitoring of Kongsfjorden and Krossfjorden

The Arctic fjords, are vital systems in the Arctic hydrographical network and serve as pulse points to measure the cause and effect of environmental change, may it be fuelled by local disturbances or global processes. As a part of Long term monitoring program, several field campaigns pertaining to hydrology, biology, chemistry and environmental studies, were conducted in 2016-17.

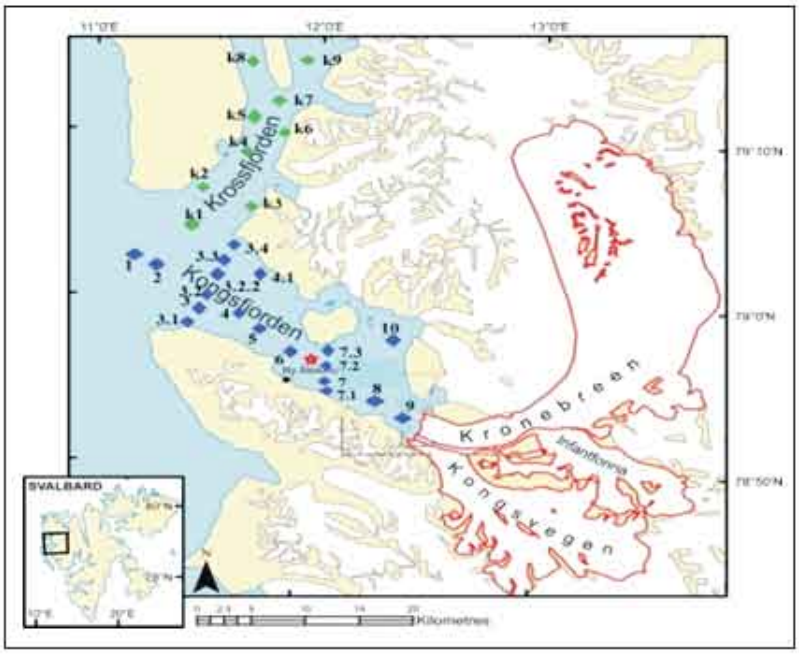

Fig 4.5: Locations of routine CTD stations at Kongsfjorden(blue squares), Krossfjorden (green squares) and IndARC mooring (red star).

Hydrogrphy of Kongsfjorden and Krossfjorden

The studies on interannual variability in hydrography were continued with the CTD and mooring measurements during 2016 in Kongsfjorden and Krossfjorden (Fig. 4.5). CTD data indicates hydrographical similarities between Krossfjorden and Kongsfjorden. However, fluorescence values in Krossfjorden were higher than that of Kongfjorden.

The data obtained from IndARC mooring showed homogenous water column with respect to temperature and salinity, which was observed during February and May 2016. In addition, Atlantic water was

delineated from 88m to deeper layers from its characteristics temperature >3°C and salinity of 34.6 psu (Fig. 4.6).

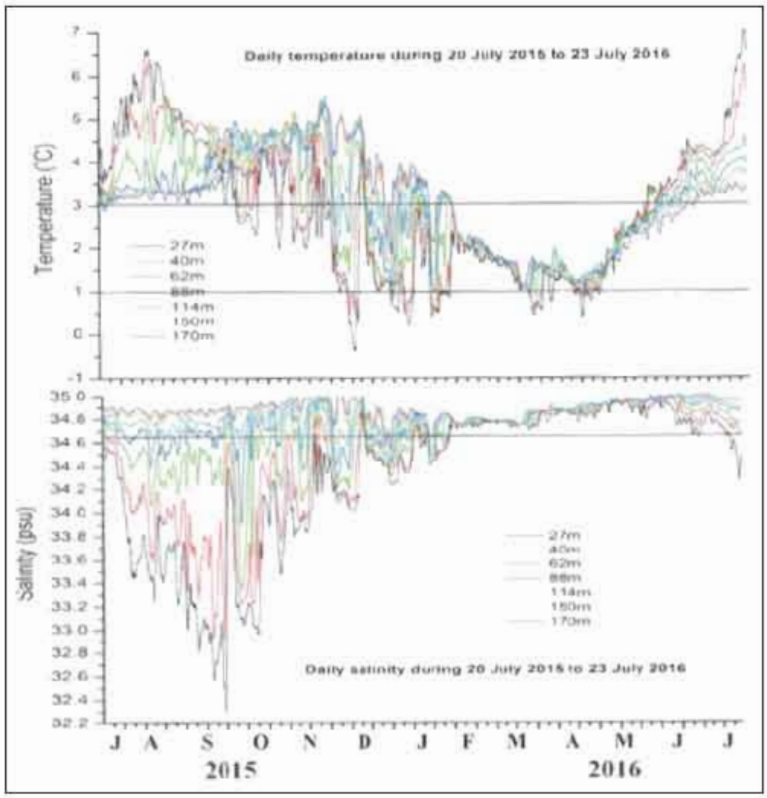

Fig. 4.6: Daily time series of temperature (°C) (upper panel) and salinity (PSU) (lower panel) from July 2015 to July 2016 obtained from IndARC mooring.

4.2.2 Mass balance and dynamics of selected Arctic Glaciers

During March-April 2016, spatial distribution of snow thickness over VestreBroggerbreen and Feiringbreen glaciers was measured using snow pits, cores and snow probe. Further, ground and aerial radar survey to measure snow and ice thickness was also done. The average snow depth was significantly less than previous year and range of snow depth was observed from 15cm in lower ablation to 290 cm in upper accumulation in VesstreBroggerbreen however it is 17-260 (few points more than 300cm) cm in Feiringbreen glacier. The observed mean density of accumulation zone snow pack for Feiringbreen (4.6 gm/cm3) are little higher than VestreBroggerbreen (4.1 gm/cm3). The collected data revealed that density of snow pack in glacier increases along the depth and the mean density of a 2m column was 350 kg/m3. The temperature profile in snow pack deep down up to 2m has a decreasing trend however it is also strongly controlled by temporal variation. The data reflected that the snow water equivalent was highly depends on the snow depth distribution over Feiringbreen glacier in 2016 and has significantly influenced mass budget of the glacier. The winter balance of VestreBroggerbren is 0.4±0.1m we for year 2015-16 which is significantly lower than previous year winter balance (0.76±0.1 m we), it is close to 50% reduction in accumulation during winter.

4.2.3 Atmospheric studies

Possible influence of tropical Ocean on intense precipitation events in Arctic

During the last week of December, an intense rain event was noticed at Ny-Ålesund, Arctic. This was found to be generated by the combined influence of a high pressure anomaly over northern Europe and its interaction with a cyclone near Iceland. The Madden Julian Oscillation (MJO) was intense and likely to influence the storm tracks in north Atlantic. During 2015 December MJO was in phase 5 and 6. During the last week of December Rossby wave trains emanated from central tropical Pacific and seems to have influenced cyclogenesis near Iceland. The high pressure over the northern Europe could be a result of sea-ice changes or

could be due to Atlantic multi-decadal oscillation. Thus intense warm and wet events in Arctic could be an interaction of tropical and high latitude variability.

4.3 Himalayan Studies

The objective of Himalayan Glaciological Programme is "to understand the response of Himalayan Cryosphere to the changing climate and its hydrological impacts by integrated studies (mass balance and dynamics of benchmark glaciers, energy and water budget, isotope hydrology etc). Various glaciological studies were carried out in selected benchmark glaciers of western Himalaya to understand glacier impact on hydrology, ecology and climate of Himalaya region.

4.3.1 Integrated study of benchmark glaciers in Chandra basin, Western Himalayas

To understand the complex behaviour that controls the observed and future changes, systematic long-term scientific investigations of Himalayan glaciers following activities were carried out:

- Extension of observatories (Automatic Weather Station and Water Level Recorder) network in Chandra basin by installing two additional AWS in Gepang glacier and Bara Shigri glacier.
- Regular monitoring of stakes network for annual, spring and summer mass balance have been carried out for all six glaciers (Sutri Dhaka, Batal, SamudraTapu, Bara Shigri , Gepang Gath and Kunzam).
- Ground based Radar survey was carried out over SamudraTapu and Sutri Dhaka glaciers to measure the ice thickness of glaciers. Based on four cross sections and center flow line survey, mean depth of ice in ablation zone of SamudraTapu and Sutri Dhaka glaciers were measured.
- Observed maximum and minimum temperatures at station "Himansh" (4080m msl) are 20.7°C and -32.9°C on 10th July 2017 and 10th Feb 2017, respectively with mean temperature of -1.4°C (Fig.4.7).
- To calculate the volume of Lake, bathymetry survey was carried out over Gepang Gath Lake. The lake is currently covers 0.91km ^{2}area and having average depth of 28.8±2.2m (with range of 0-49m).Based on in-situ measurements the estimated volume of lake is 27.04±2.1*10^6 m^3.

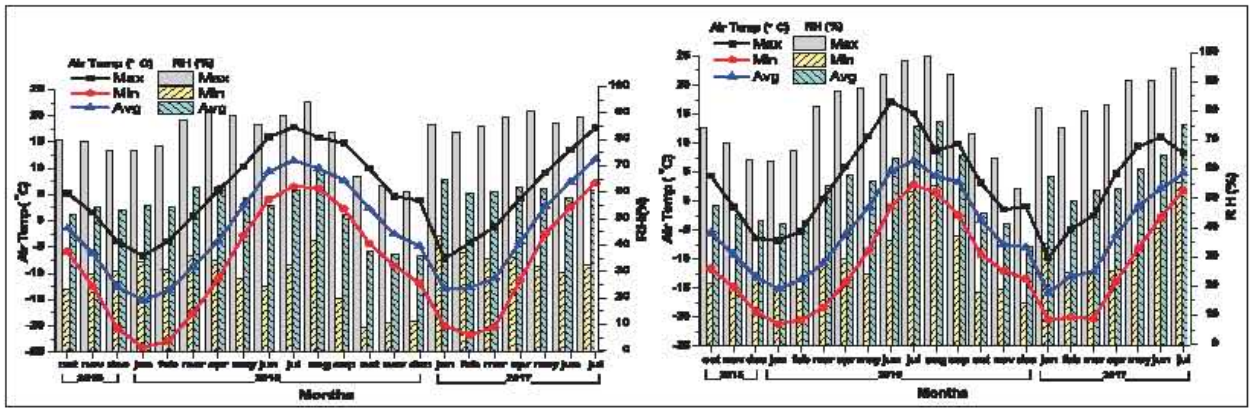

Fig. 4.7: Temperature and humidity conditions during 2015-17 at: (a) base station, (b) over Sutri Dhaka glacier.

4.3.2 Mass balance estimation using geodetic method for glaciers in Baspa basin, Western Himalaya

Remote sensing based geodetic method has applied to estimate mass balance of glaciers in Baspa basin, Western Himalaya for 11 years period (2000-2011). Out of 89 glaciers in the basin, 42 glaciers (area > 1km^2) covering 215km^2 (72%) of total glaciated area were selected for the study. A mean thinning of 50±11 m and mean accumulation of 35±11m was observed during the study period, with the cumulative mass balance varying between -36.9±1.98 and 6.47±1.98 mwe. A mean annual mass loss of -1.09± 0.32 mwe a^{-1} was observed for the entire basin, reflecting higher rate of glacial mass loss in Baspa basin than glaciers in Central and Eastern Himalayas.

4.3.3 Estimation of Mass balance for last decade (2007-2016) using Accumulation Area Ratio for Chandra basin glaciers

A loss of 0.44 ± 0.05 Gig tons of glacial mass is observed at basin scale in Chandra basin using Accumulation Area Ratio (AAR) method for a period of 10 years between 2007 and 2016. The observations revealed that the glaciers have experienced both positive and negative mass balance during this period however basin scale mass loss varies from -0.48 ± 0.76 mwe a^{-1} to -1.09 ± 0.29 m we a^{-1}.

4.3.4 Export fluxes of geochemical solutes in the Sutri Dhaka glacier meltwater

The hydrochemistry of meltwater draining from the Sutri Dhaka Glacier, Western Himalaya has been studied to understand the influence of the factors controlling the weathering processes of the glaciers during the peak ablation period. The meltwater is Ca^{2+}-HCO_3- enriched (Ca^{2+} -78.5%) and HCO3- -74.5%) as the dominant species and slightly alkaline (mean pH 8.2) in nature. The major anions are HCO3- followed by SO_4^{2-}, NO_3- and Cl^- and the major cations are Ca2+ followed by Mg^{2+}, K^+, N^{a+},and NH4+, respectively. The high C-ratio (0.75) indicates dominancy of the carbonate weathering.

4.3.5 Denudation rates and the degree of chemical weathering in the Himalayan river basins basin from ratios of meteoric cosmogenic ^{10}Be to stable ^{9}Be

The ratio of the meteoric cosmogenic nuclide ^{10}Be, precipitated from the atmosphere, to the stable nuclide ^{9}Be, released by silicate weathering, was measured in suspended sediment of the Himalayan River basin to determine denudation rates, degrees of weathering, and sediment storage in the floodplain. Denudation rates ranges from 0.5 mm yr^{-1} in the Himalayas to 0.17 mm yr^{-1} for the Ganga main stem in the lowlands. The spatial scale of the entire basin, the atmospheric delivery flux of ^{10}Be equals its sedimentary export flux of ^{10}Be equals its sedimentary export flux. Hence, fluxes can be considered to be at steady state and radioactive decay of ^{10}Be during sediment storage is not discernible. The lack of resolvable increase in ^{10}Be concentration during sediment transfer along the floodplain stretch suggests that sediment transfer time is indeed short (few kilo years). When multiplied with the basin area the 10Be/9Be-derived D of 0.14 mm yr-1 corresponds to a sediment flux of 350 Mt yr-1.

4.4 Southern Ocean Studies

4.4.1 Indian Scientific Expedition to Southern Ocean/Antarctic Waters (2016-17)

Indian Expedition to Southern Ocean/Antarctic Waters in 2016-17 was launched from Port Louis,

Mauritius on 6th January 2017 onboard chartered Ice Class Research Vessel SA Agulhas with 24 scientists on-board. Continuous observations for various atmospheric and oceanic parameters were carried out in the entire cruise track. Mooring equipments at various depths were deployed for a period of one year in the Subtropical Frontal region [40.11°S 58.5°E] (Fig.4.11). The following observations/activities were carried out (i) Retrieval and redeployment of mooring equipment; (ii) Deployment of under-ice mooring at Prydz Bay; Quantification of internal wave-driven mixing by thermistor chain mooring; (iii) Air-sea interaction, aerosol studies, oceanic volatiles; (iv) Current structure and volume transport, water masses characteristics - (AABW freshening); (v) Deployment of ARGO, SOCCOM Floats; (vi) Coring operations - Palaeoclimatic studies.

Biogeographic distribution of extant Coccolithophores in the Indian Sector of the Southern Ocean

Water samples from 9 vertical profiles down to 110 m water depth and 19 samples from the sea-surface were studied for coccolithophore abundance and distribution across oceanic frontal regions of the Indian sector of the Southern Ocean. A total of 39 taxa (including morphotypes, types and subspecies) were recorded as intact coccospheres with abundances reaching up to $750x10^3$coccospheres/l. The assemblage of the Agulhas Retroflection frontal zone and Subtropical zone is highly diverse (39 taxa) and can be linked to relatively warm, high saline and oligotrophic waters. The Sub-antarctic zone assemblage is characterized by a reduced number (13) of coccolithophore taxa, whereas the Polar Frontal zone comprises a monospecificE. huxleyi assemblage (preferentially morphotypes C and B/C). Multivariate statistics indicated that regions with elevated temperature and low nutrient concentration show high coccolithophore diversity whereas regions with high nutrient concentrations and low temperature show strongly reduced coccolithophore diversity with abundant monospecificE. huxleyi (morphotypes B/C and C) assemblages.

4.5 Past Climate and Oceanic variability

4.5.1 First evidence of denitrification vis-à-vis monsoon in the Arabian Sea since Late Miocene –Results from the IODP Expedition 355

Under the aegis of the IODP Expedition-355: Arabian Sea Monsoon, published the first record of denitrification in the Arabian Sea Oxygen Minima Zone (OMZ) since Late Miocene (the last 10 million years, Myr). The data is generated on squeeze cake samples collected from Site U1456 (16°37.28'N, 68°50.33'E; ~3640 m water depth; total depth of penetration ~1109 m). The location of Site U1456 is approximately 475 km from the western coast of India and ~820 km south of the mouth of the Indus River. The study revealed that during the last 10 Myrs, there were two periods (~3.2–2.8 Myrs ago and the past ~1 Myrs) when the oxygen levels were so low that denitrification became possible. These periods of intense OMZ/denitrification coincide with periods of enhanced productivity suggesting monsoon-induced productivity as the major factor governing the OMZ intensity at these timescales (Fig.4.8). It also implies that the monsoon attained the present strength capable of supporting the productivity required for maintaining conditions for denitrification around 1 million years back and for a period between ~3.2–2.8 Ma. It coincided with the Mid-Pliocene Warm Period

(MPWP), which was a period of global warmth with CO_2 levels (400 ppmv) similar to the present. The increase in monsoon during the MPWP could have resulted in the increased weathering and organic carbon burial, as evident by higher TOC, leading to atmospheric CO_2 drawdown that would have possibly contributed to the intensification of the Northern Hemisphere Glaciation (NHG) at 2.7 Ma.

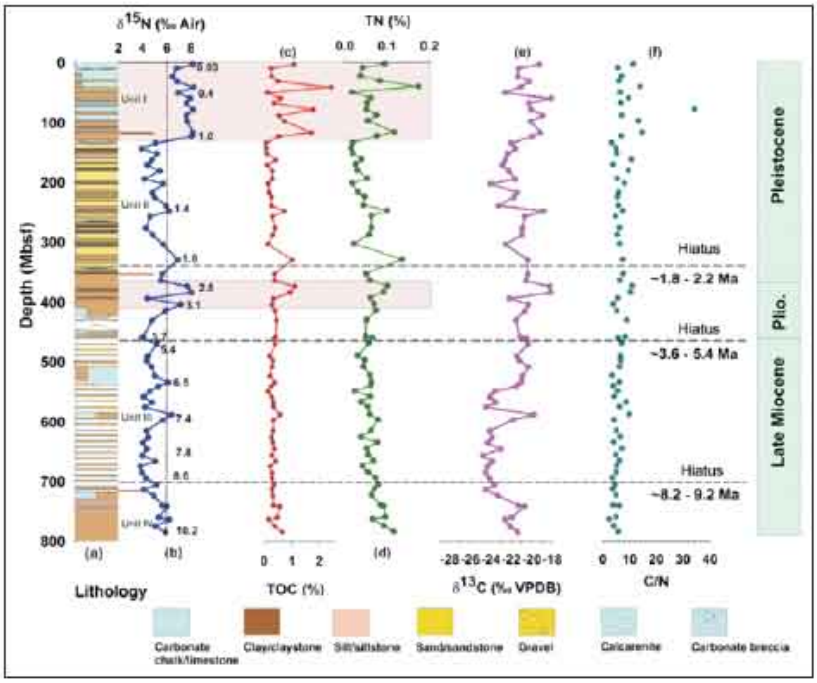

Fig.4.8: Results from the IODP Expedition 355.

4.5.2 Total Organic Carbon of marine sediments in the Southeastern Arabian Sea: Implications to monsoon variability since mid-Holocene

Past productivity variability related to the South Asian Summer Monsoon (SASM) strength is reconstructed through a suite of biogenic and inorganic proxy indicators in a well-dated core (SN-6) from the South-eastern Arabian Sea since mid-Holocene (the past 5000 years). The increasing total organic carbon (TOC) concentration of marine sediments in the Southeastern Arabian Sea (SEAS) has been interpreted to imply strengthening SASM since mid-Holocene by a few earlier studies. However, TOC concentration is also influenced by redox conditions, sedimentation rate, and an influx of terrigenous matter depending on the regional settings. So, it needs to be ascertained whether the TOC concentration of the sediments in the SEAS is a signal of productivity related to the SASM strength or preservation. The present study shows that the observed TOC increase is not a result of enhanced productivity but is because of better preservation due to the increased sedimentation rate along with increasingly reducing conditions since mid-Holocene.

4.5.3 Pliocene Arctic Climate Teleconnection (PACT)

The project titled Pliocene Arctic Climate Teleconnection (PACT) is an Indo-Norwegian project. One of the key aspects in this research effort is to understand and predict the annual onset and variability of the monsoon and its teleconnection driving Arctic climate at a still uncertain course. The mid-Pliocene Warm period (mPWP) is the most recent and best analogue to understand the impact of future global warming. Though climate models are in good agreement with empirical estimates of sea surface temperatures in most regions of the world, yet the same models underestimate the warming observed in the high northern latitudes. 'PACT' aims to address the problem by generating climate records from the Arctic that will result in an improved understanding of

ocean, sea ice, and atmosphere interactions in the Arctic during the middle Pliocene, and thus reduce uncertainties in climate models with a link to high latitudes.

4.6 Conference and Workshop

4.6.1 National Conference on Polar Sciences (NCPS-2017)

National Conference on Polar Sciences (NCPS-2017) was organised during May 16-17, 2017 at NCAOR, to bring eminent researchers, working in diverse fields from Antarctic, Arctic, and surrounding ocean realms as well as Himalayas, to identify and discuss the interdisciplinary approach to address the various scientific and operational issues (Fig.4.9).The conference was inaugurated with a plenary lecture by Dr. M. Rajeevan, Secretary, MoES on Arctic- Indian monsoon Teleconnections. Six keynote addresses by eminent scientists and 87 oral presentations in a number of parallel sessions were also made. Exclusive poster sessions with over 100 presentations have been put in place which has provided an opportunity to the young researchers in presenting their ideas.

Fig.4.9: Participants of NCPS-2017.

Chapter 5

Seismology and Geosciences Research (SAGE)

5.1 Seismology

5.1.1 Observational Seismology, Earthquake Monitoring and Services

During the period 01 January to 31 December, 2017 the National Seismological Network consisting of 84 observatories has been functioning smoothly and a total of 263 earthquake events occurred in and around India (Latitude 0-40° N, Longitude 60-100° E) were detected and auto-located (Fig 5.1). Of these, 214 earthquakes were of magnitude range 3.1 to 5.0, while 20 were of magnitude 5.1 and above.

Information pertaining to significant events was provided to all concerned state and central government agencies, dealing with relief and rescue operations in the region and also posted at website.

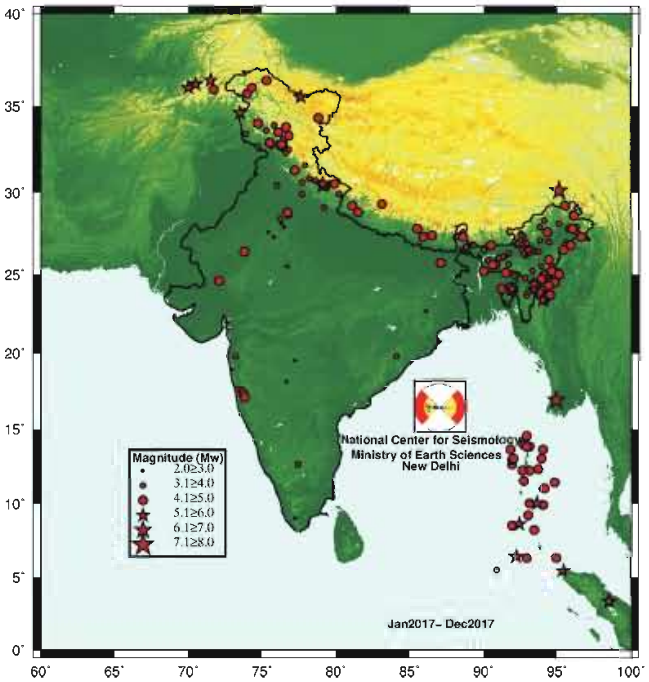

Fig. 5.1: Seismicity during January to December, 2017.

For automatic earthquake parameter dissemination, IndiaQuake, a mobile App was developed and launched. It is a faster way for communicating earthquake information with no restrictions on the number of recipients. There are two categories of events here, scrutinized and unscrutinized. Unscrutinized events are the earthquake whose parameters have been estimated automatically by the software using the incoming waveform data from remote stations. These solutions are scrutinized and confirmed by NCS, which form the category of scrutinized events.

5.1.1.1 Upgradation of Seismological Network

With a view to detect and 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 is going on, which envisages installation of 34 new stations and upgradation of 4 existing stations. With this initiative, 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 studies of 30 selected cities, falling in seismic zone V, IV, III and State Capitals has been initiated. In this direction base maps have been procured. For field work of geotechnical and geophysical investigation of these cities, RFP was prepared, approved and tenders were invited. The microzonation work is likely to be completed by FY 2021-22.

5.1.3 Scientific Deep Drilling in the Koyna Intra-plate Seismic Zone, Maharashtra

Borehole Geophysics Research Laboratory (BGRL), Karad has undertaken scientific deep

drilling and associated investigations in the Koyna seismic zone, Maharashtra. Scientific Deep Drilling in Koyna is aimed at setting up of borehole observatory (s) 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.

Drilling of Koyna pilot borehole

The highlight of the year was the successful drilling of the Koyna pilot borehole KFD1 to a depth of 3 km and the acquisition of downhole geophysical data. Passing through ~1.25 km - thick succession of Deccan basalt flows and ~1.75 km into the underlying granite-gneiss basement rocks, the borehole is the deepest drilled through crystalline rock formations in the country. A hybrid drilling technology comprising both air hammer and mud rotary techniques ensured that the drilling and associated measurements as well as well completion procedures were accomplished in 6 months time from spudding of the borehole (Fig 5.2). Cuttings were collected at 5 m intervals in basalt and 3 m intervals in basement rock. Additionally, limited cores were collected from discrete depths in the 1500-3000 m section.

To keep pace with the drilling, three field laboratories were functional on site: (i) geological lab., (ii) mud-logging lab., (iii) online gas and fluid sampling lab. A suite of geophysical logs were obtained in the 500-3000 m section. For the first time in the country, hydraulic fracturing tests were carried out at 9 test intervals in the crystalline basement section, yielding valuable information about the stress regime up to ~2.4 km depth in the Koyna seismogenic zone. KFD1 has been cased and cemented up to the bottom for future studies. Information on physical and mechanical properties obtained from in-situ and laboratory studies will be used designing the proposed deep borehole observatory at hypocentral depths in the Koyna region.

In addition, deep drilling through Deccan basalts into the continental bedrock provided unprecedented opportunity to examine the microbial life and the processes that they may catalyse deep underground. This interdisciplinary research aims to unravel subsurface microbial diversity and aids the global quest to know limits of life, mechanisms of microbial interaction with inorganic environment and their adaptation.

Fig. 5.2: A view of the drilling rig and associated equipments at the Koyna pilot borehole site.

A digital core library is under development at BGRL-MoES. Whole-round cores from the Koyna Scientific Drilling Project are optically scanned using a high resolution core scanning system to generate 360o (unwrapped) images, which are archived in digital form. First of its kind in the country, the digital core library will support scientific studies and facilitate theme-specific sampling for detailed investigations.

International Workshop

An International Workshop on "Scientific Deep Drilling in Koyna" was conducted successfully in association with ICDP during October 14-16, 2017 at Pune. The objectives of the Workshop were to (i) review pilot borehole operations and associated studies, (ii) identify key knowledge gaps and areas for future work, and (iii) design deep borehole observatory in consultation with national and international experts. There were 65 participants including 19 experts from abroad. The 3-day workshop included a field visit to BGRL-MoES Core Repository under development at Karad, where the borehole cores from pilot borehole and exploratory boreholes were displayed (Fig. 5.3).

5.2 Geological and Geophysical studies:

5.2.1 Indian Scientific Endeavors in the International Ocean Discovery Program (IODP)

The International Ocean Discovery Program (IODP) is an international marine research consortium of 23 nations for scientific drilling in the oceans to understand about earth dynamics and changing in earth climate to the rifting and drifting of the continents. India is an Associate Member of the IODP consortium. IODP-India at NCAOR acts as the Program Management Office (PMO) and coordinates all Indian scientific activities pertaining to this program. During this year, two Indian scientists participated in two IODP expeditions IODP 367 (South China Sea rifted margin A) and IODP 368 (South China Sea rifted margin B) and had unique hands-on experience in the scientific ocean drilling. Indian scientists have exclusive access to sediment/rock samples, well log data and physical properties data for further analysis and research to meet their scientific objectives.

Fig. 5.3: Display of cores from Koyna Scientific Drilling Project at BGRL-MoES, Karad.

5.2.2 Exploring the largest geoid low on the earth (IOGL)

Geoid is the equipotential surface of the Earth's gravity field which approximates mean sea level in the open ocean. The Indian Ocean Geoid Low (IOGL) centred near to south of Sri-Lanka is the most fascinating and largest geoid low in the globe. It appears as a very long wavelength feature covering the entire Indian Ocean, dominated by a significant low of -106 m. Main objective of the program is to find out a conclusive point in understanding unusual structures and related mechanisms responsible for this largest geoid low.

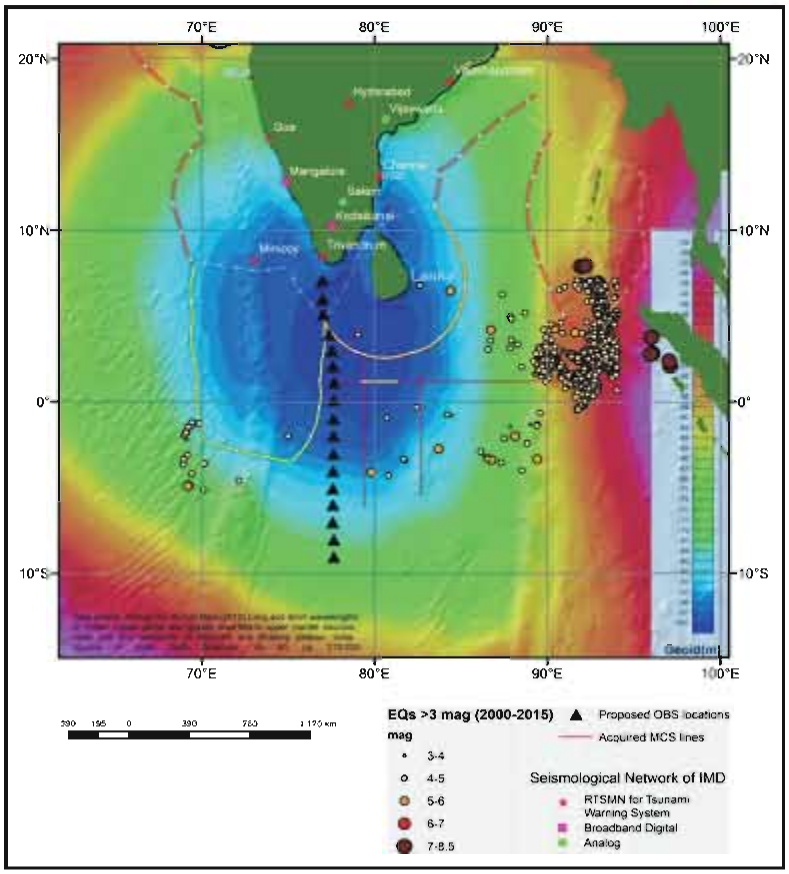

Fig. 5.4: Map showing tentative passive OBS locations in the IOGL region.

Intensive characterization of fault and fold behaviour of MCS (multi-channel seismic) data; and modelling and interpretation of 420 line km of wide-angle seismic data have led to go for deeper down the earth for better understanding of the geodynamics of the IOGL region. Passive ocean bottom seismometers (OBSs) are going to be deployed in the region for investigating the deep sources of Indian Ocean Geoid Low (Fig 5.4). To understand the surface manifestation in the region, where intense intraplate deformation is observed, recently a high resolution multi-beam bathymetry survey has been carried out onboard R/V Sagar Kanya over a selected block in the region. Gravity coring and CTD/SVP operations have been done at some locations during the survey.

5.2.3 Deep Crustal Studies (DCS)

The deep crustal studies program is aimed at understanding the rift style, basement tectonics and moho variations across the western continental margin of India (WCMI) with special emphasis on correlating onshore-offshore structures using plural geophysical data. WCMI is a tectonically significant region for geo scientific investigation as it deformed by lithospheric stretching, rifting, magmatic emplacement, sedimentation, erosion etc.

Studies in the WCMI are carried out with 2D Multichannel seismic reflection (MCS) data acquired over the profiles of thousands kilometre long, MCS data is ideally suited for detailed imaging of crustal features. Investigation on the MCS data results that sediment depositions in the south western continental margin of India

(SWCMI) occurred in the period of Late Cretaceous to recent and the maximum sediment thickness of 4.5s (TWT) marked in the shelf part. Faults system and horst graben structures with rotated fault blocks in the basin shows the failed rift in the SWCMI.

Interpretation of Multi-Channel Seismic (MCS) reflection data along the central region of Western Continental Margin of India (CWCMI) Mumbai Offshore Basin (MOB) revealed the tectonic processes that led to the development of basement tectonics, sedimentary basins and its subsidence history during Cenozoic evolution. Seismo-gravity modeling suggested that the crustal thinning and rifting had deformed the basement of WCMI which holds several horsts/grabens to intrusive type structures along with syn-rift sediments giving rise to detachment faults in the upper crust which might have led to volcanism during rift initiation. Results from basin subsidence modelling revealed a transitional to heavily stretched nature of crust along WCMI since late Paleocene.

5.2.4 Palaeo Fluids in the Petroliferous Basins of Western Offshore, India:

The National Centre for Earth Science Studies (NCESS) has taken up the challenging task of scientifically reinvestigating the abandoned exploratory well drilled by ONGC in the shallow water area of the western continental shelf region offshore to Kochi for discovering the presence of oil. Fluid inclusion techniques that have been exclusively developed by NCESS scientists for oil exploration are being employed for the purpose. Detailed petrographic analysis of samples from KK-4C-A-1 well from Kerala-Konkan (KK) basin is ongoing. Secondary hydrocarbon fluid inclusion trails and some occluded bitumen fluorescence were observed in the 3065-3070 m depth in quartz, feldspar and the cements within the sand stone, clay stone lithology. The secondary fluid inclusion trail observed is showing a clear migratory trend. It is the first time in Kerala-Konkan basin a migrating oil in the form of secondary fluid inclusion trails have been reported (Fig. 5.5). Occluded bitumen with diffused fluorescence is generally observed at a depth of 5900-5905 m and at 3220-3225 depths in KK-4C-A-1 well.

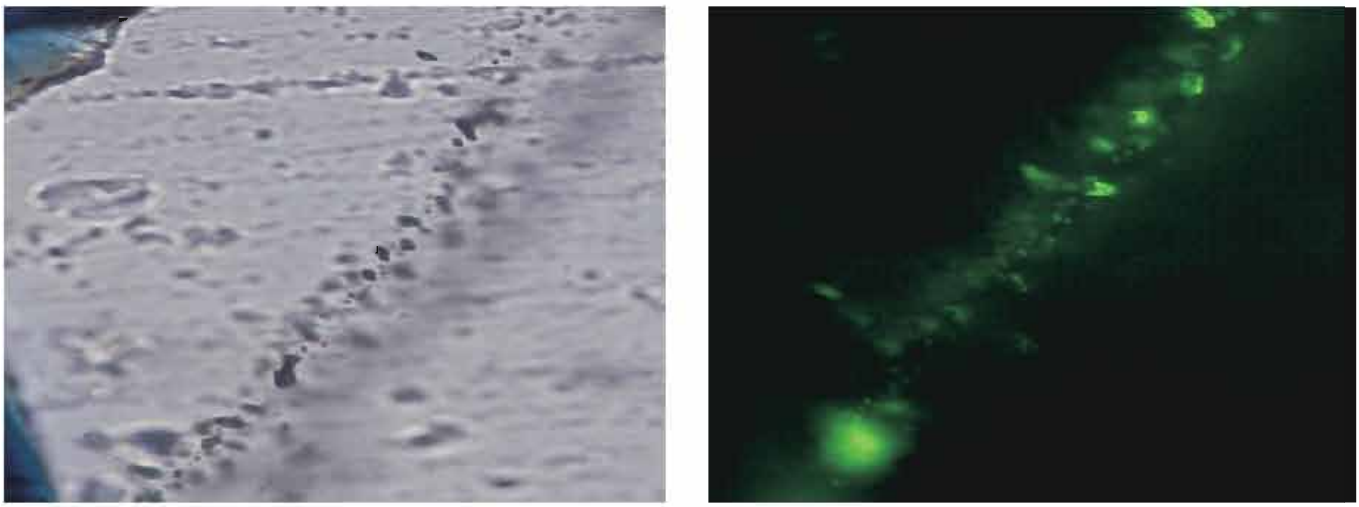

Fig.5.5: Hydrocarbon fluid inclusion trail in KK-4C-A-1 well in Kerala Konkan basin at a depth of 3065-3070 m.

5.2.5 Landslides and its triggering factors in the Western Ghats- an integrated geological, geotechnical and geophysical investigation

The major landslides in India are mainly confined along the Himalayan range, in the Western Ghats and Eastern Ghats. A total 393 landslides trolled 2415 human lives in a span of 7 years between 2000-2007 in the country. Therefore a scientific understanding on the causative factors that trigger the landslides is very important for mitigation purpose. NCESS is presently undertaking the landslide investigations in the Western Ghats using an integrated approach of geology, geophysics and geotechnical methods. In Munnar area, 62 landslides location were identified and mapped along the various traverses. There are mainly two types of the landslides present in the area; (a) rockfall, (b) debris flows. The rock falls are mainly confined in the lower reaches where the soil thickness is less and the debris flows are mainly confined in the upper part where the thick insitu and transported soil present. Most of the landslides are occurred in the area where surface slope is >30o.

Apart from landslides, the land subsidence (Soil piping) is another major hazard in Western Ghats particularly in Kerala. Four resistivity profiles are laid in between the subsidence region and the water flow outlet to verify any connectivity between these two and to locate the possible subsurface cavity structure using the 60 electrodes setup. The resistivity results clearly depict the soil layer thickness, water saturated layer beneath the 3 m depth. The top soil layer contains the unconsolidated material with rock boulders followed by water saturated layer and reaching the bed rock level at a depth of ~9 m. Any subsurface cavity with a diameter > 1 m is not seen in resistivity images of Schlumberger and Wenner configuration.

5.2.6 Development of video monitoring system for coastal applications

NCESS is in the process of developing a video monitoring system for continuous monitoring of the coast. As part of this project, a pilot demonstration system has been installed at Valiathura beach in Trivandrum on 29th September, 2016. The Valiathura beach being part of a typical high energy coast located along the SW coast of India experiences two distinct wave climates viz. the monsoon period during which the wave activity is generally high and the non-monsoon period which mostly remains calm except during rare events triggered by local meteorological conditions or due to the arrival of stormy waves from distant areas. The pilot system essentially consists of an integrated system comprising of four video cameras (three Static IR cameras and one PTZ camera) and the associated hardware and software for the recording, storage, processing and analysis of the video imagery. The first phase of this pilot work which involves field measurements, testing, calibration and validation is underway. The results are validated with ground truth measurements (Fig. 5.6).

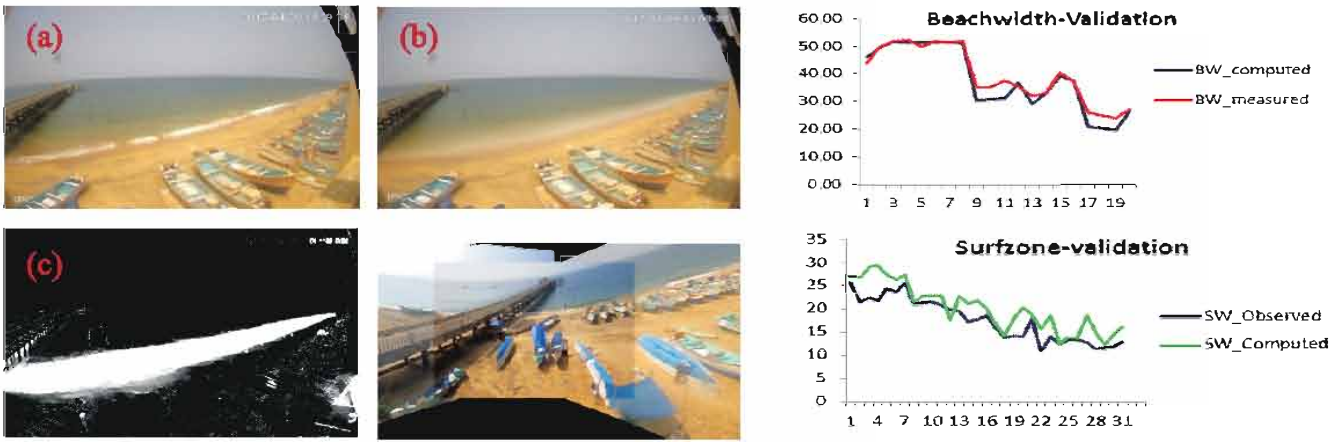

Fig. 5.6: Image products/ Beach width and surfzone validation; (a) Image, (b) Timex Image c) Variance Image and (d) Panorama Image.

5.2.7 Impact of changes in the rainfall patterns on the groundwater

Many areas in the eastern flanks of the Southern Western Ghats, especially the areas drained by the Cauvery river is in the grip of large scale water related problems and the lack of adequate knowledge on the groundwater potential and the factors affecting the recharge process is a major setback challenging sustainable agriculture and livelihood in the area. Therefore, as a first step, a study has been undertaken to understand the relationship between the changes in the rainfall pattern and its effect on the groundwater recharge in the Cauvery river basin. The study is based on the observed seasonal groundwater level of the area during the period 1996 to 2016. Throughout the river basin, there is a marked change in the number of rainy days over the years, with increase in high intensity rainfall events and decrease in moderate rainfall events, without any significant change in the decadal mean annual rainfall (Fig.5.7).

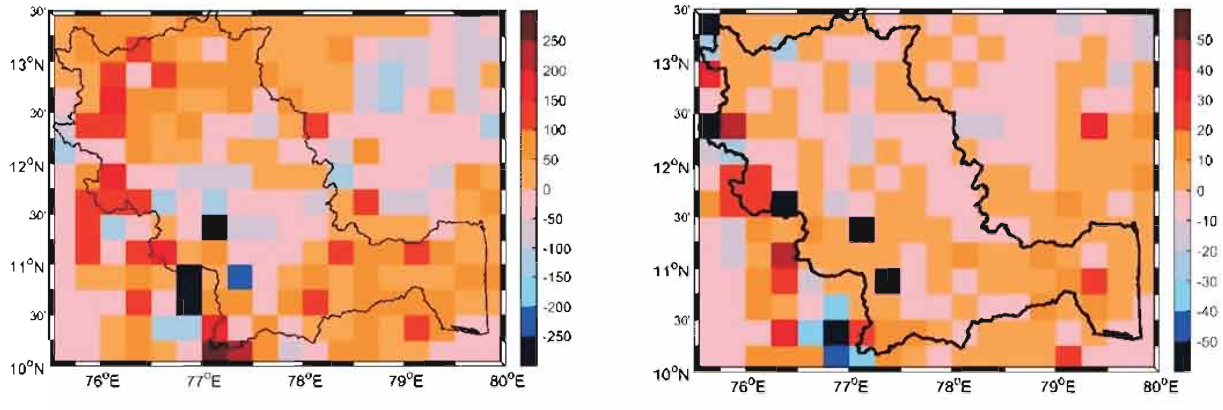

Fig. 5.7: (a) Changes in the total number of high intensity rainfall events and (b) Changes in the total number of moderate rainfall events for the period between 1982-1996 and 1997-2011.

5.2.8 Cloud microphysics and lightning

The Atmospheric Processes (AtP) Group of NCESS has focused on three aspects.

1) Microphysical characteristics of rainfall during different seasons over a coastal tropical station using disdrometer
2) Variations in monsoon low level jet and thermodynamic structure in wet and dry rainfall episodes over southwest India
3) Particulate Matter Concentrations in the Southern Tip of India: Temporal

The following are the salient findings/ observations:

The rain Drop Size Distribution (DSD) over the tropical region exhibit pronounced variations during different monsoon seasons. Diverse rain intensity bins and their relative contributions towards total rainfall are dissimilar for different seasons. The study reveals that maximum events are the heavy drizzle/light rain type, but the contribution of rainfall (mm) is mainly registered on heavy rain type. Relative rainfall contribution from different mean diameter bins shows that diameter 1-2mm and 1-3mm are the major contributors to the total rainfall

Investigation was carried out to understand the variations in summer monsoon rainfall, jet streams and thermo-dynamical structure of lower troposphere as well as large-scale circulation features, in relation with wet and dry spells of rainfall over southern tip of India, a coastal station Thiruvananthapuram, Kerala. Analysis for the recent years (2010 to 2015, except 2012), also revealed the dominance of north-westerly winds over the southern tip of India, with strengthened cyclonic circulation over the southern tip and weakened winds over central India, during the wet spells compared to the dry spells.

Temporal variation, meteorological influences and source identification of particulate matter (PM) concentrations in the southern tip of India shows the importance of local sources and long range transport. The highest concentrations were found for PM10 with moderate to strong winds, which represent the presence of local emissions as well as long-range transport. The study bring to light that the highest probability to get high concentrations of PM is from south-southwest direction having a wind speed of 5 ms^{-1}.

5.2.9 Multi-Temporal InSAR Processing to understand plausible Surface Deformation over an Estuarine Island in the Southwest Coast of India

Surface deformation on the Earth's surface can be caused by various phenomena like earthquakes, landslides, over exploitation of groundwater leading to subsidence in metros, consolidation of underlying beds, subsurface erosion, etc. The measurement and monitoring of deformation over the earth's surface can be unraveled through Differential Interferometric Time Series processing of Synthetic Aperture Radar Datasets. The DInSAR time series analysis has become an indispensable method in most of all space time phenomena monitoring of earth processes. The study is an attempt to address evidences of plausible subsidence activity leading to environmental degradation and related issues in the Munroe Island – an estuarine island within the Ashtamudi Lake along the southwest coast of India. The state-of-the-art technology of time series differential interferometric SAR (DInSAR) based persistent scatterer Interferometry technique is implemented using 31 Sentinel 1A TOPS datasets to estimate the line of sight displacement of the permanent scatterers in the estuarine island. The preliminary results from the

time series InSAR processing reveals that the persistent scatterers show ample signatures of uneven displacement velocities.

5.2.10 Regional Brainstorming Session (BSS) entitled "36th IGC: A Unique Opportunity for advancement in Geo-sciences"

As a part of ongoing series of preparatory level activity for 36th IGC 2020, a two days Regional Brainstorming Session (BSS) entitled "36th IGC: A Unique Opportunity for advancement in Geo-sciences" has been conducted at National Center for Antarctic and Ocean Research (NCAOR), Goa during 17-18 August 2017 (Fig. 5.8). The programme which was organized by the 36 IGC Society, New Delhi in association with NCAOR, Goa and GSI, Mangaluru had a participation of about 100 scientists from various organizations. It had 9 technical sessions covering 11 themes such as Ice Sheets; India-Antarctic connection and records; Climate and Paleo-Climate; Marine Geology Scientific Deep Drilling; Off-shore Mineral exploration; Geophysical Exploration Techniques; Geomagnetism; Coastal Processes; Geo-archaeology and Education/Outreach etc.

Fig. 5.8: Participants of IGC Brainstorm Session.

Chapter 6

Research, Education, Training and Outreach (Reachout)

Earth System Science is interdisciplinary in nature and the atmosphere, ocean, geosphere, biosphere and cryosphere are its components. In order to understand the individual components and also study the interactions amongst them, it is necessary that adequate capacity building programs are initiated that not only help in generating trained manpower but also add to the existing knowledge in the field.

The research and development activities of MoES, are centered around delivery of mission mode projects that are time-bound and require specialized manpower. Thus, target oriented training programs and human resource development is an integral part of the activities of MoES. Towards this direction, MoES has established an institutional mechanism to generate trained manpower through three training schools established at IMD, IITM and INCOIS. In addition to the in house training schools, there is a need to continuously add to existing knowledge through integration of new ideas and application of new knowledge for improvement of weather and climate forecast. This can be effectively done through involvement of various R & D institutes in the country by 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 in 2011 and continued during the XII plan. The main objective of the program was to generate a large pool of dedicated weather and climate scientists, who on successful completion of the 18 month induction training will be placed in various constituent units of MoES. In addition, the CAT school also offers various other targeted training programs and regularly conducts training for the JRF-PhD program of IITM. Towards this direction, three batches of trainees were placed in various units of MoES on successfully completing the induction training. The following training Programmes / Workshops were conducted under CAT during 2017-18:

- 13-16 February 2017: International Workshop on Representation of Physical Processes in Weather and Climate Model (INTROSPECT 2017)
- 4-7 April 2017: Training Workshop on Lightning and Extreme Weather Events.
- 23-26 May 2017: International NASA-ARSET workshop on Remote Sensing,
- 10-14 July 2017: National training workshop on Greenhouse gas measurement, interpretation and inverse modelling.
- 31-July to 04-Aug 2017: Targeted Training Activity (TTA) on "Monsoons in a changing climate" the Abdus Salam International Centre for Theoretical Physics (ICTP),

Trieste, Italy. This TTA was organized by IITM, ICTP and the World Meteorological Organization (WMO), Geneva, Switzerland.

In addition to the above, the Centre successfully conducted the training for IITM JRF PhD program. The two semester course work was completed in May-2017.

6.2 Training in Operational Meteorology

The major training activities conducted at the Meteorological Training Institute (MTI), India Meteorological Department during 2017 are listed below.

A One year Met-II & Advanced Meteorological Training course (AMTC) in General Meteorology was completed in September 2017. The trainees included Six Meteorologists (Gr-II) from IMD, 9 officers from Indian Navy, 1 officer from the Indian Coast Guard, 2 officers from Mauritius and 1 officer from Fiji. A fresh AMTC Batch started in September 2017 with 6 officers from Indian Navy, 2 officers from the Indian Coast Guard and 1 officer from Mauritius.

A Six Months Forecasters Training course for 20 officers was completed in February 2017. A Six months Forecaster Training course is being conducted for 46 trainees from IMD, which will be completed in December 2017. The Integrated Meteorological Training courses were also conducted for IMD officials on various topics. A meeting was held at MTI IMD Pune for conducting a short-term training of 1 month for Meteorologists from 7 pacific islands in Operation/Maintenance of Meteorological Instruments.

6.3 International Training Centre for Operational Oceanography (ITCOocean)

ITCOocean is currently operational with the state-of-the-art facilities available at INCOIS, Hyderabad. So far, over 681 scientists including 576 from India and 105 from 34 other countries have been trained at this centres in various aspects of operational oceanography. The other infrastructure facilities like building and training hostel are being established which are expected to be ready by 2018. It is also envisaged to invite world class faculties and trainees from around the world and work out a curriculum for long duration courses (of 3-9 months). The recent upgradation of the center to UNESCO Category-2 Centre (C2C) as a training facility will provide an opportunity for India to emerge as a leading country in the Indian Ocean. This will also help India to forge cooperation and improve engagement among the counties of the Indian Ocean, including South Asian and African states bordering the Indian Ocean. This C2C is intended to improve skill of students and other participants which will increase the employment opportunities within and outside India.

6.4 BIMSTEC- Center for Weather and Climate

The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic cooperation (BIMSTEC) Member Center for Weather and Climate (BCWC) has been established at the National Center for Medium Range Weather Forecasting (NCMRWF) to enable enhanced regional cooperation on observing systems, forecast information, early warning systems and capacity building. The program was evaluated by an Independent Review Committee (IRC) which recommended its continuation during 2017-20. The proposal has been approved for its continuation at a total cost of Rs 13.54 crores. Forecast products including the extreme rainfall forecasts for the BIMSTEC countries are

disseminated through NCMRWF website. Research work to further improve the forecast products are being carried out.

6.5 R & D FUNDING IN EARTH SYSTEM 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, MoES supports research projects in academic and research institutes in the various areas of Earth system science. The program earlier named *"R & D in Earth & Atmospheric Science"* was reviewed by an independent evaluation committee chaired by Prof G.S.Bhat. The committee recommended the continuation of the program during 2017-20. The program was approved for its continuation during 2017-20 at a total cost of Rs 240 crores covering all themes under Earth System Science (Atmospheric Science, Geoscience, Cryosphere & Hydrology, Ocean Science, Seismology, Technology Research Board, and Earth System science Technology Cells).

The program *Drugs from Sea* being handled separately in XII plan was also reviewed by an independent review committee (IRC) and is continuation was approved under the program. Thus the areas of research funding are (i) Atmospheric Science including Climate Science; (ii) Geoscience; (iii) Ocean Science & Resources, (iv) Hydrology & Cryosphere; (v) Earth System Technology (vi) Seismology and (vii) Drugs from Sea.

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

The following new research projects were recently funded.

(i) Atmospheric Research:

- "Lightning impact on ozone precursor over Indian region and its implications on tropospheric ozone" by Birla Institute of Technology (BIT) Mesra, Jaipur.
- "Assimilation of Ground Radar data with Weather Research & Forecast Model in Information Theoretic Framework" by IIT Bhubaneswar
- "Microphysics of Cloud droplet and Aerosols: Experimental and computational study" by Indian Institute of Science, Bangalore
- "Effect of climate change on convectively coupled equatorial waves and MJO and their influence on extreme weather precipitation events over Indian region" by IIT Bhubaneswar.
- "Developing a Virtual Soil Moisture methodology using Optical and Microwave Satellite Imagery for surface Soil Moisture Mapping" by Sathyabama University.

(ii) Geoscience:

- "Multi-Scale imaging of the deep geology of India – Eurasian region and the adjoining sea" by Institute of Science Education and Research (IISER), Pune.
- "Tectono-thermal evolution of the Lohit Batholith along Dibang and Lohit Valleys, India using Fission Track and (U-Th)/He Thermochronology" by Wadia Institute of Himalayan Geology (WIHG), Dehradun.

- "Surface Geochemical Prospecting for Hydrocarbon Exploration in Parts of Cambay Basin" by Gujarat Energy Research & Management Institute (GERMI), Gandhinagar.
- MELTS and P-T pseudosection modeling approach to understand the petrogenesis and pre-Himalayan metamorphism of Wangtu Gneissic Complex and associated enclaves, Sutlej Valley" by Indian Institute of Science Education and Research (IISER), Bhopal.
- Geo archaeological investigations to assess the existence and reconstruction of an ancient port at Gopakapattinam, Goa: scientific and cultural aspects" by CSIR National Institute of Oceanography (NIO), Goa.

(iii) Cryosphere and Hydrology:

- A 100 ka Glaciation–deglaciation history of Ladakh and its comparative evaluation with the Quaternary sediments on the northern fringe of the Thar Desert, Center of Advance Studies in Geology, University of Delhi.
- Development of a remote sensing based method for the rapid reconstruction of time series of formative water discharges of the Ganga and Brahmaputra rivers in the Himalayan Foreland Indian Institute of Science Education and Research (IISER), Bhopal.

(iv) Ocean Science:

- Development & Characterization of Food Products using Sunderban Macro Algae (Enteromorpha intestinalis): Jadavpur University, Kolkata.
- Development of a New Integral Approach for the Treatment of Phenolic Wastewater using Bioremediation in Combination with Nano-Composite by Developing Microstructure Bioreactor: IIT Guwahati,
- A case study on effect of coastal oil and Chemical Intrusion on compactions and consolidation behavior of Mangalore soil & water:
- Exploring India Medieval Coastlines using Geospatial Analysis and Historical Records: IISc, Bangalore:
- Development and characterization of efficient drilling fluid systems to explore huge natural gas hydrate resource in the offshore of India: ISM, Dhanbad.
- Bioremediation of oil spills and removal of aromatic hydrocarbons using graphene, graphene oxide and its nano-composite and marine macro organisms: Jadavpur University.

(v) Seismology:

- "Application of Advanced Statistical Signal Processing Algorithms for Earthquake Precursors Using GPS-TEC" by K.L.E.F. University, Green fields Vaddeswarm, Guntur.
- "Dynamic slip of earthquakes with available data" by IIT, Hyderabad.
- "Evaluation of Liquefaction Earthquake Hazard of Kutch Region'' by IIT, Gandhinagar.

6.6 Earth System Science and Technology Cells (ESTC)

The ESTC program was initiated with an aim to develop theme based network projects involving researchers from various universities, colleges and academic institutions to work together on a

specific theme. The principal investigator from the lead university acts as the ESTC's Principal Coordinator (PC) and is responsible for formulating the science plan and for overall coordination or successful implementation of the sub-projects. This model of ESTC was formulated with an aim to encourage capacity building of young researchers engaged in the network projects.

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.

6.7. Progress of ongoing projects

(a) Focused research

(i) Atmospheric Research including Climate Change

Annual Grant to NIAS to support various research and development activities including Ph.D programme in particular in the area of environment climate change and energy sector – Completed: National Institute of Advanced Studies (NIAS) has been given an annual grant for 5 years to support the various research and development activities including Ph.D programme in particular in the area of environment, climate change and energy sector. Under this project, two Ph.D.s have been awarded, 6 Ph.D.s are at various stages of their dissertation and 28 publications on multi disciplinary aspect in Indian and foreign journals have been published.

Design and Development of a Unified Modelling System for Seamless Weather and Climate Predictions of Monsoons by IIT Delhi_– Completed: In line with the objectives of the project, design and development of icosahedral-hexagonal (icohex) grid model has been accomplished and coupling with physics has been tested. Numerical experiments with idealized suite of testbed have been performed and results closely agree with other models. modules for preparing the boundary conditions have been developed on the icohex grid and an Ensemble Kalman Filter based LMDZ-DART data assimilation system has been developed. This is a unique work that has been carried out in India. Under this project 3 Ph.D.s awarded/submitted and 5 papers have been published in journals.

(ii) Geosciences:

Metamorphic Trajectory of the granulites from the Jagtiyal Section, Andhra Pradesh by Banaras Hindu University (BHU), Varanasi- Completed: Jagtiyal section is an integral part of Eastern Dharwar Craton (EDC) and contain quartz-free sapphirine-spinel-bearing granulites, kornerupine – bearing granulites, maficgranulites, opx-crd gneisses, Under this project 4 papers have been published in peer-reviewed journals.

(iii) Technology Research Board

Design and Development of Ka-band polarimetric Doppler weather radar: The project for Design and Development of Ka-band polarimetric Doppler weather radar is being implemented by SAMEER, Mumbai. Significant work in this regard has been carried out by SAMEER. Various components/subsystems viz. Antenna (Ready for integration), Trailer & Scissor lift, Cabin, UPS, Chiller, DG Set & Dry air system, Work Station, Power Distribution Unit (PDU), DC Power Supply unit, Exciter sub-system, IF receiver & Tx sample unit, EIKA's Controller & Monitoring Unit (CMU) and BITE, PDU unit for Cabin, Microwave Assembly Unit, Radar Controller Software, have been developed/ procured and are ready for integration.

Design and Development of Solar Multi-Effect Desalination (MED) Plant: The project for design & development of pilot Solar multi-effect desalination system was granted to IIT, Chennai. The pilot plant has been set up at Vivekananda Kendra, Kanyakumari. The plant consists of sub-systems viz; multi-effect desalination system (MED), solar thermal flat plate collector water heating system, off-grid ground-mounted solar photovoltaic (PV) power plant system and brackish water intake and drain system. The MED system has been pressure tested as well as vacuum tested. Also, a trial run has been carried out for few days by using grid power.

(b) Human Resource Development

- Supported Human Resource Development through Sponsorship of 5 MTech and 5 PhD students in various fields of Earth Sciences at IIT Delhi.
- Supported User Oriented M.Tech Program on Ocean Technology at IIT Madras through fellowship of 10 students.

ESSO Chairs/Visiting Chairs:

- Prof. J.C.R. Hunt, Cambridge University, UK is working as Sir Gilbert Walker MoES Chair Professor at IIT Delhi taught a course on "Special Module in Atmosphere and Ocean" in Feb 2017.
- Prof. V. Chandrasekar, Department of Electrical & Computer Engineering, Colorado State University has joined IIT Kharagpur as Samudragupta MoES Chair Professor.

6.8 Awareness and Outreach Program

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. Ministry also supports the National and International Earth Science Olympiad.

Exhibitions

During the year, the Ministry participated in 17 Exhibitions. The details of a few of these exhibitions are follows:

i. India International Trade Fair-2017, 14-27 November, 2017 at Pragati Maidan, New Delhi. The MoES Pavilion was awarded the "Special Appreciation Certificate" for Excellence in Display at the IITF 2017, Pragati Maidan. New Delhi.

Dr Vipin Chandra, Joint Secretary, MoES receiving the "Special Appreciation Certificate" Award for Excellence in Display at the IITF 2017, Pragati Maidan. New Delhi.

ii. "Science & Technology Innovations during the Monsoon Session" which was held on 28th July to 11th August, 2017 at Parliament House Annexe, New Delhi. Hon'ble MP's visited Ministry's pavilion during Science & Technology Innovations during the Monsoon Session, Parliament House Annexe, New Delhi

iii. India International Science Festival (IISF) -2017, 13th to 16 October, 2017 at Chennai. Under the Mega Science, Technology & Industry Expo, Various Theme Pavilions highlighted the achievements of Indian Space, Defence, Energy, Agriculture, Healthcare, Industry/Trade, Rural Development, Environment/ Climate Change, Earth Sciences, Ocean, Bio Sciences/ Biotechnology, Women Empowerment, Education, Urban Development, and Tourism/Culture. About 350 institutions took part and exhibited their R&D activities in the Mega Expo.

Hon'ble Minister Dr Harsh Vardhan visited Ministry's pavilion during IISF 2017 at Chennai.

The Vice President of India, Shri M.Venkaiah Nadu, delivered the valedictory address in the concluding ceremony of IISF2017 in Chennai

Valedictory function at IISF 2017 at Chennai.

Earth Day Celebration-2017

"Earth Day" has been celebrated across the country on 22nd April 2017 and the event was organized at 65 centers across the country including schools, college and universities. The theme was "Sustainable 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 6000 children participated, prizes at National level was distributed on Ministry's foundation day.

Painting Competition being organized in different parts of the country.

Children were awarded for painting Competitions for Earth day 2017 at Vigyan Bhawan, New Delhi.

Participation in International Earth Science Olympiad

The Ministry sponsored "11th International Earth Science Olympiad (IESO)" conducted at Cote d'Azur, Nice France during 22-29 August 2017. Children from 30 Countries participated in the event.

Indian team won one Gold Medal and one Bronze Medal.

Chapter 7

International Cooperation

Ministry of Earth Sciences regularly undertakes research and development through involvement of national and international researchers for providing skillful weather forecast, climate information, ocean state, monitoring earthquakes, early warning for tsunamis and other phenomena.

MoES extensively engages with the best institutes overseas in the field of Earth system Sciences to solve some of the key challenges in weather and climate related to the Indian region. Moreover this also helps in optimum utilizations of resources, infrastructure, data etc. MoES has undertaken collaboration with various International organizations. The progress made under various collaborations is given as follows.

7.1 Cooperation with NOAA, USA

MoES and the National Ocean and Atmospheric Administration (NOAA) signed a Memorandum of Understanding in 2008 on Earth Sciences and Observations. Under this, ten joint research and development activities have been undertaken in the field of monsoon, ocean observations, tropical cyclone, Tsunami, INSAT 3D, Predictive Capabilities on Marine Fisheries and Harmful Algal blooms, development of an ocean wave modeling and assimilation system for the Indian Ocean Region to enhance the capability to generate a skillful global wave model systems especially for monsoon conditions.

The Implementing Agreement (IA) on Technical Cooperation for the **"Study of Dynamical Seasonal Prediction of Indian Summer Monsoon Rainfall "** was signed on 6 November 2010 between NCEP, NoAA and MoES for a period of five years. As per the objective of this IA, a Monsoon Desk was established at NCEP to serve as the modality to coordinate numerical model simulations and diagnostics between NCEP, IITM and IMD. Major accomplishments of the Monsoon Desk have been (i) Establishment of a dynamical extended range forecast system at the IITM for monsoon prediction (ii) Establishment of a Global Forecast System and Global Ensemble Forecast System (GEFS) at NCMRWF (iii) Development of an Earth System Model at IITM (iv) Transfer of modelling infrastructure between NCEP and MoES institutes (v) Satellite data assimilation etc. In order to continue efforts in development of India's Earth System model and coupled system model with better prediction skill, the IA has been renewed in June 2017 for a period of five years. The Monsoon desk will continue to provide support on specific problems in GFS/CFS, and will continue providing CFSv2 related data as necessary. The work on CFSv3 and training in Global Land Data Assimilation System (GLDAS) will be taken up under the renewed IA.

7.2 Cooperation with UK Met Office (UKMO)

In 2016 MoES signed a Consortium Agreement with the U. K. Met Office (UKMO), Korea Meteorological Administration (KMA), the Commonwealth of Australia through its Bureau of Meteorology and 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, for Core partnership on Unified Model (UM)" for weather and climate forecast. This MoU enables 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.

7.3 MoU on Cooperation in Earth Sciences

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

7.3.1 Implementing Agreement (IA) on "Predicting the Variability of the South Asian Monsoon"

Under this IA, three projects involving Indian and UK scientists are studying different aspects of physical processes affecting the monsoon to improve the computer simulation models. 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 involving UK's BAe-146-301 atmospheric research and India's Sagar Nidhi and Sindhu Sadhna research ships was carried out during the period June-July 2016. The data collected in the campaign are being analyzed for results.

7.3.2 IA on "Atmospheric Pollution and Human Health in an Indian Megacity"

Under the IA on Atmospheric Pollution and Human Health in an Indian Megacity signed between Ministry of Earth Sciences (MoES) and Department for Biotechnology (DBT) and UK's Natural Environment Research Council (NERC) and the Medical Research Council (MRC), five projects have been supported. The projects aim to address different aspects under four science themes agreed under the IA namely (i) Emission validation and sources; (ii) Processes: physical and chemical; (iii) Exposure validation and health outcomes and (iv) Mitigations and interventions. Out of these, four proposal will be funded by MoES and one by DBT. The four proposals funded by MoES are as follows:

- Megacity Delhi atmospheric emission quantification, assessment and impacts (DelhiFlux) by IIT Roorkee, NPL, NEERI & IIT Kanpur.
- Process analysis, observations and modelling - Integrated solutions for cleaner air for Delhi (PROMOTE) by IITM Pune, NARL, IIT Madras & IRADe.
- An Integrated Study of Air Pollutant Sources in the Delhi National Capital Region (NCR) by IIT Delhi, NPL
- Clean Air for Delhi Through Interventions, Mitigations and Engagement (CADTIME) by IIT Madras, CRRI, NEERI, IIT Bombay.

Two campaigns have been planned to address the objectives under the five projects. The winter campaign which has commenced on November 2017 will continue till first week of February 2018. Thereafter the summer campaign will commence in first week of April 2018 and will last till onset of Monsoon over India.

7.3.3 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 have been funded. 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. This includes developing decision support/expert tools for the river basins, say for flood forecasting. The emphasis is on modelling and quantification of different components of water cycle. It is expected that the integrated models will encompass key hydrological

processes and how they interact in order to advance understanding of how fluxes and storage within heterogeneous basins affect water availability and water quality.

7.4 India-UK Virtual Joint Centre on Water Security" (IUKWC)

MoES and the NERC,UK are working together to support research in the area of "Sustaining Water Resources" and has set up a "India-UK Virtual Joint Centre on Water Security" (IUKWC) at IITM, Pune. 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 visit. Various scientific activities were undertaken by the joint centre.

7.5 Cooperation with Belmont Forum Countries

An MoU was signed in February 2013, between MoES and the Belmont forum Countries to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. MoES is participating in 4 Collaborative Research Areas (CRA) namely Coastal Vulnerability, Food Security, Biodiversity and Climate Predictability and Inter-regional linkages.

7.6 Cooperation with Research Council of Norway (RCN)

Under the MoU with RCN, three proposals in Geo hazards and five proposals in Climate Systems in Polar regions were recommended for funding. The PI of all the proposals have initiated the work as outlines in their objectives. The progress of proposals under Climate Systems in Polar Regions is as follows.

Ocean - sea-ice - atmosphere teleconnections between the Southern Ocean and North Atlantic during the Holocene (OCTEL)

The aim of this project is to examine ocean, sea ice and atmospheric interactions in the Southern Ocean and North Atlantic to understand the interhemispheric teleconnections that occurred within the last 11,700 years with special focus on the last 2000 years. Sediment cores were collected from Kongsfjord-Rjipfjord in Svalbard, Arctic and samples are being analysed. A Training workshop on "Quantitative reconstruction and numerical methods for analysis of past climate variability using diatoms" was organised by NCAOR, Goa and NPI, Norway from 21st Nov to 24th Nov 2017 to train the selected participants on using diatoms for past reconstruction.

Mass balance, dynamics, and climate of the central Dronning Maud Land coast, East Antarctica (MADICE)

This project will investigate ice dynamics, current mass balance, and millennial-long evolution in the coastal region of the central Dronning Maud Land and past changes in atmospheric dynamics and sea ice in this region. The NCAOR-NPI team is jointly undertaking glaciological field studies and ice core drilling in the study area during the current (2017-18) season. The NCAOR team has taken out 153.1 m ice core at one of the ice rise. A summer school on "Antarctic climate variability and ice dynamics" was conducted at NCAOR, Goa, during 08-11 May 2017 which was attended by 35 young scientists from various R&D and academic institutions.

Pliocene Arctic Climate Tele-connections (PACT)

The aim of the PACT project is to explore the teleconnections between the Arctic climate

variability during the Mid-Pliocene Warm Period (MPWP) with South Asian and Australian Monsoon systems. In this project, the sediment samples from the Eastern Arabian Sea (EAS) (IODP Expedition 355, Site: 1457 B, C and 1456 A, B) and the Arctic Ocean (ODP Leg 151, Site: 910C) are being used. The samples from the mid-Pliocene sections from the above-mentioned sites are being analysed for various proxies.

Quantifying Impacts of South Asian Aerosols on Regional and Arctic Climate

The main objective of this project is to quantify regional and Arctic climate impacts of South Asian aerosol emissions, by updating present emission inventories and tracing the aerosol impacts through teleconnections, and physical and chemical processes.

Counteracting effect of future Antarctic sea-ice loss on projected increases of summer Monsoon rainfall

The main aim is to investigate that the ISM is sensitive to future Antarctic sea-ice loss, which will (at least partially) counteract the general tendency towards increased monsoon rainfall over India, and may contribute to increase its sub-seasonal variability. Six Coupled Model Inter comparison Project Phase 5 (CMIP5) models were selected based on the model's representation of monsoon dynamics over Indian region. Model validation and evaluation were done using dataset for the period 1979-2005 for different parameters.

The proposals approved under Geohazards theme and their progress is as follows:

- **Intraplate Seismicity in India and Norway: Distribution, properties and causes:** The main aim is to increase the understanding of intraplate earthquakes both in India and Norway by combining seismological and geodetic data with state-of-the-art modelling techniques.
- **Delineation of the target fault-zone for Koyna scientific deep drilling by accurate location of micro-Earthquakes:** The main aim of the project is to locate microseismicity on continuous data from the borehole seismometers. Six borehole seismometers installed so far are providing quality data that permits detection of even smaller earthquakes of magnitude-0.1 M. The absolute locations of earthquakes using the dense broadband seismic network comprising of 23 surface seismic stations that provide accuracies up to ± 600 m has now been improved to ±300 m with the addition of these 6 borehole seismic stations.
- **Landslide hazard assessment in NE India along the Gangtok-Tsomgo/Changu Lake and Gangtok-Chungthang-Lachen corridors:** The objective of the project is to prepare detailed hazard maps along the two important corridors and specify risk at local scale level. A preliminary survey of the two corridors in Sikkim was carried out by the Indo-Norway project team in May 2017. This first detailed field survey is scheduled during February-March 2018. Some of the soil samples collected during preliminary survey are being tested for their static and dynamic characterization.

7.7 Cooperation with UNESCO/IOC

The ministry has been actively working with the Intergovernmental Oceanographic Commission of UNESCO towards establishment of a Category-2 Centre(C2C) of UNESCO for Operational Oceanography at INCOIS,

Hyderabad. The IOC Assembly unanimously supported the proposal from India to establish the C2C at Hyderabad. This was finally approved by the 39th Session of UNESCO General Conference held on 7th November 2017. On 15th December 2017, the Cabinet accorded approval for the same.

The establishment of UNESCO C2C as a training facility will provide an opportunity for India to emerge as a leading country in the Indian Ocean. This will also help India to forge cooperation and improve engagement among the counties of the Indian Ocean, including South Asian and African states bordering the Indian Ocean.

7.8 Cooperation with International Seabed Authority (ISA)

The Council of the International Seabed Authority (ISA) on 10th August 2017 approved the extension of contract between Ministry of Earth Sciences (MoES), Government of India and the ISA (an Institution set up under the Convention on Law of the Sea to which India is a Party) for exploration of Polymetallic Nodules (PMN) for a further period of 5 years (2017-22). By extending the contract, India's exclusive rights for exploration of PMN in the allotted Area of 75,000 sq km in the Central Indian Ocean Basin (CIOB) will continue and would open up new opportunities for resources of commercial and strategic value in area beyond national jurisdiction. India signed a 15 year contract on 25th March, 2002 for exploration of PMN in CIOB with the ISA.

7.9 Cooperation with Chinese Earthquake Administration (CEA), China

An MoU was signed between MoES and Chinese Earthquake Administration (CEA) on 15 May 2015 concerning cooperation in the field of Earthquake Sciences and Earthquake Engineering, for a period of five years. Subsequently, first Joint Indo-China Committee meeting was held in January 2016 in New Delhi and it was decided to launch a joint call for proposal covering specific themes viz. (i) Seismic Hazard, (ii) Subsurface Structure, (iii) Precursory Research, and (iv) Earthquake Engineering in NW and NE Himalaya. The first priority is to be attached in NW Himalaya (J&K, Himachal, Uttarakhand) and second priority in the Sikkim, Assam, adjoining Tibet and seismic gap area of 1950 earthquake in NE Himalaya. Joint call for proposal and independent joint committee are being finalized.

7.10 Cooperation with International Continental Scientific Drilling Programme (ICDP), Germany:

MoES had signed a MoU with German Research Centre for Geosciences (GFZ), on behalf of members of ICDP on January 7, 2011 to carry out "Scientific Deep Drilling Programme in Koyna Region, Maharashtra" and became a member of ICDP on Jan 7, 2011. The validity of this MoU was for 5 years. Recently, the Cabinet has approved the proposal for signing the MoU on the Membership of the ICDP between Ministry of Earth Sciences, Govt. of India and the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, for a period of five years. Accordingly the MoU was signed on 30th August 2016.

The MoU will facilitate engagement of internationally renowned experts from ICDP to accomplish scientific deep drilling and associated investigations in the Koyna region. As a part of the membership agreement, ICDP will also provide technical/ operational support, facilitate capacity building in terms of manpower training in key scientific areas.

7.11 Cooperation with Korea Meteorological Administration (KMA)

The 4th bilateral meeting on cooperation between the KMA and the MoES was held at the KMA headquarters on 9 November 2017. The four areas of cooperative activities include the folowing

- Strengthening weather satellite data exchange system
- Cooperation on Global Information System Centres (GISC) operations
- Cooperation on WMO(World Meteorological Organization) GAW (Global Atmosphere Watch) Activity
- Cooperation on Climate Services

7.12 Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)

RIMES is an international and intergovernmental institution, owned and managed by its 33 Member and Collaborating States, for building capacities in the generation and application of user-relevant early warning information. Currently, the Government of India serves as the Council Chair. The 9th RIMES Council Meeting and the 3rd RIMES Ministerial conference was held at Port Moresby, Papua New Guinea during 23-25 August 2017. It focused on discussions issues relating to enhancement of multi-hazard early warning capacities and to broadening of the RIMES institutional development process. Afghanistan, Djibouti, Mozambique, Tonga, and Yemen joined as the new RIMES Member States. INCOIS started providing OSF(Ocean State Forecasts) services to various countries including Comoros, Mozambique and Madagascar. Dr M. Rajeevan, Secretary, Ministry of Earth Sciences, and Chair, RIMES Council, launched the system for operational use in the presence of David Grimms, President of World Meteorological Organization (WMO) and other dignitaries from the 48 countries of Indian and Pacific Ocean region at the 3rd RIMES Ministerial conference.

Chapter 8

Publications, Awards and Honours

A total number of 398 research papers were published in 2017 by MoES centres under its various programs, the details of which are given below.

	ACROSS	OSTORMS	PACER	SAGE	Total
Publications with Impact Factor (A)	191	63	39	40	**333**
Publications without Impact Factor (B)	28	15	13	9	**65**
Total Publications (A+B)	219	78	52	49	**398**
Cumulative Impact Factor	**548.593**	**120.962**	**122.519**	**70.141**	**862.215**

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Patents awarded

1. 'A computer implemented System for transmitting High frequency Ocean ambient noise in Real time (SHOR)', M. Ashokan, G. Latha, G. Raguraman & A. Thirunavukkarasu 2016. This patent has been awarded to NIOT by the Patent Office, Germany: 20 2016 003 923 dated 19th July 2016 for a term of 10 years. The patent is for the invention of a system for transmitting high frequency ocean ambient noise through various modes of communications in real-time for marine applications.

2. 'A Light Weight Low Frequency Band Width (2-18 kHz) Transmitter For Marine Applications', Dhilsha Rajapan, P.M.Rajeshwari, A.A.Gnanaraj, Raju Abraham, M.A.Atmanand (Patent no. #288881 dt. 30/10/2017): Granted for 20 years with effect from 21st April 2010. This is used as the acoustic transmitter for the indigenously developed Sonar as technology demonstration.

Awards and Honours

- Dr. Vineet Gahalaut, Director, NCS was elected as a Fellow of the Indian Academy of Sciences for his research contributions in Earth Sciences.
- Dr. O.P.Mishra, NCS was elected as a Fellow of the National Academy of Sciences for his research contributions in Earth Sciences.
- Dr. Kunal Chakraborty, Scientist, INCOIS was selected for the INSA Medal for Young Scientists for 2017 for his outstanding contributions on modeling of marine ecosystem variability in the Indian Ocean.

- Dr. S. L. Singh, IMD was awarded the Certificate of Excellence by the World Meteorological Organization (WMO) for his Services to WMO particularly to The WMO Technical Commission for Basic Systems.
- Dr. Gufran Beig, IITM was appointed as an Honorary Professor, Amity University, Rajasthan from January 2017.
- Dr. Ashwini Kulkarni, IITM was selected to represent India in the CORDEX Asia ESD Committee which was formed to encourage the statistical downscaling activity over the Asian region.
- Dr. Thara Prabhakaran, IITM was nominated as a member in the Expert Team for WMO Weather Modification.
- Dr. J Sanjay, IITM was nominated as a Member, WCRP CORDEX science Advisory Team (SAT) for 3 years with effect from 01 January 2017.
- Dr. Yogesh Tiwari, IITM was nominated as a Member and IPCC First Lead Author for the elaboration of the 2019 refinement to the 2006 IPCC guidelines for National Greenhouse Gas Inventories.
- Dr. Roxy Mathew Koll, IITM was nominated as a Lead Author in the IPCC Special Report on the Ocean and Cryosphere in a changing climate.
- Dr. R.Venkatesan, NIOT received the - Lockheed Award for Ocean Science and Engineering – 2017 for the technical accomplishment in the field of marine science, engineering or technology. He also received the 'Certificate of Merit' for outstanding services to the World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC) of UNESCO and Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) in the recognition of his extensive contributions to promoting and developing data buoy activities in ASIA. ,
- Shri D.Rajasekhar, NIOT has been bestowed with the 'Adroit Researcher Award 2017' [MHRD, IIT Bombay & Green Thinkerz Forum] in recognition of his outstanding contribution for 'developing & implementing numerous engineering solutions.
- Shri Tata Sudhakar, NIOT received the IETE Hari Ramji Toshniwal Award 2017 by Institution of Electronics and Telecommunication Engineers on September 17, 2017.
- Dr. M.A. Atmanand, NIOT was awarded with Institution of Electrical and Electronics Engineers Inc. (IEEE) Oceanic Engineering Society's (OES) "Presidential Award" for his outstanding services to the (IEEE) Oceanic Engineering Society.
- Dr. G.Latha, NIOT received M.S. Narayanan Memorial Lecture Award of the Acoustical Society of India for the year 2016.

Chapter 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 MoES 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 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	2015-16 Actuals			2016-17 Budget Estimates			2016-17 Actuals		
REVENUE SECTION		**Plan**	**Non-Plan**	**Total**	**Plan**	**Non-Plan**	**Total**	**Plan**	**Non-Plan**	**Total**
1	3403- Oceanographic Research	444.24	36.58	480.82	573.90	50.72	624.62	367.76	44.60	412.36
2	3425- Other Scientific Research	59.94	34.17	94.11	49.90	7.98	57.88	35.65	7.44	43.09
3	3451- Secretariat Expenditure	0.00	24.96	24.96	0.00	30.78	30.78	0.00	29.24	29.24
4	3455- Meteorology	304.51	295.14	599.65	401.20	382.97	784.17	420.82	381.37	802.19
CAPITAL SECTION										
1	5403- Capital Outlay on Oceanographic Research	1.90	0.00	1.90	15.00	0.00	15.00	7.89	0.00	7.89
2	5455- Capital Outlay on Meteorology	91.02	0.00	91.02	160.00	0.00	160.00	66.58	0.00	66.58
	Grand Total	901.61	390.85	1292.46	1200.00	472.45	1672.45	898.70	462.65	1361.35

9.4 Report of the Comptroller and Auditor General of India

Sl. No.	Year	No. of Paras/ PAC reports on which ATNs have been submitted to Monitoring Cell after vetting by Audit	Details of the C&AG paras/PAC reports on which ATNs are pending			No. of ATNs with Audit
			No. of ATNs not sent by the Ministry even for the first time	No. of ATNs sent but returned with observations and audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by Audit but have not been submitted by the Ministry to PAC	
1	2007	One [Para No. 5.1 Report No. 2 of 2007 on "Wasteful Expenditure of Rs.33.08 lakh by IMD for procurement of precision Ni-Span C"]	NIL	NIL	NIL	NIL
2	2008	One [Para 7.1 of Report No. 3 of 2008 -Non-achievement of the objectives of Modernizing the Accounting and Personnel Management Functions (IMD)].	NIL	NIL	NIL	NIL
3	2013	NIL	NIL	NIL	NIL	One (Para No. 8.1 of Report No. 22 of 2013- Irregular Introduction of Pension Scheme and Diversion of Funds)

4	2014	One [Para 5.1 of Report No. 27 of 2014 - National Data Buoy Project (NIOT Chennai)]	NIL	One (Para No. 5.2 of Report No. 27 of 2014- Irregular Payment of Gratuity)	NIL	NIL
5	2015	One [Para No. 6.2 of Report No. 30 of 2015 on "Installation and Upkeep of Meteorological Observatories by RMC, Kolkata" (IMD)]	NIL	One (Para No. 6.1 of Report No. 30 of 2015- Unfruitful Expenditure due to non-functional website)	NIL	NIL
6	2016	NIL	NIL	One (Para No. 6.1 of Report No. 12 of 2016- Non-Establishment of desalination plants and wasteful expenditure).	NIL	NIL
7	2017	NIL	One (Para No. 7.2 of Report No. 17 of 2017 - Irregular Implementation of promotion scheme).	One (Para No. 7.1 of Report No. 17 of 2017 - Non recovery of fuel charges due to improper contract management).	NIL	NIL

9.5 Staff Strength

Strength of all groups of Ministry of Earth Sciences including all the constituents of Earth System Science Organisation (ESSO) is as below:-

S. No.	Groups of Posts	MOES	NCMRWF	CMLRE	ICMAM	IMD	NIOT	NCAOR	INCOIS	IITM	NCESS	TOTAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1	Group A	54	50	17	16	465	91	47	47	180	72	1039
2	Group B	35	18	04	03	3900	54	17	27	64	28	4150
3	Group C (including MTS)	66	27	15	06	2692	23	23	-	70	59	2981
	TOTAL	**155**	**95**	**36**	**25**	**7057**	**168**	**87**	**74**	**314**	**159**	**8170**

MOES = MINISTRY OF EARTH SCIENCES
NCMRWF = NATL. CENTRE FOR MEDIUM RANGE WEATHER FORECASTING
CMLRE = CENTRE FOR MARINE LIVING RESOURCES AND ECOLOGY
ICMAM = INTEGRATED COASTAL MARINE AREA MANAGEMENT
IMD = INDIA METEOROLOGICAL DEPARTMENT
NIOT = NATIONAL INSTITUTE OF OCEAN TECHNOLOGY
NCAOR = NATIONAL CENTRE FOR ANTARCTIC AND OCEAN RESEARCH
INCOIS = INDIAN NATL CENTRE FOR OCEAN INFORMATION SERVICES
IITM = INDIAN INSTITUTE OF TROPICAL METEOROLOGY
NCESS = NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

9.6 Official Language Implementation

Efforts are being made constantly for the promotion of official language. Under Prithvi Vigyan Maulik Pustak Lekhan Yojna three books have been selected for the first, second and third prize respectively. During the year Hindi fortnight was organized on 01.09.2017 to 15.09.2017.During this fortnight various Hindi competitions were held to create an atmosphere conducive to use of Hindi in official work.

The cash scheme for Original work in Hindi introduced by Department of Official Language has been implemented. An incentive scheme for officers for giving dictation in Hindi is in operation. In this year Committee of Parliament on Official Language has inspected 5 offices under this ministry. Hindi Section conducted O.L. inspection of 5 sections of this Ministry. The year also saw organization of three OLIC meetings and Hindi workshops in terms of the stipulation from Department of Official Language. Official Language inspection of ICMAM and NIOT was carried out on 18 December and 20 December respectively. During this inspection one joint Hindi workshop was also organized for ICMAM and NIOT staff.

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	Un-identified posts	VH	HH	OH	VH	HH	OH	Total	Un-identified 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

Representation of SCs/ STs/ OBCs in Government Services in respect of Ministry (Proper)

Group	Representation of SCs/ STs/ OBCs as on 1.1.2017				Number of appointments made during the calendar year 2016											
					By Direct Recruitment				By Promotion				By Deputation			
	Total No. of employees	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 including MTS	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**

9.7 Implementation of Orders of CAT/Court Judgements:

All the judgements/ orders of the Hon'ble CAT or any other courts have been implemented or contested in proper form 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 (107 Questions) and Rajya Sabha (49 Questions) last year.

9.9 Vigilance Activities and Achievements:

Dr. M.P. Wakdikar, Sc. 'G' continues to be CVO of this Ministry w.e.f. 31.12.20014. 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 is in existence. One Complaint of Sexual Harassment was reported in the year 2016-17. The Committee carried out six meeting to consider the live case and submitted the fact finding to the Competent Authority.

A workshop on Sexual Harassment at workplace was held on international women's day on 8th March, 2017, at MoES. This was followed by interactive session in which all the officers/staff of MoES participated.

9.10 Significant Audit Points Printed in Audit Reports of 2017.

Two audit points have appeared in the audit reports of 2017.

Chapter 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 MoES 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 Dr. R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO.
3. PAMC on Geosciences, chaired by Prof. Ashok Singhvi, PRL, Ahmedabad.
4. PAMC on Ocean Science and Resources chaired by Dr. Satish Shetye, Former Director, NIO.
5. PAMC on Seismicity and Earthquake Precursors chaired by Dr. M. Ravi Kumar, DG, Institute of Seismological Research, Gandhinagar.
6. PAMC on National Programme on Atmospheric Chemistry chaired by Prof. M.M. Sarin, Physical Research Laboratory, Ahmedabad.
7. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, Dr. Raja Ramanna Chair Professor, National Institute of Advanced Studies, Bengaluru.
8. Research Advisory Committee of IITM chaired by Prof. J. Srinivasan, IISc, Bengaluru.
9. Research Advisory Committee of NCMRWF chaired by Prof. J. Srinivasan, IISc, Bengaluru.
10. Research Advisory Committee of INCOIS chaired by Prof. G. S. Bhat, IISc, Bengaluru.
11. Scientific Advisory Council of NIOT chaired by Dr. P.S. Goel, Dr. Raja Ramanna Chair Professor, National Institute of Advanced Studies, Bengaluru.
12. Research Advisory Committee of ICMAM chaired by Dr. Y. V. N. Krishna Murthy, Director, National Remote Sensing Centre, Hyderabad.
13. Research Advisory Committee of CMLRE chaired by Dr. R. Ramesh, NISER, Bhubaneswar.
14. Research Advisory Council of NCAOR, chaired by Dr. Shailesh Nayak, Former Secretary, MoES.
15. Research Advisory Council of NCESS chaired by Dr. S.K. Tandon, Professor Emeritus, IISER, Bhopal.
16. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof. Sulochana Gadgil, IISc, Bengaluru.
17. Committee For MoES Research Fellowships and Chairs, chaired by Dr. R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO, Bengaluru.

सत्यमेव जयते

Government of India
Ministry of Earth Sciences