ANNUAL REPORT

2018-2019

सत्यमेव जयते

Government of India
Ministry of Earth Sciences

FRONT COVER

ANNUAL REPORT
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Ocean Moored Buoy Network in the Indian Ocean (OMNI) along with the Ocean Reserach Vessel Sagar Nidhi. Data from eight OMNI will be shared with the international scientific community.

BACK COVER

Systematic and continuous oceanographic & acoustic data being collected from 2014 by Indian Arctic Moored Observatory (IndARC)

सत्यमेव जयते

ANNUAL REPORT
2018-19

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 like tropical cyclones, storm surge, floods, heat waves, thunderstorm and lightning and earthquakes etc. In addition, the ministry has the mandate of harnessing living and non-living resources, ocean survey 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. Several major milestones have been accomplished under the five major programs of the MoES during the last year, which are illustrated below:

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

India Meteorological Department (IMD) has the mandate of providing weather and climate services in the country. IMD augmented its observational network to further improve forecast skill. Some of the major augmentation efforts include the commissioning of the S-Band Doppler Weather Radar at Goa, indigenously developed GPS based pilot sonde at New Delhi, indigenously developed Drishti Runway Visibility Range (RVR)/ Automatic Weather Observing System (AWOS) systems at 8 airports, a new Meteorological Observatory at Meteorological Centre Amravati (Capital city of Andhra Pradesh). A new Cyclone Warning Centre also was established at Thiruvananthapuram, Kerala with effect from October 2018 to provide cyclone alerts and warnings for the states of Kerala and Karnataka.

The lightning location network, which was set up over Maharashtra has been expanded to other parts of the country with the induction of 28 additional sensors. A mobile App named as "DAMINI" has been developed to disseminate the information on lightning to the public.

The field campaign namely the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Phase-IV campaign was conducted near Solapur in Maharashtra to understand the physical process involved in enhancement of precipitation. In total 240 hours of aircraft observations were taken during the field campaign. The third phase of the winter fog experiment at Indira Gandhi International (IGIA) Airport, New Delhi and Hissar was also conducted. High quality observations on Fog events have been collected from this field campaign.

The Ministry of Earth Sciences has augmented its High Performance Computer

(HPC) facility by 6.8 Peta Flops (PF) which has been installed at two of its constituent units namely, Indian Institute of Tropical Meteorology (IITM), Pune with 4.0 Peta Flops capacity and National Centre for Medium Range Weather Forecasting (NCMRWF), Noida with 2.8 Peta Flops capacity. The HPC facility 'Pratyush' at IITM and "MIHIR" at NCMRWF were dedicated to the nation by Dr. Harsh Vardhan, Minister for Earth Sciences on 8th January 2018 and 30th January 2018, respectively. With this facility, a paradigm shift in weather and climate modeling activity for operational weather forecasts has been achieved.

A Global Ensemble Forecast System (GEFS) for short and medium range prediction at 12 km using 21 members of the model was commissioned on 01st June 2018. Improvements have been made in the Data Assimilation system for assimilation of newer observations, including Indian satellite observations.

During 2018, six tropical cyclones against the normal frequency of 4.5 cyclones formed over North Indian Ocean (NIO). The World Meteorological Organization (WMO) appreciated IMD for tropical cyclone advisory services during Cyclonic Storm Sagar over Arabian Sea (16-21 May), Extremely Severe Cyclonic Storm Mekunu over Arabian Sea (21-27 May), VSCS Luban (06-15 October) and VSCS Titli (08th-13th October) which helped minimize the impact and saved many lives.

A new early warning system of air quality in Delhi was developed in collaboration with National Center for Atmospheric Research (NCAR), USA and was launched on 15th October 2018. The system will assimilate data from around 36 monitoring stations and satellite data on stubble burning and dust storms. These warning services were provided to Central Pollution Control Board (CPCB). India Meteorological Department and Power System Operation Corporation Limited (POSOCO) have launched a web portal dedicated exclusively to the energy sector. The Mumbai Weather Live Mobile App has been developed by collating ground weather observations recorded by IMD and the Municipal Corporation of Greater Mumbai, observations from SAFAR-Mumbai, to provide live location specific information on rainfall over the Mumbai City. Currently, the app covers about 100 sites spread across Mumbai city, suburban areas, Navi Mumbai and the surrounding areas.

1.2 Ocean Services, Modelling Application, Resources And Technology (O-SMART)

Indian National Centre for Ocean Information Services (INCOIS) continued to provide forecasts on the state of the oceans, the Potential Fishing Zone (PFZ) advisories and species specific advisories for a wide spectrum of users. The advisories are being disseminated in smart map and text form on daily basis, depending on satellite data availability, except fishing-ban period and during adverse sea-state. During the period 1st January - 31st December 2018, multilingual Potential Fishing Zones (PFZ) advisories were made available on 299 days.

The Indian Tsunami Early Warning Centre (ITEWC) monitored 37 earthquakes of magnitude $\geq$ 6.5 during the period 01st January 2018 to 31st December 2018. For these earthquakes, ITEWC disseminated the bulletins as per standard operating procedure to its regional and national stake holders through Email, FAX, GTS and SMS.

In an effort to reach out to users in the open ocean directly through the satellite, INCOIS successfully tested the programme in

collaboration with ISRO through its NavIC satellite during Jan 04th-06th, 2018. The test messages to the boats in the deep ocean were reported to be received without fail by the end user/fisherfolks in the boats. The application will be particularly useful to users in the open sea with no other available means of information.

Dr. Harsh Vardhan, Honourable Minister laid the Foundation Stone for the world's first ever Ocean Thermal Energy Conversion (OTEC) powered desalination project in Kavaratti, Lakshadweep on 22nd October. This would not only pave the way for setting up of more environmentally friendly self-sustainable desalination plants but also help in scaling up the OTEC technology for mainland uses. NIOT has taken up the task of establishing 1.5 Lakh liters per day capacity LTTD plants in Amini, Androth, Chetlat, Kadamat, Kalpeni, and Kiltan Islands of UT Lakshadweep at a cost of Rs. 187.87 crores. The Atal Centre for Ocean Science and Technology for Islands in Port Blair was inaugurated by Dr. Harsh Vardhan, Hon'ble Minister on 15th September 2018.

The National Centre for Coastal Research (NCCR) and the Government of Tamil Nadu have signed a Memorandum of Understanding (MoU) for the operationalization of the Chennai Flood Warning System (C-FLOWS) which has been developed for the city of Chennai. The C-FLOWS, a project initiated by the office of the Principal Scientific Advisor (PSA) was developed as a multi-institutional project involving IIT-Bombay, IIT-Madras, IRS-Anna University, and MoES institutes.The System is undergoing trials during the current NE Monsoon. A status report on, "Seawater quality at selected locations along India coast" was released on 27th July, 2018 in New Delhi on the occasion of Foundation Day of MoES.

The coastline of India is undergoing changes due to various anthropogenic and natural interventions. Precise information on shoreline changes is essential to address the various coastal problems such as coastal erosion, closure of river / lagoons / creeks mouths, etc. NCCR has prepared a status report on shoreline changes for the period 26 years (1990 to 2016) and the report was released on 27th July 2018. The Beach Restoration project in Puducherry has been successfully completed by scientists at National Institute of Ocean Technology (NIOT). Demonstration of submerged reef at Puducherry has resulted in formation of a wider beach at Puducherry. A total of 5 cruises were undertaken onboard FORV *Sagar Sampada* in the eastern Arabian Sea and the Andaman Sea and inventorised the marine biodiversity. The surveys have yielded numerous new records and new species to the inventory of Indian Ocean fauna.

1.3 Polar and Cryosphere Research (PACER)

The 37th Annual Indian Scientific expedition to Antarctica (ISEA) consisting of 116 persons (54 scientists, 62 logistic support staff) from 28 different national organizations was launched to carry out 31 scientific projects under cryosphere and ice core studies, remote sensing studies, lacustrine studies, and environmental studies. An additional antenna for augmentation of Data Reception System (DRS) and Data Communication System (DCS) was successfully installed and commissioned at Bharati station by National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO).

The Indian research station 'Himadri' at Ny-Ålesund, Svalbard, Norway was manned for over 120 days by 32 Indian researchers who carried out 19 different scientific projects. The

Gruvebadet station was made fully operational with instruments like Radiometer profiler, Micro rain radar, Aethalometer, Nephelometer, Multistage impactor, Net Radiometer etc. collecting data round the year. Six benchmark glaciers (Sutri Dhaka, Batal, Bara Shigri, SamudraTapu, Gepang and Kunzam) of Western Himalaya were monitored since 2013 to understand glacier impact on hydrology and climate of Himalaya region.

A team consisting of 42 scientists from 8 different research institutions/universities carried out multi-disciplinary observations in Southern Ocean during the 10th Indian Southern Ocean expedition (ISOE-10) to understand the complex process of physical, biogeochemical and air-sea interactions and their role in the ecosystem of Indian Sector of Southern Ocean. National Polar Data Center (NPDC) was made functional at NCPOR, Goa for managing and sharing data of Indian Polar Research related to broad spectrum of disciplines, including oceanography, glaciology, resources and environmental science, biology & ecology, atmospheric science, etc.

1.4 Seismology and Geoscience Research (SAGE)

The National Seismological Network now comprises of 115 seismological observatories spread across the country and the earthquake detection capabilities are improved to a minimum threshold earthquake magnitude of 3.0. The Seismic Microzo-nation work related to Geophysical investigations has been initiated for the four selected cities, namely, Chennai, Bhubaneswar, Coimbatore, and Mangalore. In addition, microzonation for the 8 more cities, considered to be important from seismic point of view, is being taken up separately on priority through academic and research organizations in India. The list includes, Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad.

The Borehole Geophysical Research Laboratory (BGRL), Karad near Koyna, Maharashtra has completed the drilling of 3.0 km pilot hole for seismological observations. The Koyna pilot borehole passed through 1247 m of Deccan basalt and continued into the granitic basement up to 3000 m. Down hole geophysical logs acquired in the borehole provided crucial information about the physical and mechanical properties of the rock formation, fracture/ fault zones, in-situ stress regime, fluid flow zones and temperature regime..

The National Centre for Earth Science Studies (NCESS) has initiated setting up Critical Zone Observatories at three different hydroclimatic regions in the south India: 1) Munnar – Humid high-altitude observatory; 2) Silent Valley Twin Watershed – tropical east and west flowing humid to semiarid transition region; and 3) Trichy - Cauvery delta region.

1.5 REACHOUT

The main objectives of the REACHOUT program are:

i) To support various R & D activities in the thrust areas of different components of Earth System Sciences that are theme and need based;

ii) provide training and create awareness amongst the public, students, academicians and user communities about the various fields of Earth System Science.

During the current year, a specific call for research proposal was made for Thunderstorm and Meso-scale Processes Prediction (THUMP). A total number of 26 proposals have been received

in response to the above call. These proposals are being reviewed for providing financial support.

1.6 International Interface

MoES regularly partners with international institutes for scientific collaboration in all fields related to earth sciences to broaden the scope of research through trans-national joint projects and joint developmental work.

The three-day India-USA Colloquium on Earth Observations and Sciences for Society and Economy was held at National Institute of Oceanography (CSIR-NIO) at Dona Paula during 11-13 June 2018. This event marked ten years of US-India Science collaboration and helped in setting the course of action for the next decade in the areas of weather, climate, ocean and fisheries. India and United States expressed to work in co-operation, exchanging valuable data and findings and help each other in research and development activities in ocean and earth sciences. A Memorandum of Understanding (MoU), was signed between MoES and United States Geological Survey (USGS) on 1st November 2018, to enable the sharing of expertise available with both organizations and adoption of the latest state-of-the-art technology in the field of Earth Science. The BIMSTEC Centre for Weather and Climate (BCWC) organized the first Governing Board (GB) Meeting, Scientific Advisory Committee (SAC) Meeting and Workshop on "Severe Weather/Climate Disaster Warning for BIMSTEC Region" during 30-31 July 2018. The meetings and workshop was attended by participants from Bangladesh, Bhutan, Nepal, Myanmar, Sri Lanka and Thailand. India was declared as the Chairman of Governing Board for the first term.

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

The first Sustainable Blue Economy Conference (SBEC) was held at Nairobi, Kenya from 26-28 November 2018 which was attended by MoES scientists. MoES has also joined the UNEA's Global campaign on 'Clean Seas' on 5th June, 2018. It has initiated the programme on Marine Litter & Micro plastics research and participated in 02 major expert group meetings on marine pollution along with other member States and accredited Major Groups and Stakeholders held at Nairobi and Geneva.

1.8 Scientific Publications

A total number of 406 research papers were published during 2018 by MoES scientists under various programs of the Ministry. The total impact factor (1009.5) this year is much higher than the previous year (862 in 2017), which means research papers in this year were published in journals with higher impact factor (Fig. 1.1).

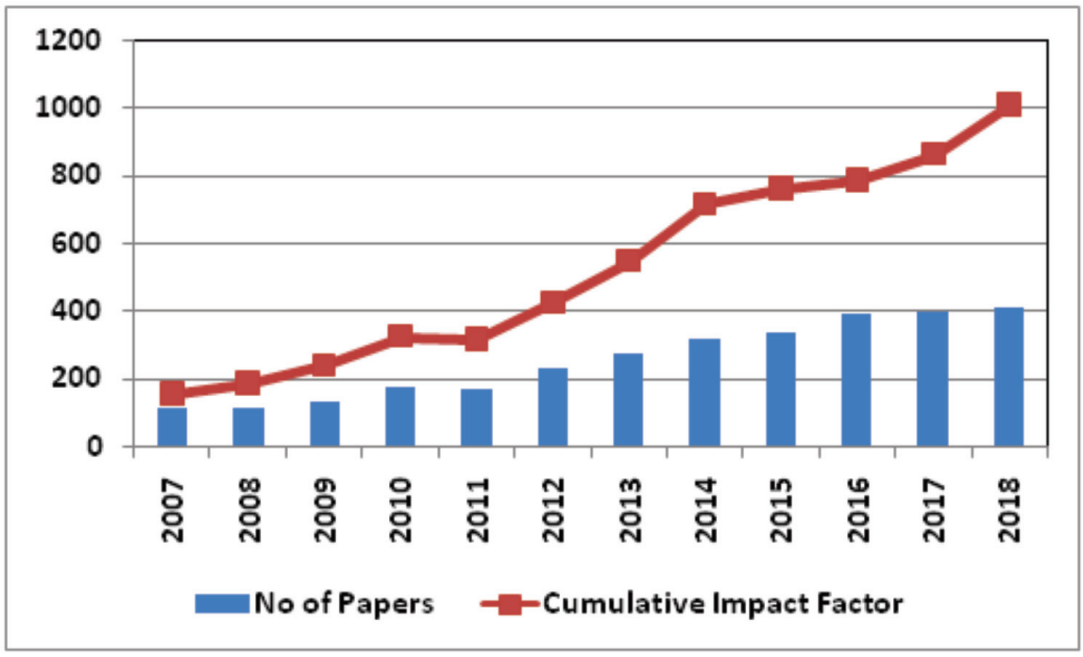

Fig. 1.1 Number of research papers and cumulative impact factor year wise

1.9 Budget Expenditure

The total outlay for the Ministry for the year 2018-19 was Rs.1800 crores which has been retained at the RE stage also. The expenditure profile for the last 11 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	1597.69	1547.73
2018-19	1800.00	1800.00	1320.00*

**As on 31/12/2018*

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CHAPTER 2 Atmosphere and Climate Research, Observations Science and Services (ACROSS)

Introduction

The Ministry of Earth Sciences provides Weather, Climate and Hydrological Services to various users round the clock and round the year. Both operational and research aspects for these services are implemented under the Umbrella program ACROSS.

During the year, many significant achievements have been made on providing weather and climate services. Many major improvements also have been made in the observing systems and data assimilation in numerical models. Observational campaigns also have been taken up as special atmospheric observations help us to understand model deficiencies and to improve the accuracy of models. A Global Ensemble Forecast System (GEFS) for short and medium range prediction at 12 km was commissioned on 1st June 2018. A new early warning system for air quality in Delhi developed in collaboration with National Center for Atmospheric Research (NCAR), USA was launched on 15th October 2018. Details of significant achievements made under ACROSS are given below:

2.1 Observing Systems and Field Campaigns

Maintenance and strengthening of atmospheric observational network is absolutely required to sustain and improve skill of weather forecasts. India Meteorological Department (IMD) has been augmenting its observing system networks over the past years. During 2018, the following up-gradation of the network has been made.

- The S-Band Doppler Weather Radar (DWR) at Goa was inaugurated on 12th June 2018 by Dr. M Rajeevan, Secretary, Ministry of Earth Sciences.
- The indigenously developed GPS based pilotsonde was installed and commissioned on 23rd March 2018 at RMO AYANAGAR. The second system was commissioned with effect from September 2018 at Mumbai.
- Five New Aeronautical Met. Stations (AMS) were commissioned at Jagdalpur, Hisar, Jharsuguda, Pakyong and Pithoragarh under RCS-UDAN Scheme.
- Eleven Drishti RVR systems indigenously developed by CSIR-NAL were commissioned at Amritsar, Mumbai, Chennai, Kannur, Cochin, Hyderabad and Delhi. Another integrated AWOS-RVR including Drishti system is also installed at Bhubaneswar Airport.
- A new Meteorological Observatory has been setup at Meteorological Centre Amravati (Capital city of Andhra Pradesh)
- Three Laser Ceilometers were installed at Mangalore (Bajpe), Delhi and Kolkata airports.
- The wind instruments were installed at Pantnagar, Port Blair (Command Office), Lengpui, Kadapa, Bhuntar, Hissar, Pithoragarh airports for aviation purpose.

- IMD has completed second phase of augmentation of Skyradiometer network by commissioning of 8 skyradiometers at Jaipur, Raipur, Gangtok, Minicoy, Pondicherry, Aurangabad, Sagar and Amaravati.
- IMD has set up a countrywide network of 25 nos. Global Navigation Satellite System (GNSS) stations for "Earth and Atmospheric studies" to derive integrated precipitable water vapor (IPWV). The IPWV data is being used for nowcasting and assimilated in NWP models to improve weather forecasting.
- Software for forecasting and tracking of evaluation of cloud cluster acquired from National Institute for Space Research/ Centre for Weather Forecast and Climate Studies (INPE//CPTEC), Brazil has been customized for INSAT-3D and operationalized.
- License agreement has been signed between India Meteorological Department and EUMETSAT Germany for obtaining data and product generated by EUMETSAT Geostationary Satellites and its Polar orbit Metop Satellites and Terrestrial link has been set at NCMRWF, Noida.

2.1.1 Satellite products for weather forecasting services

At present the processed data of INSAT-3DR Imager and Sounder is being obtained from (Space Application Centre (SAC), Ahmedabad through dedicated NKN connectivity and images generated at IMDPS are disseminated on IMD website on real time basis. The satellite products are being used extensively for weather forecasting services. All these images and products are disseminated in a real time basis through dedicated IMD website. Satellite data and images are also used in monitoring various other significant weather phenomena such as Fog and thunderstorms.

The satellite and lighting merged products (Fig. 2.1) are also operationalised at the IMD website. The merged lightning & satellite cloud top temperature operational product is a joint collaboration of IMD, IITM & Indian Air Force. Work is going on to merge (all 3 types of instrument data) Satellite + RADAR and Lightning data for the weather forecast.

2.1.2 High Altitude Cloud Physics Laboratory (HACPL)

Expansion of lightning network: The lightning location network over Maharashtra has been expanded to other parts of the country with the induction of 28 additional sensors. New sensors have been installed over Kerala, North India, Northeast India, Odisha, West Bengal and Himalayan region. A mobile App has been developed to disseminate the information on lightning to the public (Fig. 2.2). It gives information on exact location of lightning strike and its movement and also gives warning about the possibility of lightning in the next 30 minutes. Similarly an SMS alert system has also been developed in association with Reliance Foundation. It sends audio and text message warnings to people in the area of impending lightning strikes. Alert will be sent if lightning occurs in around 30 km radius.

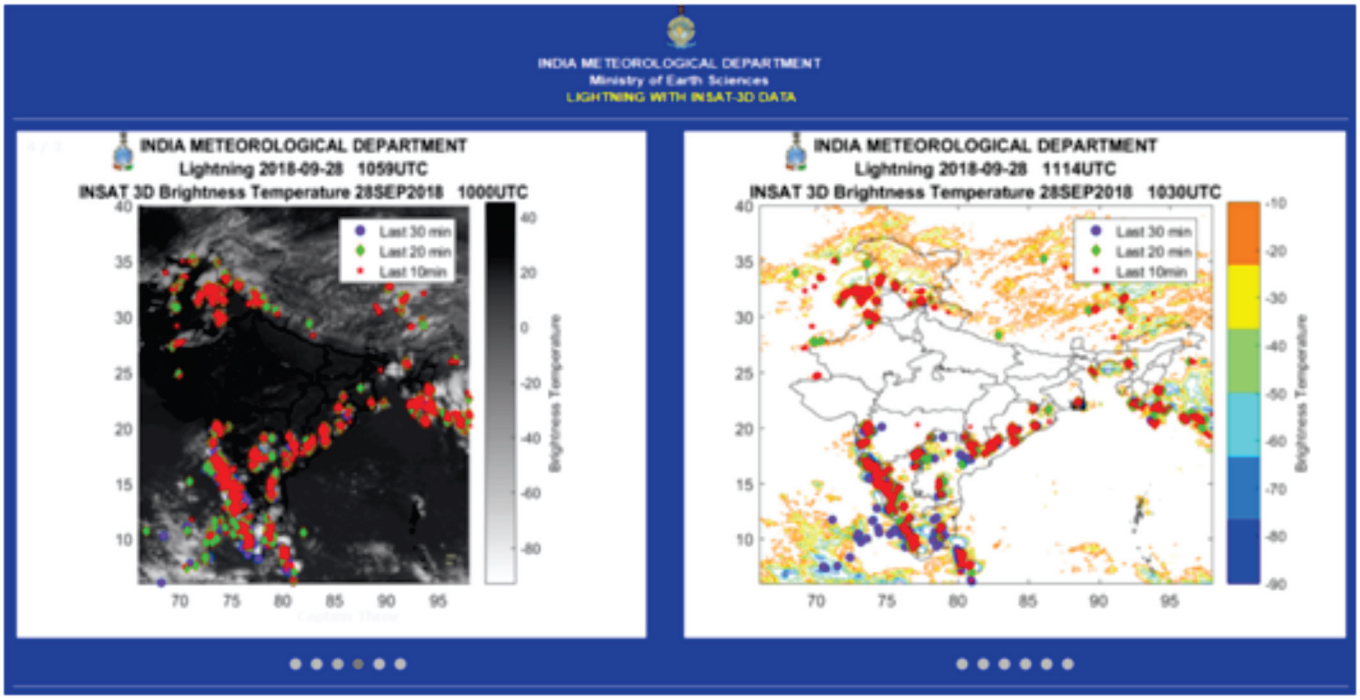


Fig. 2.1 Satellite and lightning merged products developed by IMD

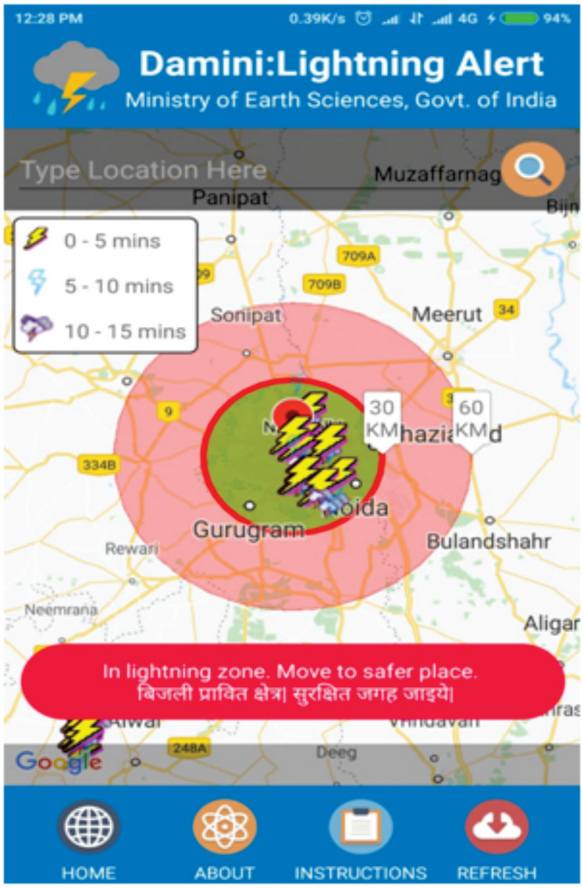


Fig. 2.2 Mobile App developed by IITM MoES to disseminate the information on lightning

2.1.3 Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Phase-IV Cloud Seeding Experiment

The Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) aims at understanding cloud and rainfall processes in tropical clouds. The main goal of the observational campaign of 2018-19 (CAIPEEX Phase-IV) is to provide high quality observations of cloud and precipitation related processes in natural and seeded clouds over the rain shadow region and to investigate suitable conditions under which cloud seeding works. As part of the experiment, IITM has established an observational facility at Solapur, and Tuljapur, Maharashtra. A seeder (Beechcraft C-90) and an instrumented research aircraft (Beechcraft B200) were used for airborne seeding and *in-situ* observations in clouds. A dual polarimetric C-band radar was established at Solapur to guide the aircraft. In total 122 rain gauges were

Fig. 2.3 CAIPEEX Phase-IV Cloud Seeding Experiment

installed in the seeding area for detailed observations of surface rainfall.

As part of the experiment, 240 hours of airborne observations were carried out from Baramati, Aurangabad and Solapur airports and changes in cloud before and after seeding and precipitation development in clouds was observed. High quality observations of aerosols and raindrops were collected in convective clouds. 83 randomized seeding cases were obtained.

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

The third phase of winter fog experiment was conducted at Indira Gandhi International (IGIA) Airport, New Delhi and Hissar during 10th November 2017 – 15th February 2018. New instruments such as Microwave radiometer, Ceilometer and MARGA were installed at IGIA along with permanent sensors such as EC system, radiation sensors, soil temperature and moisture sensors (at 5 levels). Fog forecasts both in terms of Visibility for Delhi and IGIA were generated at 2 km resolution and additionally, for the entire northern region at 4 km resolution including major airports such as Varanasi, Lucknow, Jaipur and Hissar.

2.2 Global and Regional Data Assimilation

2.2.1 GFS Data Assimilation-Forecast System

In order to support numerical prediction systems used operationally for short, medium, extended range and seasonal forecasts and to generate perturbations for their high resolution Global Ensemble Forecast System (GEFS), a new version (V-14/NEMSIO) of T1534L64 GFS system for data assimilation was implemented from June 15th, 2018 onwards. The assimilation system is used in two modes, one in early cycle mode (with 2 hour cut-off) and another in updated cycle mode (with 5 hour cut-off) for all the four cycles viz., 00, 06, 12, 18 UTC, in a day, to prepare the initial conditions for further forecast preparation.

2.2.2 NCMRWF Unified Modelling System (NCUM)

A new improved NCUM assimilation-forecast system with 12 km horizontal resolution and 70 vertical levels has been implemented to produce ten day global forecasts of NCUM based on 00 UTC and 12 UTC analyses. Fig. 2.4 depicts NCUM seamless prediction system implemented in Mihir HPCS with different domains starting from 330 m Delhi Model to coupled model for extended range prediction system. The 4-km regional model (bigger box) covers the BIMSTEC region. The NCUM data assimilation (DA) system uses an intermittent data assimilation cycle, producing analysis at every six hours. The hybrid 4D-Var DA system of NCUM uses flow dependent background errors derived from the high resolution (12-km) ensemble forecasts of NCMRWF Ensemble Prediction System (NEPS).

Improvements have been made in the NCUM DA system for assimilation of newer observations, including Indian satellite observations. INSAT-3D imager and sounder radiance, INSAT-3D atmospheric motion vectors, Megha-Tropiques (MT) SAPHIR radiance and MT-ROSA radio occultation measurements, SCATSAT ocean surface winds are assimilated operationally in the new NCUM DA system in addition to other conventional and satellite observations available from the global observing system. A regional (4-km resolution) NCUM DA system with 4D-Var method was implemented which assimilates Indian Doppler Weather Radar (DWR) radial wind observations, in addition to the various satellite and conventional observations.

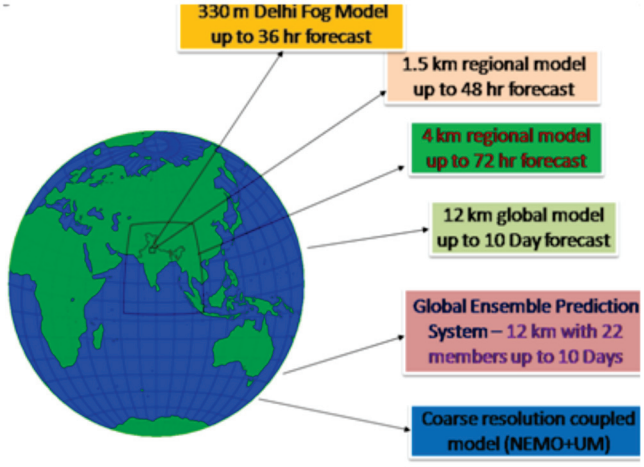


Fig. 2.4 Seamless implementation of NCUM with different domains

The latest version of NCUM global (NCUM-G) model has ENDGame (Even Newer Dynamics for General Atmospheric Modelling of the Environment) dynamic core which incorporates many improvements in the dynamics and physical processes of the model. NCUM-G model has time-step of 5 minutes and runs twice daily (00 and 12 UTC).

The regional version of NCUM (NCUM-R) at 4 km horizontal resolution with explicit rain-processes was also upgraded for a large domain covering BIMSTEC region to the East. Prognostic dust scheme was introduced in NCUM-R with LBCs updated 3-hourly from NCUM-G Delhi fog model (DM) for the visibility and fog forecasting was upgraded with prognostic dust and cloud droplet number tapering changes to realistically simulate the visibility changes due to the model relative humidity variations. An upgraded version of NCMRWF Unified Model (NCUM-R) was also implemented over the Jammu and Kashmir domain at 1.5 km resolution during Sri Amarnathji Yatraduring July-August 2018. Fig. 2.5 shows the accumulated predicted precipitation (cm) for the Sri Amarnathji Yatra domain, from NCUM-R-1.5 km (Upper right), NCUM-R 4km (lower left) and NCUM-G (lower right) valid for 24th September, 2018 against the 25-km resolution rainfall analysis (upper left). NCUM-R-1.5km model could capture the spatial distribution as well as the intensity of

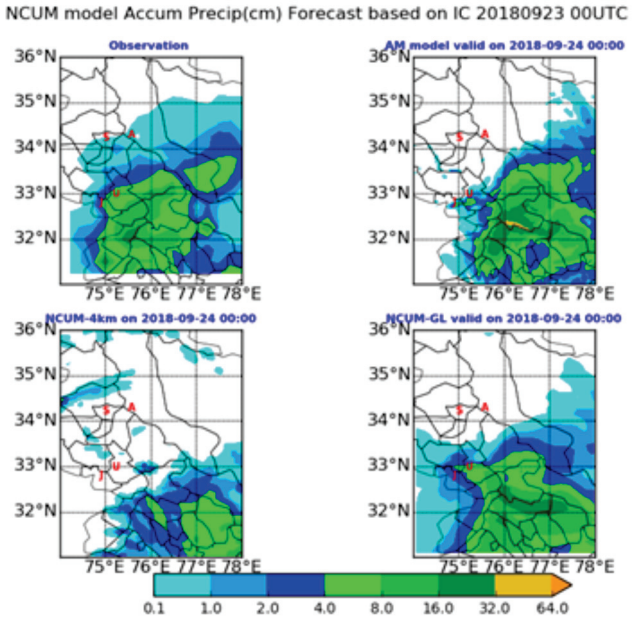


Fig. 2.5 NCUM Precipitation forecast for Shri. Amarnathji Yatra

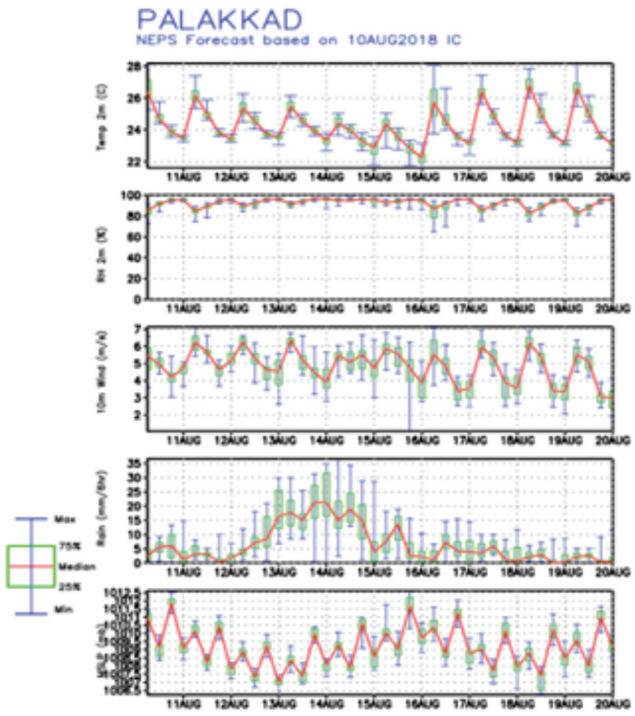


Fig. 2.6 EPSgram for Palakkad district (Kerala), IC:00UTC 10th August 2018

precipitation better when compared to NCUM-G and NCUM-R-4km.

2.2.3 NCMRWF Ensemble Prediction System (NEPS)

The global ensemble prediction system of NCMRWF (NEPS) has been upgraded with a horizontal resolution of 12 km and this is the highest among all the operational global operational weather forecast centres in the world. The upgraded NEPS provides 10-day probabilistic forecasts using 23 ensemble members (22 perturbed + 1 control). The deterministic model running at 12 km resolution is used as the control forecast. Apart from real-time products of NEPS EPSgrams for 660 districts of India are prepared. Fig. 2.6 depicts the EPSgram for Palakkad district of Kerala based on the initial condition of 10th August 2017. It may be noted that the NEPS has successfully predicted very heavy rainfall during 13 – 16 August over the district four days ahead.

A regional ensemble prediction system, NREPS with 4.4 km horizontal resolution and 80 levels in the vertical direction extending up to a height of 38.5 km has also been installed and is being used to analyze extreme weather events. Fig. 2.7 shows observed rainfall, Day 2 ensemble mean rainfall forecast and Day 2 probabilistic rainfall forecast for tropical Cyclone "Titli" valid for 00 UTC 11th October 2018.

2.2.4 Model Verification

The Root Mean Square Error (RMSE) of 850 hPa winds computed against the radiosonde observations for Monsoon (JJAS) 2007 onwards is shown in Fig. 2.8. RMSE over the years shows a steep decreasing trend. The improved forecast performance in the models can be attributed to increased volume of data, improved data assimilation methods and increased model grid resolution in recent years.

Improved skill in predicting the rainfall > 2cm/day and >5cm/day is illustrated in the Fig. 2.9 over Core Monsoon Zone (68º – 88 ºE and 18º – 28ºN). The figure shows Critical Success Index (CSI) computed for NCUM rainfall forecasts over India during six monsoon (JJAS) seasons from 2013 to 2018. The CSI, which is also known as the threat score, measures the fraction of observed events that were correctly predicted. This score varied from 0 to 1. A value of 0 indicates no skill and a value of 1 indicates perfect score. During 2013 to 2018, NCUM model resolution has increased from ~25km (N512) in 2013 to ~12 km (N1024L70) in 2018.

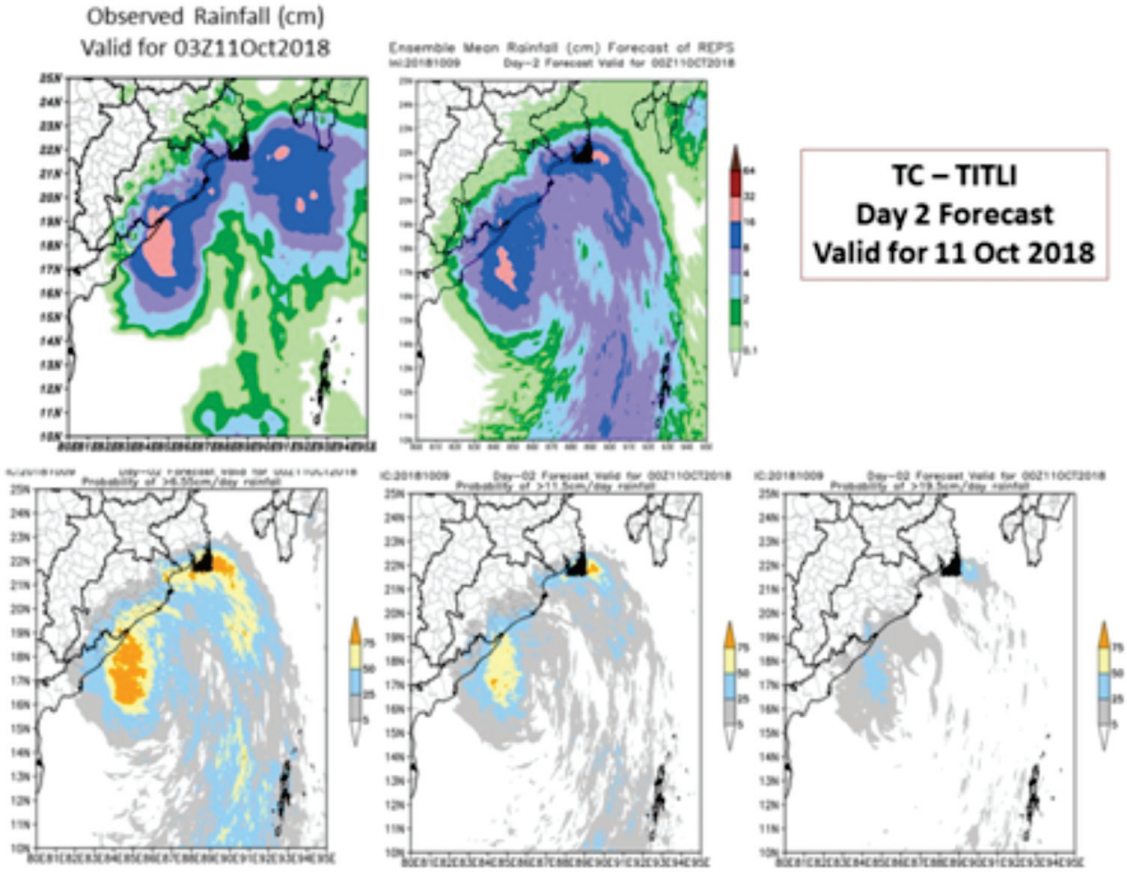


Fig. 2.7 Observed rainfall, Day 2 Ensemble mean forecast and Day 2 probabilistic rainfall forecast valid for 11th Oct. 2018

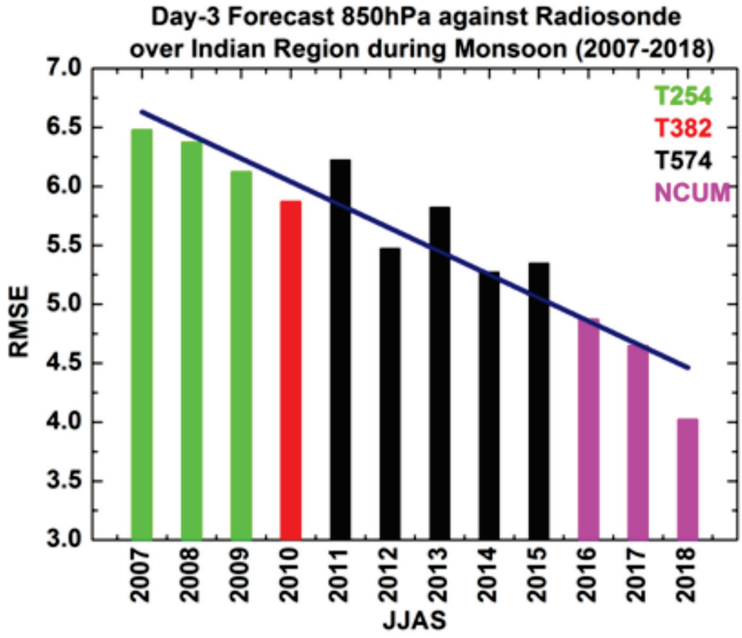


Fig. 2.8 Root Mean Square Error (RMSE) of 850 hPa predicted winds against in-situ observations over Indian region for Monsoon (JJAS) 2007- 2018

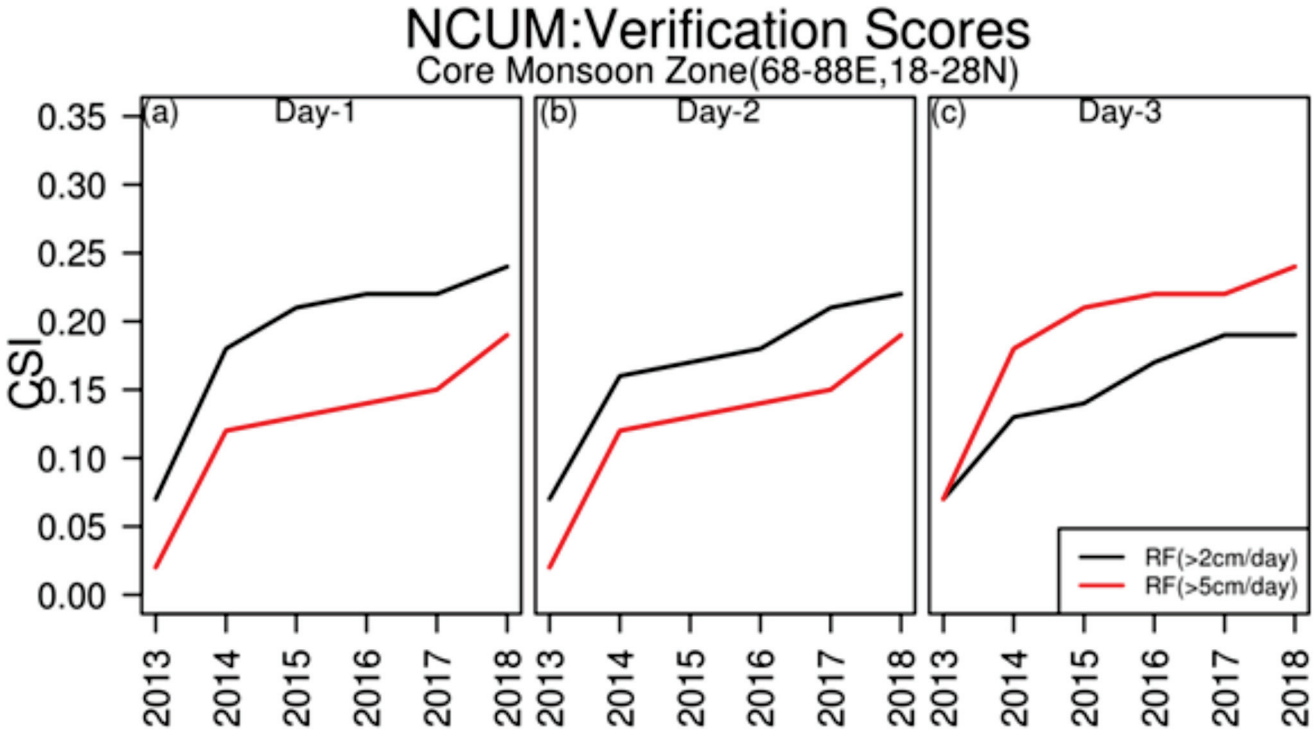


Fig. 2.9 Critical Success Index (CSI) computed for NCUM rainfall forecasts over India during six monsoon (JJAS) seasons from 2013 to 2018.

2.2.5 Coupled Seamless Modeling System

All major weather/climate prediction centres are planning to move towards the Seamless Modeling Framework due to its faster model development cycle. At NCMRWF, NEMO Ocean model based Global Ocean Initialization System based on NEMOVar has been implemented and is producing global ocean analysis in real-time, which is used in the seamless coupled modeling system. NEMOVar can assimilate a variety of in-situ and satellite data as input on daily basis. NEMOVar has 75 layers in the vertical, out of which 35 layers are in top 300 meters. 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 ocean system is 25 km.

2.3 Monsoon Mission

- After the successful completion of Phase-I (2012-2017), the Ministry of Earth Sciences (MoES) launched the Monsoon Mission Phase-II (2017-2020) in September 2017 with emphasis on predicting extremes and development of climatic applications based on monsoon forecasts, especially in the field of agriculture and hydrology, while continuing model development activities. In collaboration with IMD, ICRISAT, work has been initiated on climatic applications in agriculture and hydrology. Various modifications in the CFS source code as suggested by different projects under Monsoon Mission phase-I are being tested for possible improvement in skill and associated processes.
- A Global Ensemble Forecast System (GEFS) for short and medium range prediction at

12 km using 21 members of the model has been developed and is operational since 1st June 2018. The resolution (12 km) of the EPS is the highest among all the operational global operational weather forecast centres in the world. The Ensemble forecasts enhance the weather information being provided by the current models by quantifying the uncertainties in the weather forecasts and generate probabilistic forecasts. The GEFS ensemble and probabilistic forecast have been found to be useful for providing useful guidance for extreme weather and heavy rain episodes. The ensemble forecast also provides the probabilistic guidance for track and intensity of cyclones and depressions.

- In the Fig. 2.10 below, a demonstration of the ensemble forecast for the 10th June heavy rain event over Mumbai is shown. 21 ensemble members and their corresponding forecast is also shown. It is evident that each member slightly differ from other and based on all these, the forecast probability exceeding a threshold (6 cm day-1) is also shown. This figure clearly brings out the fact that the inherent limitation of NWP model in giving a single value forecast of heavy rainfall can be

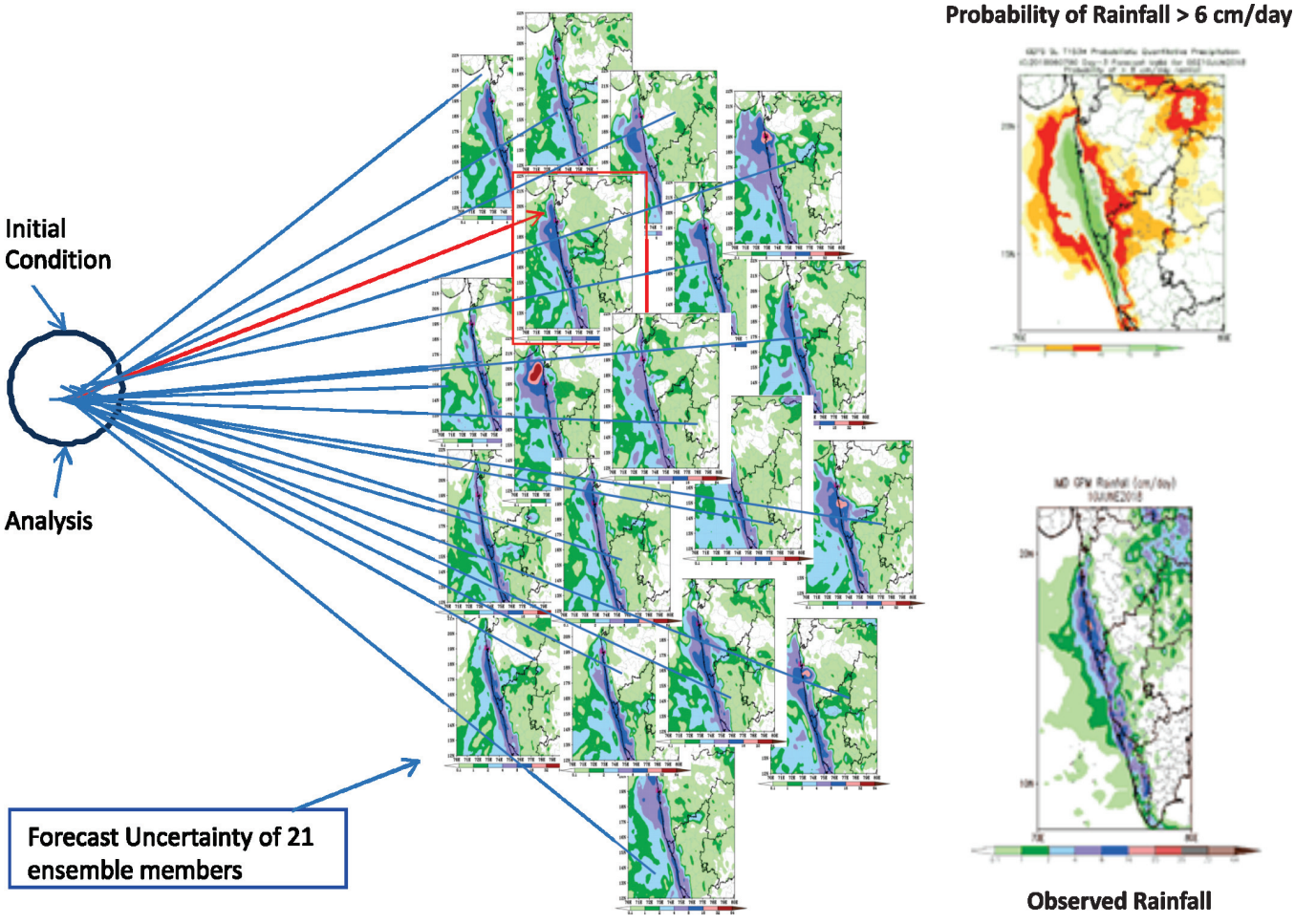


Fig. 2.10 Ensemble forecast based on IITM GEFS with 72 hour lead for the heavy rain and its probability over Mumbai valid for 10th June 2018 with initial condition of 7th June 2018

misleading (as seen in the spread of forecast among 21 members) while the probability of rain exceeding a threshold rain is more meaningful.

- A coupled ocean-atmospheric data assimilation system using Local Ensemble Transform Kalman Filter (LETKF) technique (weakly coupled) has been developed and implemented for CFSv2 at Aaditya HPC.
- The extended range prediction products using the Multi Model Extended Range Prediction System are being regularly produced and used operationally. The MME forecasts are prepared using CFS (T126 & T382) and GFS (T126 & T382). Each resolution of CFS and GFS is having 4 ensemble members. During Monsoon 2018, the model correctly predicted revival of monsoon during July 2018. Application of extended range forecast is being explored for providing block level outlook for next 2-3 weeks for crop management.
- **Seasonal Prediction:** The seasonal forecast runs using the Monsoon Mission Climate Forecast System are being used operationally.

2.4 Centre for Climate Change Research

Long-term climate simulations using the IITM Earth System Model (IITM-ESMv2) with focus on the South Asian Monsoon

Long-term climate simulations are performed using the improved IITM Earth System Model version 2 (IITM-ESMv2), a sequel to the earlier version (IITM-ESMv1), to assess climate variability and change with special focus on the South Asian monsoon. A 300 year spin-up and 500 year preindustrial control (PI Control) simulations are performed with IITM-ESMv2 as part of Coupled Model Inter-comparison Project (CMIP6) experiments. The PI control (present-day) experiment is a multi-century simulation using GHG, aerosols, land-use and land-cover and other forcing corresponding to 1850 (2005) condition. Time-series of global mean air temperature and top-of-atmosphere (TOA) net radiation flux from the 500 year PI Control simulation is shown in Fig. 2.11. The model is successful in simulating pre-industrial climate with a global mean temperature of 14^0 C and top of atmosphere radiation imbalance of about 0.8 Wm^{-2}.

Multi-century simulations corresponding to pre-industrial and present-day conditions show major improvements in capturing key aspects of time-mean atmosphere and ocean large-scale circulation. The improved IITM-ESMv2 is found to be more robust and is able to provide improved simulation of South Asian monsoon and its variability. IITM-ESM is the first climate model from India participating in the Coupled Model Inter-comparison Project phase 6 (CMIP6) experiments for contributing to forthcoming IPCC sixth assessment report (AR6).

Unravelling Climate Change in the Hindu Kush Himalaya

The Coordinated Regional climate Downscaling Experiment (CORDEX) South Asia generated ensemble of high resolution (0.5^0 longitude-latitude resolution) dynamical downscaling of the fifth phase of the CMIP5 general circulation models (GCMs) using regional climate models (RCMs) project significant warming over the Hindu Kush Himalayan region in the future. In the near term (2036–2065), the region is projected to warm by 1.7–2.4^0C for representative concentration pathway 4.5 (RCP4.5) and 2.3–3.2^0C for RCP8.5. In the long

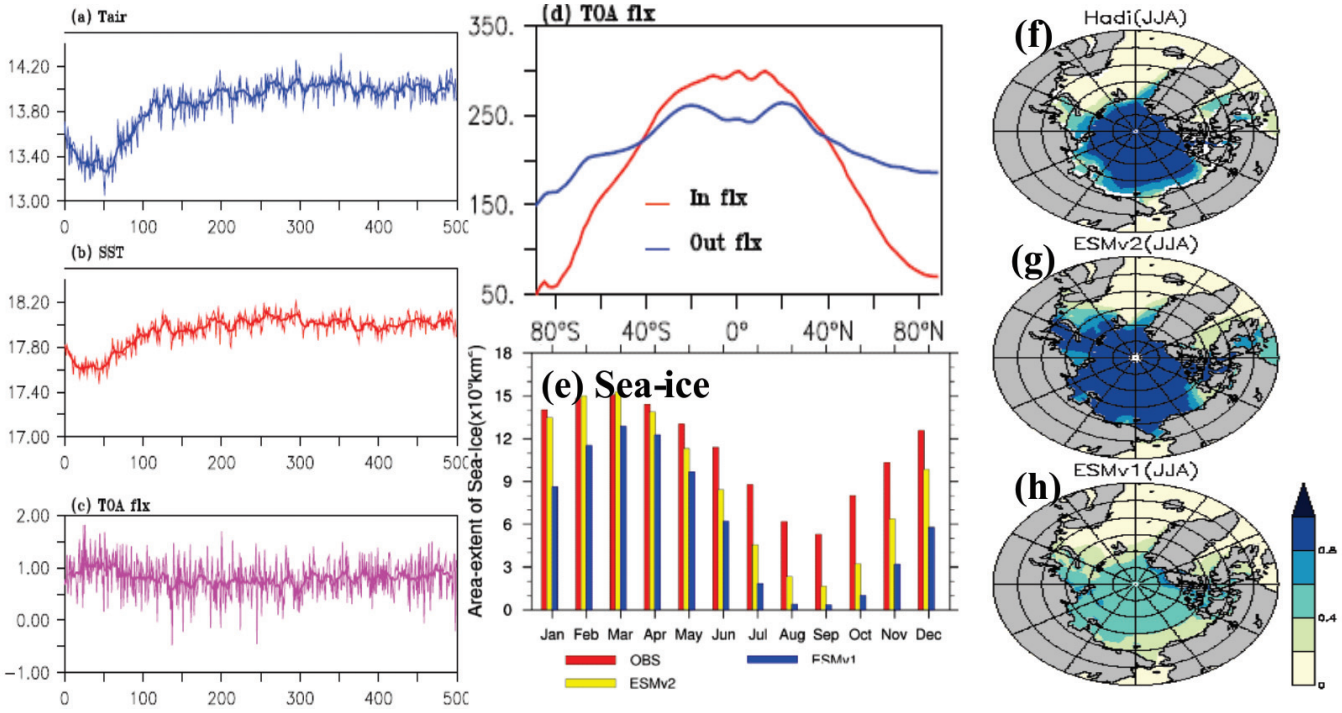


Fig. 2.11 Time-series plots from the Pre-Industrial (PI) control simulation of IITM-ESMv2 of global mean annual mean (a) Surface air-temperature (^{0}C), (b) Sea surface temperature (^{0}C), and (c) Net radiation flux at the top-of-atmosphere (TOA, Wm^{-2}). (d) Latitudinal variation of annual mean zonal mean components of TOA flux (Wm^{-2}) and (e) Seasonal distribution of sea-ice extent (x106 Km^2). Spatial map of mean sea-ice concentration (%) over the Arctic during Northern Summer (June to August) from (f) Observations, (g) ESMv2, and (h) ESMv1.

term (2066–2095), regional warming is projected to be 2.2–3.3^{0}C for RCP4.5 and 4.2–6.5^{0}C for RCP8.5. Monsoon precipitation is projected to increase by 4–12% in the near future and by 4–25% in the long term. Winter precipitation is projected to increase by 7–15% in the Karakoram, but to decline slightly in the Central Himalaya.

2.5 South west Monsoon and North East Monsoon 2018

Southwest Monsoon during June to September

Onset

Based on an indigenously developed statistical model, it was predicted on 18th May, 2018 that monsoon will set in over Kerala on 29th May with a model error of ± 4 days. The forecast for monsoon onset over Kerala for this year was very accurate, as the both predicted and realized date of onset was on 29th May 2018.

Consensus forecast for the 2018 Southwest monsoon season (June to September)

Rainfall over South Asia was issued in 12th Session of the South Asian Climate Outlook Forum (SASCOF-12) from 19th to 20th April at Pune. Summary of the forecast statement was:

Normal rainfall is most likely during the 2018 southwest monsoon season (June – September) over most parts of South Asia. However, above normal rainfall is likely over some areas of east central India and south-eastern parts of the region. Below-normal rainfall is likely over some areas of southern, north-western and north-eastern parts of South Asia.

Long Range Forecasts

The first stage forecast for the season (June- September) rainfall over the country as a whole issued in April was 97% of the LPA with a model error of ± 5%. The forecast issued in 30th May, 2018 remained the same as 97% of the LPA with a model error of ± 4%. The actual season rainfall for the country as a whole was 91% of LPA. Out of the total 36 meteorological subdivisions, 23 subdivisions constituting 68% of the total area of the country received normal season rainfall, 1 subdivisions received excess rainfall (1% of the total area), and 12 subdivisions (31% of the total area) received deficient season rainfall.

The forecast for seasonal rainfall for 4 broad homogeneous regions namely North-West India, Central India, South Peninsula and North-East India was 100%, 99%, 95% and 93% of LPA respectively, all with a model error of ± 8%. The actual rainfall over these 4 broad homogeneous regions was 98%, 93%, 98% and 76% of respective LPA. The monthly rainfall over the country as a whole was 95% of LPA in June, 94% of LPA in July, 92% of LPA in August and 76% of LPA in September.

The forecasts for the monthly rainfall over the country as a whole for the months of July & August issued in June were 101% & 94% respectively with a model error of ± 9%. The actual monthly rainfalls during July and August were 94% & 92% of LPA respectively. Thus the forecast of July & August rainfall was accurate.

The forecast for the second half of the monsoon season (August–September) for the country as a whole was 95% with a model error of 8% of LPA against the actual rainfall of 86% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole was a slight overestimate to the actual rainfall.

The Table 1 below gives the summary of the verification of the long range forecasts issued for the 2018 Southwest monsoon. Fig. 2.12 shows the per cent departure rainfall for 36

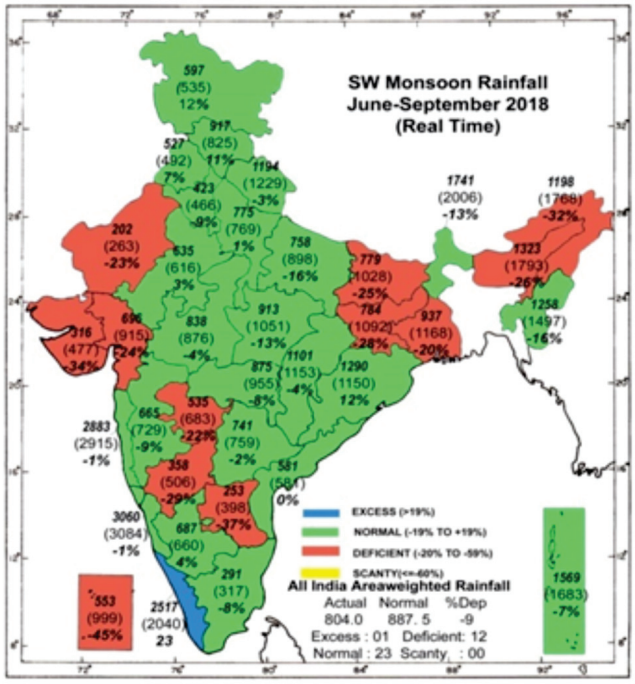


Fig. 2.12 Subdivision-wise southwest monsoon rainfall during June to September, 2018

meteorological sub divisions during the 2018 southwest monsoon season.

Forecast based on the Monsoon Mission Coupled Forecasting System (MMCFS)

The MMCFS (with spectral resolution of T382 ~38 km in the horizontal) has been used to generate dynamical seasonal forecast for the 2018 South-West Monsoon season rainfall. The model predicted that the 2018 monsoon season (June to September) averaged over the country as a whole is likely to be 99% •±5% and 102 ± 4% of long period model average (LPMA) using the April and May initial conditions respectively.

Table 1: Verification of long-range forecast southwest monsoon 2018

Region	Period	Forecast (% of LPA)	Actual Rainfall (% of LPA)		
		16th April	30th June	3rd August	
All India	June to September	97 ± 5	97 ± 4		91
Northwest India	June to September		100 ± 8		98
Central India	June to September		99 ± 8		93
Northeast India	June to September		93 ± 8		76
South Peninsula	June to September		95 ± 8		98
All India	July		101 ± 9		94
All India	August		94 ± 9	96 ± 9	92
All India	August to September			95 ± 8	86

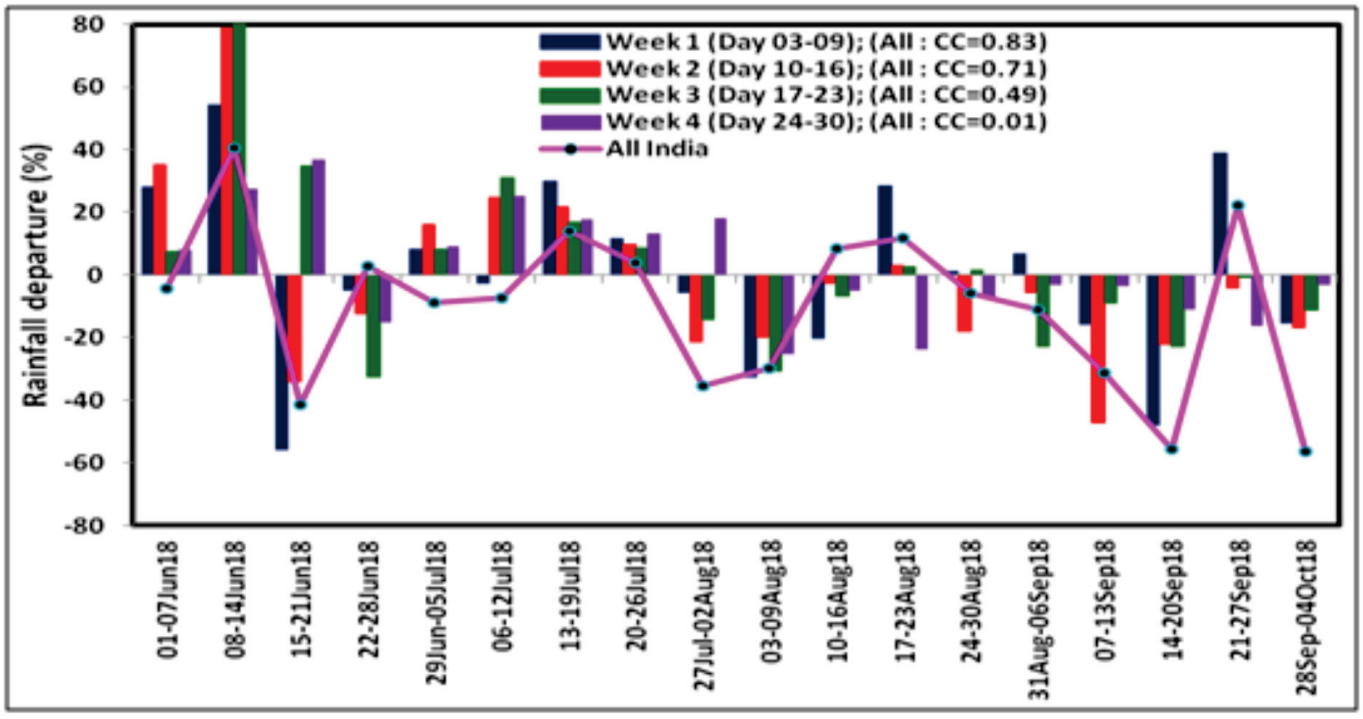


Fig. 2.13 Performance of ERF forecasts for 4 weeks during monsoon season 2018

Extended Range Forecasts

As shown in Fig. 2.13, the Extended Range Forecasts showed useful skill upto three weeks on all India level. On smaller spatial scales (homogeneous regions and met subdivision levels) the forecast shows useful skill up to two weeks. On met subdivision level the category forecasts up to two weeks are being used for agro-advisory purpose. The transition from normal monsoon condition to weak monsoon condition in week 2 forecast valid for 27th July to 2nd August, 2018 based on the initial condition of 18th July, 2018 was well captured in the model.

2.6 Northeast Monsoon

The 2018 forecast of Northeast monsoon rainfall over South Peninsula was released on 29th September. The summary of forecasts is given below:

IMD's operational forecast for the 2018

Northeast monsoon season (October-December) rainfall over south Peninsula (Tamil Nadu, Coastal Andhra Pradesh, Rayalaseema, Kerala and South Interior Karnataka) is most likely to be normal (89% -111% of long period average (LPA)) with a tendency to be in the positive side of the normal. The LPA of the North-east monsoon seasonal rainfall over the south Peninsula for the base period, 1951-2000 is 332.1 mm.

The 2018 Northeast monsoon seasonal rainfall over Tamil Nadu is most likely to be above normal (e" 112% of LPA). The long period average (LPA) of the Northeast monsoon seasonal rainfall over Tamil Nadu for the base period, 1951-2000 is 438.2 mm.

2.7 Tropical Cyclone Monitoring and Prediction

There were 13 cyclonic disturbances (depressions and cyclones) over the north Indian Ocean (NIO) and adjoining land regions during 2018 (upto November) against the long period average (LPA) of 12 disturbances per year based on data of 1961-2017.

Out of 13 systems, 6 intensified into tropical cyclones against the normal frequency of 4 cyclones per year over north Indian Ocean (NIO) based on LPA. Occurrence of six cyclones in a year last occurred in 1998. The cyclones formed in 2018 are:

i. Cyclonic Storm SAGAR over Arabian Sea **(16-21 May)**

ii. Extremely Severe Cyclonic Storm MEKUNU over Arabian Sea **(21-27 May)**

iii. Cyclonic Storm Daye over Bay of Bengal and adjoining Myanmar **(19-22 September)**

iv. Very Severe Cyclonic Storm TITLI over Bay of Bengal **(08-13 October)**

v. Very Severe Cyclonic StormLuban over Arabian Sea **(06-15 October)**

vi. Severe Cyclonic StormGaja over Bay of Bengal **(10-19 November)**

- Out of the six cyclones, three cyclones crossed the Indian coast during 2018 against the normal of about 2 such cyclones per year.
- Cyclone Sagar was the first cyclone to cross coast to the west of longitude 45^0E during satellite era (since 1965).
- In a rarest of rare occurrence, cyclones Luban and Titli developed simultaneously over the Arabian Sea and Bay of Bengal. Such type of simultaneous occurrence of severe cyclones occurred in 1977.
- Gaja had an anticlockwise looping track during it's movement over the BoB and it intensified just before landfall. First such looping track over Bay of Bengal occurred in 1996.

Brief summaries of the two cyclones affecting India are given below:

VSCS Titli: Very Severe Cyclonic Storm (VSCS) Titli originated from a low pressure area (LPA) which formed over southeast Bay of Bengal (BoB) and adjoining north Andaman Sea in the morning (0830 IST) of 7th October. It intensified into a very severe cyclonic storm at 1130 IST of 10th. It crossed north Andhra Pradesh and south Odisha coasts near Palasa (18.8^0N/84.5^0E) to the southwest of Gopalpur during 0430-0530 IST of 11th as a VSCS with the wind speed of 140-150 gusting to 165 kmph. The landfall point forecast errors were about 15.6, 15.6 and 46.7 km for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 115.4 km respectively. The track forecast errors were about 98, 114 and 113 km for 24, 48 and 72 hrs lead period against past five year (2013-17)

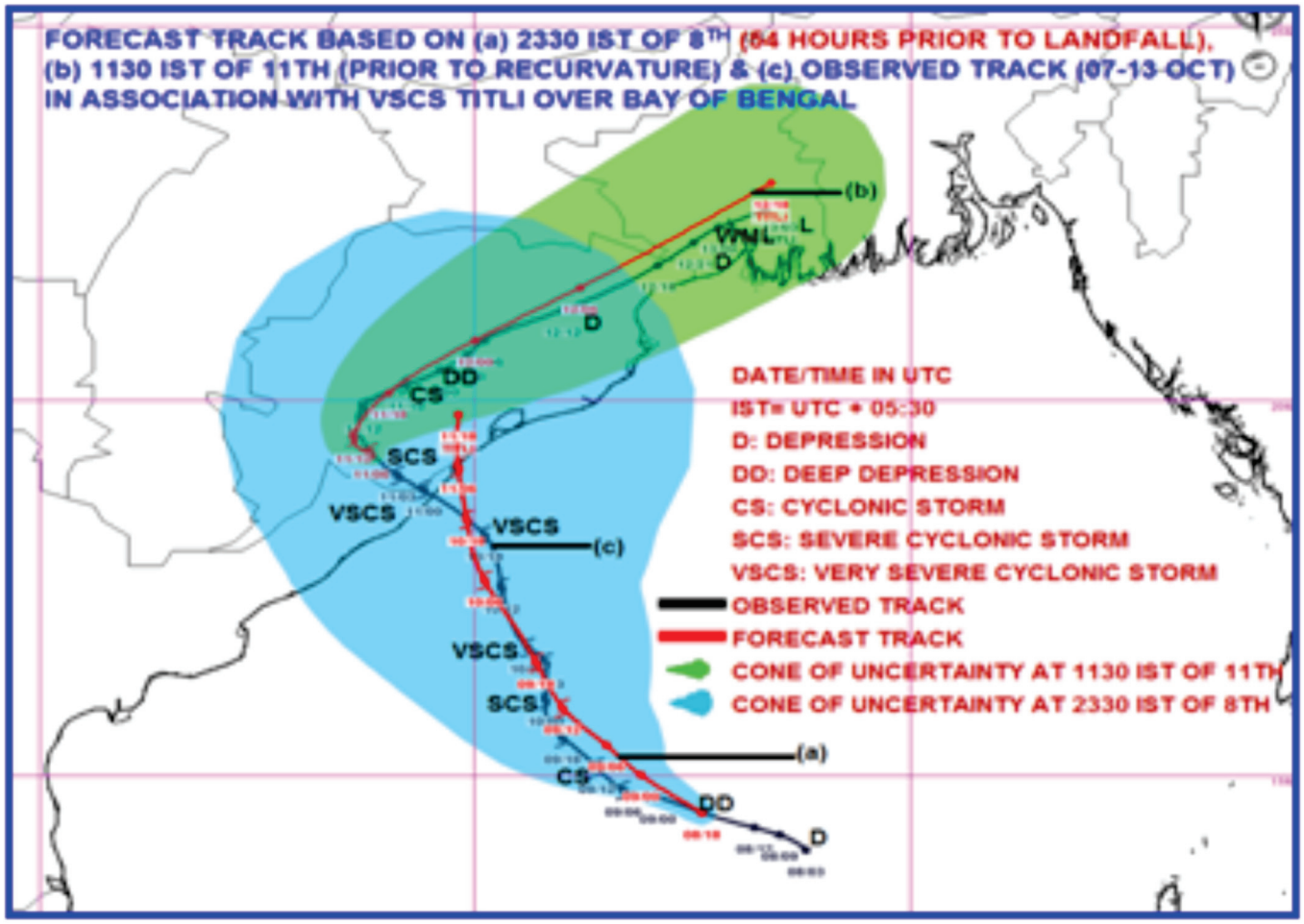


Fig. 2.14 Observed track of VSCS Titli and forecast based on 1800 UTC of 8th and 0600 UTC of 11th (prior to recurvature)

average errors of 93, 144 and 201 km respectively. Typical forecast tracks depicting the accuracy in track are presented in Fig. 2.14.

SCS Gaja : It developed from the low pressure area that developed over Gulf Of Thailand and adjoining Malay Peninsula on 8th November. It crossed Tamil Nadu and Puducherry coasts between Nagapattinam and Vedaranniyam near latitude 10.45^{0}N and longitude 79.8^{0}E during 0030-0230 hours IST of 16th with the wind speed of 110-120 gusting to 130 kmph. With the formation of depression at 0830 IST of 10th November, India Meteorological Department (IMD) predicted it to intensify into a severe cyclonic storm. Also it predicted that it would move west-northwestwards during next 48 hours and then west-southwestwards towards north Tamil Nadu – south Andhra Pradesh coasts. The landfall over Tamil Nadu coast during evening hours of 15th (around 0800 UTC) was predicted on 11th early morning (0000 UTC) more than 4 days in advance. At 1430 IST of 12th November, it further indicated the landfall of the cyclonic storm over Tamil Nadu coast between Cuddalore and Pamban, around Nagapattinam. Thus the landfall point forecast error has been about 31, 43, 70 and 73 km for 24, 48, 72 and 96 hrs lead period respectively. Accordingly, the heavy rainfall, wind and storm surge over Tamil Nadu and Puducherry was predicted by IMD 3

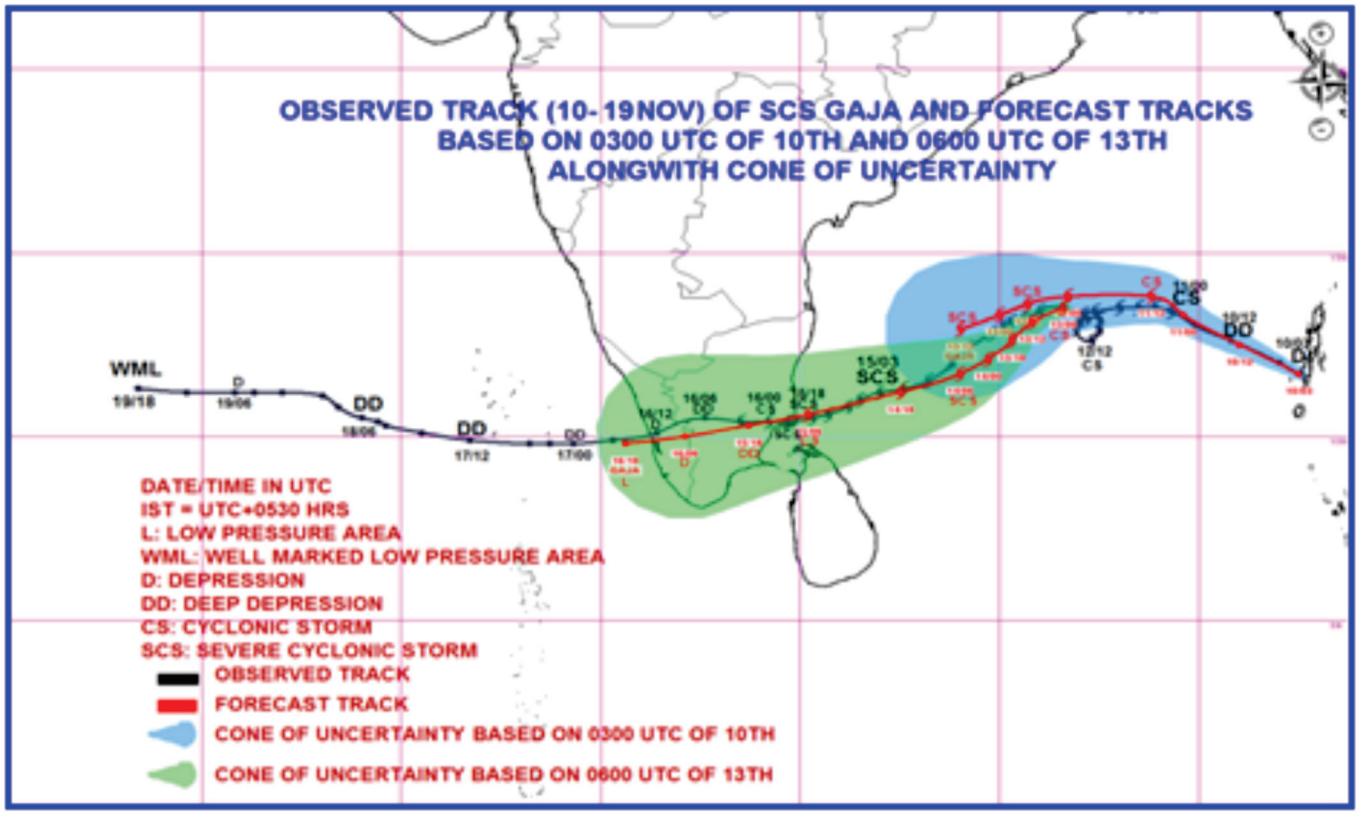


Fig. 2.15 Predictdd and observed tracks of SCS, Gaja demonstrating accurate track and landfall point forecast.

days in advance. Typical forecast tracks demonstrating the accuracy in track are presented in Fig. 2.15.

The World Meteorological Organization (WMO) appreciated IMD for tropical cyclone advisory services during Cyclonic Storm SAGAR over Arabian Sea (16-21 May), Extremely Severe Cyclonic Storm MEKUNU over Arabian Sea (21-27 May), VSCS Luban (06-15 October) and VSCS Titli (08-13 October) which helped minimize the impact and saved many lives.

Cyclone Warning Centre Thiruvananthapuram

IMD has the mandate to monitor and issue warnings regarding tropical cyclones over the north Indian Ocean. A new Cyclone Warning Centre has been established in Thiruvananthapuram with effect from Oct 2018. The centre was inaugurated by the Secretary, MoES on 23rd October 2018.

2.8 Meteorological Services

2.8.1 Metropolitan Air Quality and Weather Services

SAFAR-AQMS at highly urbanized location in Delhi: Dr. Harsh Vardhan, Hon'ble Union Minister of S&T, Earth Sciences, Environment, Forecast and Climate Change inaugurated an air quality monitoring and forecasting station for the benefit of the citizens of one of the most crowded locations of Delhi in Chandni Chowk (Fig. 2.16) near Town Hall which will also monitor PM1, Hg and UV-radiations, in addition to routine air pollutants and weather parameters.

Air Quality Early Warning System for Delhi: A new early warning system of air quality in Delhi developed in collaboration with National

Fig. 2.16 Dr. Harsh Vardhan unveiling the air quality monitoring and forecasting station at Chandni Chowk in New Delhi.

Center for Atmospheric Research (NCAR), USA was launched on 15th October 2018 (Fig. 2.17). The system will assimilate data from around 36 monitoring stations run by the Central Pollution

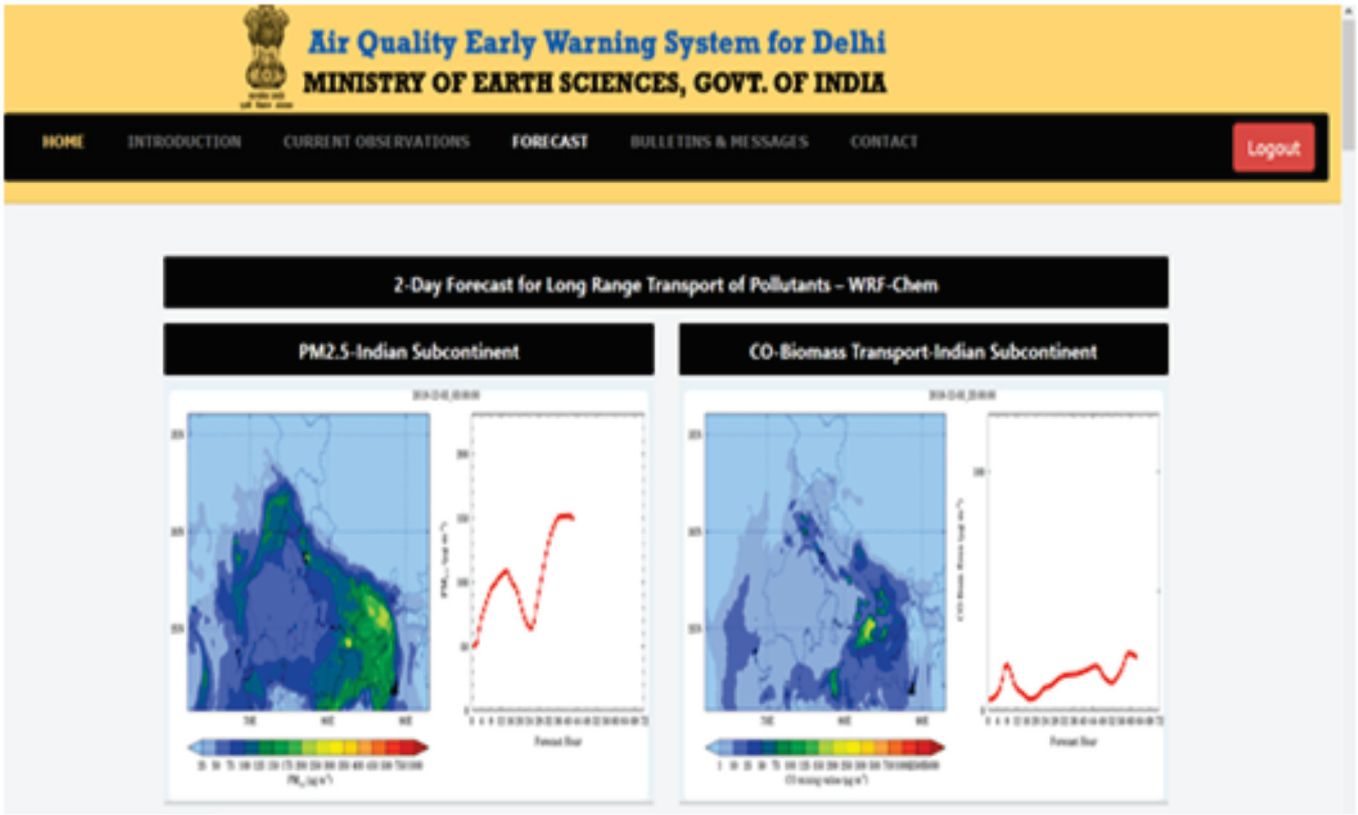


Fig. 2.17 The Website of Air Quality Early Warning System for Delhi developed by MoES

Control Board (CPCB), Delhi Pollution Control Committee (DPCC), and System of Air Quality and Weather Forecasting and Research (SAFAR). Information from satellites on stubble burning in northwest India or dust storms along with the prevalent meteorological factors will help improve the initial conditions of the dynamical chemistry transport model thereby resulting in accurate prediction of air-quality. This newly developed system will enable the Graded Response Action Planto be implemented in advance.

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

At present 658 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 to help farmers to cope with climate risks and uncertainties and effectively use seasonal forecasts. At present, agromet advisories are disseminated under PPP mode and through Kisan Portal to about 40 million farmers. Farmer's awareness programmes were organised at 23 Agromet Field Units to popularise the services across the country during the year. During monsoon 2018, Experimental Block level agromet advisory services have been started from existing AMFUs in 200 blocks of 50 districts.

To start All India block level Agromet Advisory services to farmers, IMD and ICAR are jointly extending the AAS network for establishment of District Agromet Units (DAMUs) in KVK premises. Each DAMU will be equipped with one Subject Matter Specialist (Agro meteorology), one Observer, AWS and expert panel to help preparation of block level weather forecast based crop specific advisory. DAMU has started functioning in 10 KVKs in Bihar. Training on block level advisory preparation has been also organised for SMS for 10 KVKs.

2.8.3 Hydro-meteorological Services

The necessary technical and operational support was provided to various Central/State Govt. organizations and other agencies in the field of Hydromet design, flood forecasting rainfall monitoring for water management and agricultural planning purposes etc. Real-time daily rainfall statistics is made operational for 681 districts, 36 states and UTs, 36 met sub divisions, four homogeneous regions and country as a whole during the whole year. Preparation of district wise rainfall statistics is enhanced to 681 districts from earlier 660 districts in the country. 189 new stations were included in District-wise Rainfall Monitoring System (DRMS). The "South Asia Flash Flood Guidance System" under WMO was also implemented on experimental basis in IMD for the South Asian countries viz., India, Sri Lanka, Bangladesh, Nepal and Bhutan.

2.8.4 Services to Power Sector

India Meteorological Department (IMD) and POSOCO have launched a web portal dedicated exclusively to energy sector. A Reference Document on Weather Portal for Energy Sector was launched by Hon'ble Minister of State (IC), Ministry of Power and New & Renewable Energy, Shri. RK Singh on 29th August, 2018.

As the demand of power consumption changes due to change in weather conditions, the forecasts of weather including temperature, wind and rainfall helped in better load assessment including generation and distribution

of power.

2.8.5 Advances in Heat Wave Warning

IMD has upgraded its heat wave warning services with the seasonal outlook of temperature, extended range forecast (up to two weeks) of maximum and minimum temperature and district level heat wave warning (upto five days). IMD is also working with different states for implementation of Heat action plan at states and cities. To keep all heat wave related products, a dedicated page has been created in IMD website. The major heat wave epochs over India were during 22-29 May, 2018 over central & northwest India and during 16-20 June, 2018 over East India. The warning for the same was given 3 to 5 days in advance (Fig. 2.18).

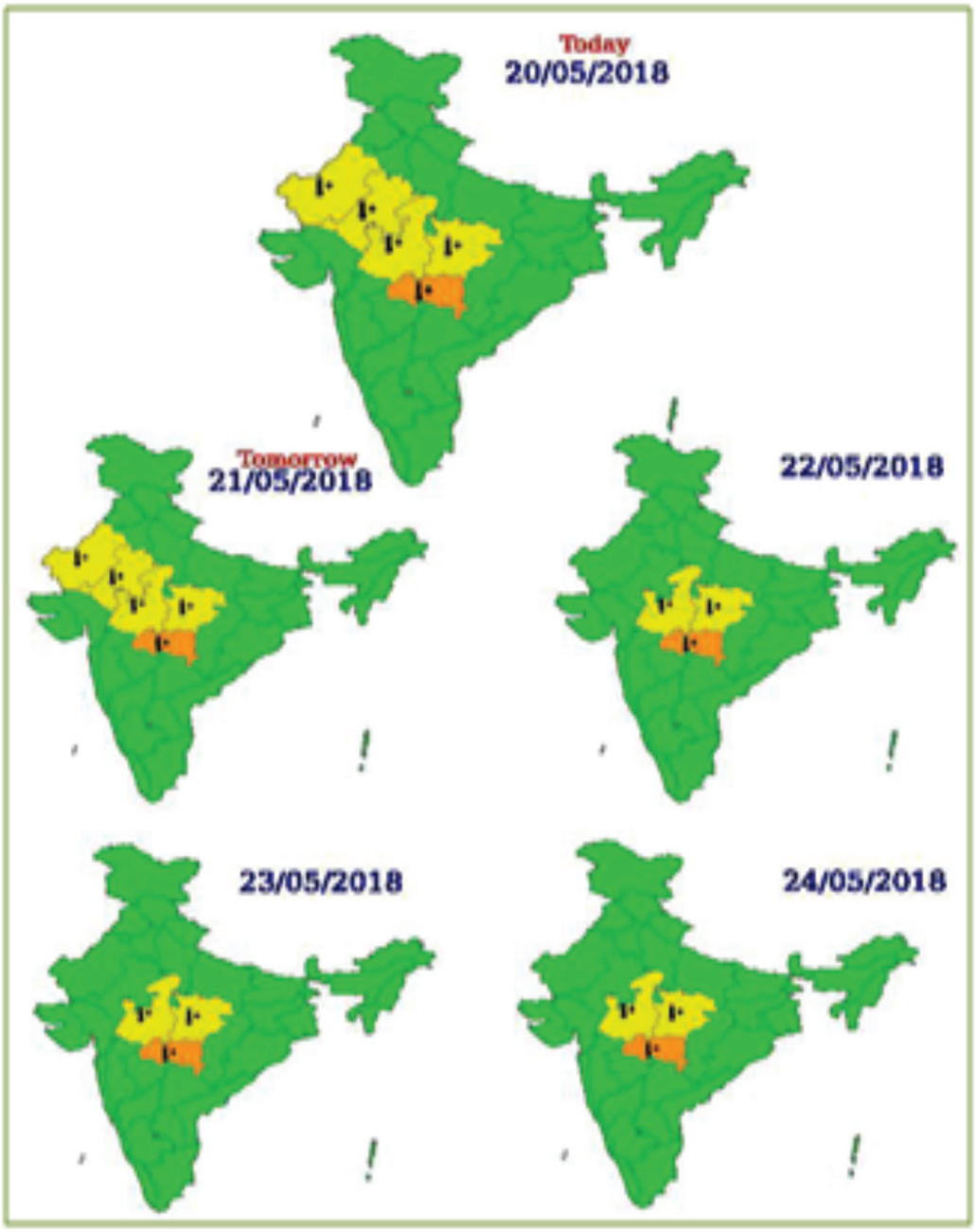


Fig 2.18 Five day advance warnings of Heat Wave during 20-25 May 2018

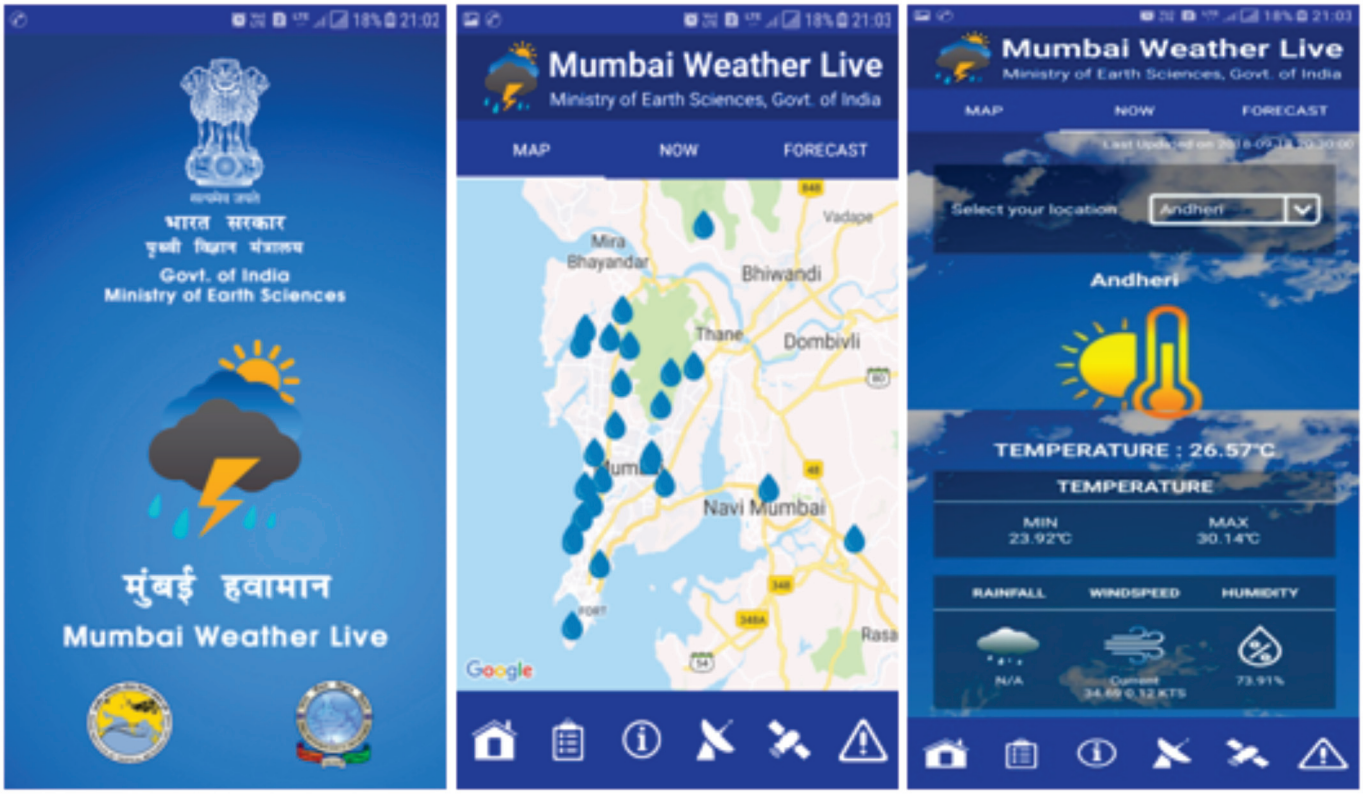


Fig. 2.19 Screenshots of the Mumbai Weather Live (MWL) Mobile App.

2.9 Outreach and Dissemination

A Mumbai Weather Live Mobile App has been developed by collating ground measurements recorded by IMD and the Municipal Corporation of Greater Mumbai, observations from SAFAR-Mumbai, to provide live location specific information on rainfall. Currently, the app covers about 100 sites spread across Mumbai city, suburban areas, Navi Mumbai and surrounding areas.

India Meteorological Department in collabora-tion with MapmyIndia has developed a Web Application and Mobile App for providing weather forecast and warning for the enroute city forecasts for Shri Amarnathji Yatra and Chardham Yatra pilgrimage.

■

CHAPTER 3 Ocean Services, Modelling Application, Resources And Technology (O-SMART)

The overarching objectives of the scheme O-SMART are: (i) provide a suite of Ocean Information services, (ii) develop technology for sustainable harnessing the ocean living and non-living resources, (iii) promote front-ranking research in Ocean Science and (iv) conduct scientific survey of oceans. The ocean advisory services and technologies being rendered and developed under the scheme play a pivotal role in the development activities over dozen sectors, working in the marine environment including the coastal states of India, contributing significantly to the GDP. The scheme is implemented primarily by five institutes of the Ministry under the overall supervision and guidance of the program office at the Ministry. Some of the major achievements during the year are as detailed below:

3.1 Ocean Sciences and Services

3.1.1 Tsunami Services

Towards improving the Tsunami services, a global model was configured for numerical simulation of Tsunamis in the event of earthquakes in the global oceans (TUNAMI-FF). This model simulates all stages of a tsunami from its origin, including propagation in the ocean and arrival times at different coasts and wave amplitudes at beach (~ 1 m water depth). This model has been made operational for the prediction of Tsunami in real time in the global oceans. At present, this model takes 15-20 minutes to complete a real-time prediction of a tsunami.

An earthquake of magnitude 7.5 M occurred at Minahassa Peninsula, Sulawesi on

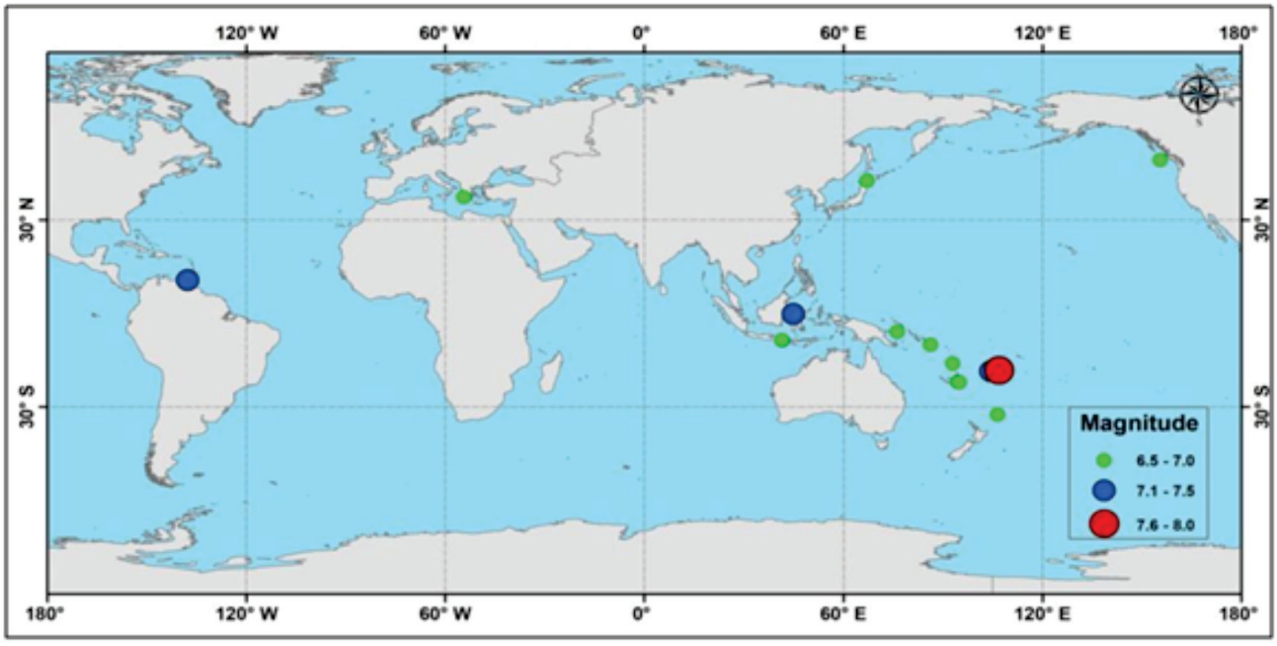


Fig. 3.1 Location map of earthquakes of magnitude ≥ 6.5 monitored at ITEWC during 2018-19

28th September 2018 15:32 IST. The event epicenter was 0.19^0 S 119.89^0 E at a focal depth of 10 km. The Indian Tsunami Early Warning Centre (ITEWC) issued a bulletin with an evaluation of No Threat to India. Even though the earthquake happened on land part with strike slip faulting, a major tsunamiwas generated causing death of about 1000 people in Palu and surrounding regions in Indonesia.

The ITEWC monitored 37 earthquakes of magnitude ≥ 6.5 during the period 01st January to 31st December 2018. (Fig. 3.1) For these earthquakes, ITEWC disseminated the bulletins as per standard operating procedure to its regional and national stake holders.

3.1.2 Customization of storm surge model for real-time tsunami inundation modeling

A finite element based **ADvanced CIRCulation Model (ADCIRC)** model has been customized for real-time tsunami inundation modeling model which was successfully tested using the 2004 Boxing Day tsunami event. The model was used during the recent Palu tsunami event to compute wave arrival time and inundation extents and the simulations were in agreement with the published news reports. The modeled results were validated against tide gauge station data at Pantolan which were found to be in good agreement.

3.1.3 Real-time Storm Surge Warning Service

ESSO-INCOIS successfully had monitored and issued storm surge bulletins to India Meteorological Department (IMD) during Very Severe Cyclonic Storm 'Titli' and cyclone 'Luban' using an enhanced decision support system. The predicted maximum storm surge was about 2 m and the maximum inundation was about 300 m during 'Luban'.

3.2 Marine Fisheries Advisory Services (MFAS)

3.2.1 Potential Fishing Zones (PFZ) and Tuna PFZ Advisories

INCOIS continued to provide its flagship service of Potential Fishing Zone (PFZ) advisories, which contains information on the regions of fish availability. PFZ advisories are generated based on the satellite data on Sea Surface Temperature (SST) and ocean colour along with other environmental parameters such as water clarity and sea level. There was a remarkable growth in

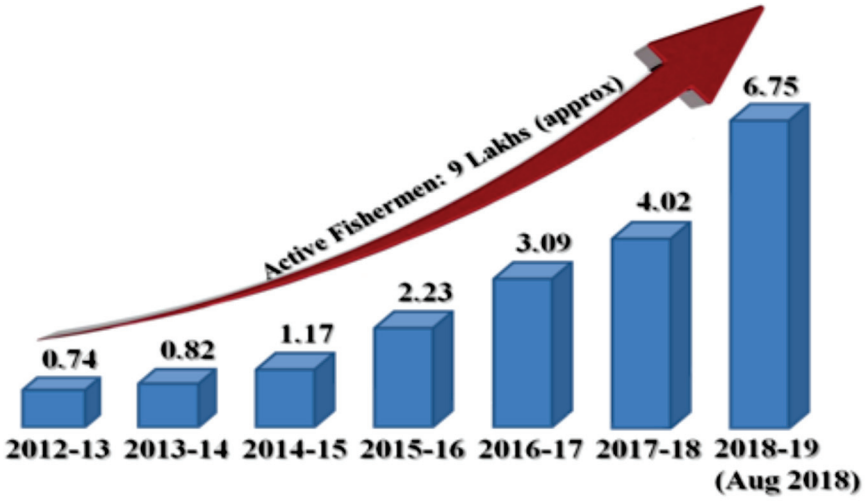


Fig. 3.2 Growth of INCOIS MFAS user-base over the years (numbers in Lakhs).

user community during 2018 as seen in Fig 3.2.

The advisories are being disseminated in smart map and text form on daily basis, depending on satellite data availability, except fishing-ban period and during adverse sea-state. During the period January 1 - December 31, 2018, multilingual Potential Fishing Zones (PFZ) advisories were made available on 299 days. In addition, during the FY 2017-18, INCOIS provided 220 Tuna advisories also, that included information on the maximum fishing depth.

3.2.2 Species specific research efforts

The Indian Oil sardine (IOS, Sardinellalongiceps) stock off southwest coast of India has been identified as research focus under the technical cooperation on 'Development of Predictive Capabilities on Marine Fisheries and HABS' between National Ocean and Atmospheric Administration (NOAA), USA and Ministry of Earth Sciences (MoES). Progress of the collaborative efforts and the details of jointly developed predictive model were presented during the Indo-US Science Colloquium held at NIO, Goa during 11-13 June 2018. This was followed by the bilateral workshop held at NCAOR, Goa during 14-15 June, 2018. The workshop focused on development of short-term IOS PFZ forecast and validation. Observational cruises jointly conducted by INCOIS and CMLRE, onboard FORV Sagar Sampada, have been agreed upon. For this, training for MoES scientists in the USA (CalCOFI and NOAA ships) has been identified as immediate requirement.

3.3 Ocean State Forecast (OSF) Services

INCOIS continued to provide a range of services on state of the ocean for a wide spectrum of users. INCOIS issued specific localized alerts on the occurrence of perigean

Fig. 3.3 Participants of NOAA-MoES bilateral workshop-2018 on 'Development of Predictive Capabilities on Marine Fisheries and HABS'

spring tides and associated wave/current features for the coasts of Kerala, Goa and West Bengal during 3-5 January 2018. INCOIS also provided early warning, during April 20-24, 2018, on the swell surges and rough sea conditions along the Indian coastline, especially west coast and Island union territories. These swell surges are caused by long period swells originating from the distant southern Indian Ocean. The life and livelihoods of the west coastal and Island coast parts could be saved due to these timely warnings. A typical plot of peak wave period at 02:30 IST on 22nd April 2018 and the damage caused by this event is depicted through a sample photo in Fig. 3.4.

In an effort to reach out to users in the open ocean directly through the satellite, INCOIS successfully tested the programme in collaboration with ISRO through its NavIC satellite during Jan 04-06, 2018. The test messages to the boats in the deep ocean were reported to be received without fail by the end user/fisher folks in the boats. The application will be particularly useful to users in the open sea with no other available means of information. A training on "INCOIS services through the ISRO satellite NAVIC" was also imparted to the Fisheries Department officials (trainers) and selected representative fisher-folks from all the 14 districts of Kerala on 31st January 2018 at Thiruvananthapuram.

Dissemination of OSF services through All India Radio stations (7 stations in Tamil Nadu) was inaugurated 18th June, 2018 at Puducherry. The forecasts are being sent on daily operational basis to the AIR offices at Chennai, Tiruchirapalli, Karaikal, Puducherry, Nagarcoil, Tirunelveli, Tuticorin, for its broadcast.

A number of Electronic Display Boards (EDBs) installed at several fishing harbours along the coast are the most popular means by which the ocean information/advisories/forecasts from

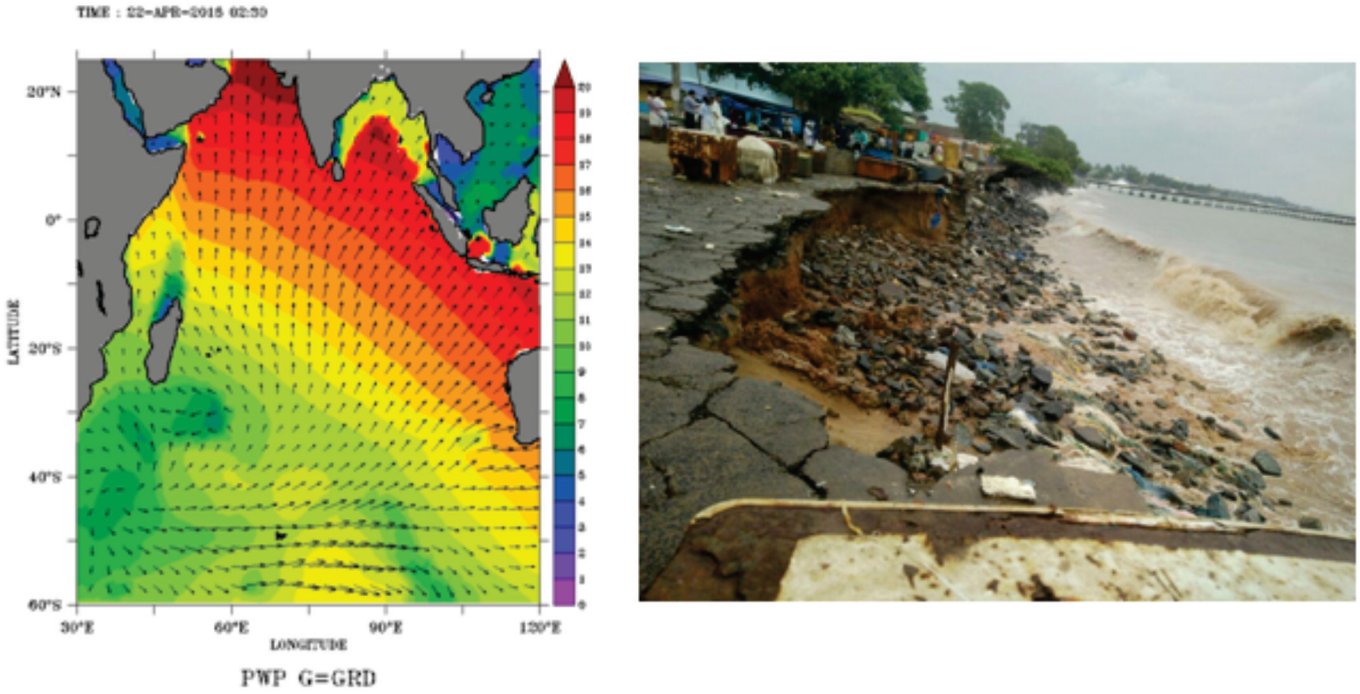
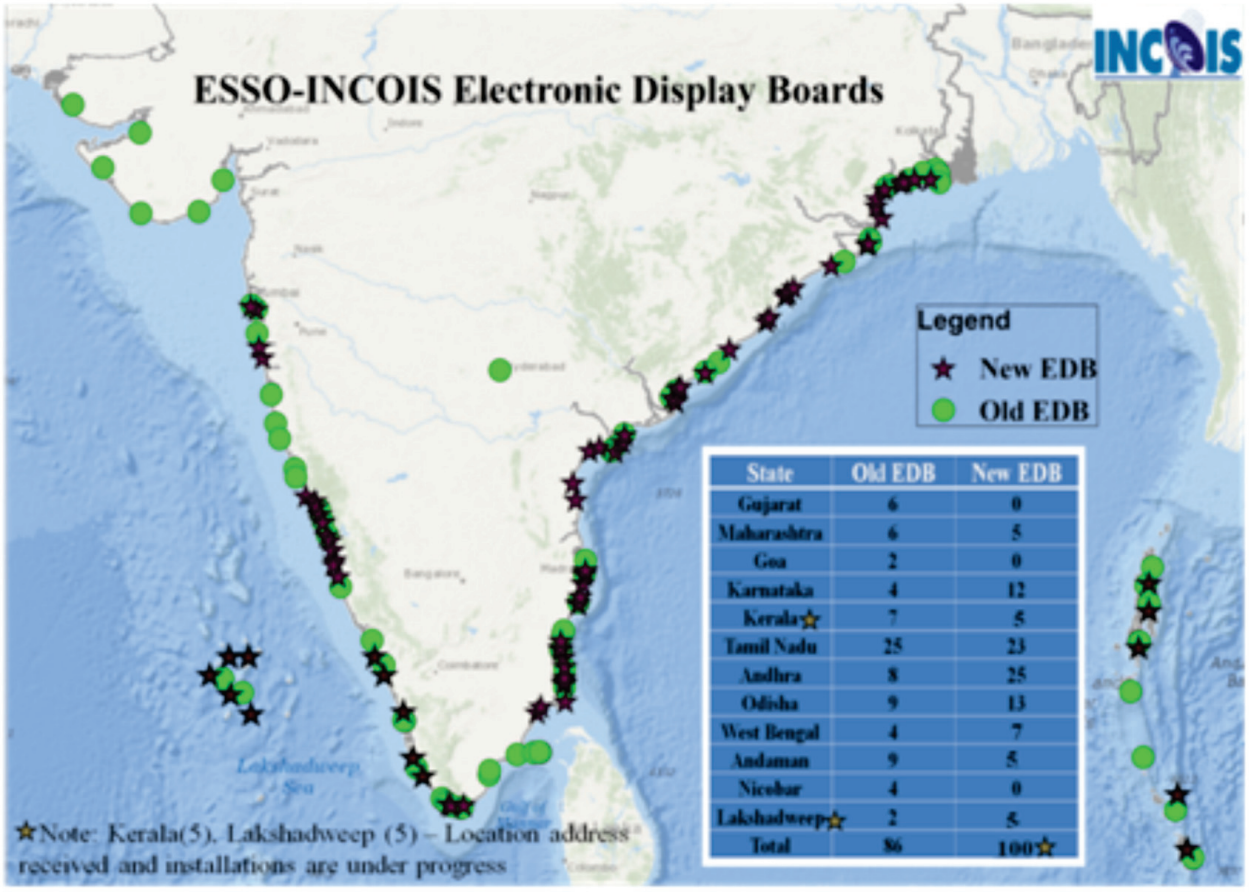


Fig. 3.4 Peak wave period (in seconds) during 22nd April 2018 and a sample photo showing the damage (erosion) occurred at the Kozhikode coast in Kerala.

INCOIS are disseminated. The EDBs are now being upgraded with Digital Display Systems (DDS) which are powered by solar panels and supported by dissemination software developed in-house. A total number of 90 DDS have already been installed which is in addition to already existing 86 EDBs. (Fig. 3.5)

3.4 Data Services

INCOIS, the National Oceanographic Data Centre (NODC) for the oceanographic data in the country continued, 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 High-Frequency (HF) radars. Further, the required data has been regularly disseminated to various agencies in the country in near-real time for operational purposes. The centre also provides tailor-made data and products via request based offline data dissemination mode to cater researchers their various R&D endeavours. The data centre also obtained and archived delayed mode data from various observing systems such as Expendable Bathythermographic (XBT/XCTD) observations, Met observations (NODPAC), OSCAT data (SAC), CTCZ programme data, Acoustic Doppler Current Profiler (ADCP) data, OMNI buoys etc. Several valuable historical datasets available in the physical forms such as cruise reports or handwritten notes are also being digitized and archived.



State	Old EDB	New EDB
Gujarat	6	0
Maharashtra	6	5
Goa	2	0
Karnataka	4	12
Kerala★	7	5
Tamil Nadu	25	23
Andhra	8	25
Odisha	9	13
West Bengal	4	7
Andaman	9	5
Nicobar	4	0
Lakshadweep★	2	5
Total	86	100★

Fig. 3.5 Existing constellation of EDB. (EDB as green circles and DDS as red stars).

3.5 Ocean Observation Network

The ocean observation network encompasses a wide range of state-of-the art observing systems viz., Argo Floats Drifters, Moored Buoys, Tide Gauges, High Frequency (HF) Radars, Current Meter Array, Acoustic Doppler Current Profiler (ADCP), Tsunami Buoys, and Wave Rider Buoys. These observing systems can bebroadly classified into moored buoys, drifters and floats., The Indian Moored Ocean Observing Network (MOON), serving the Nation incessantly for the past 21 years has received international recognition for the quality and continuity of met-ocean data and services to the society. Under the MOON, a 12 deep ocean OMNI buoy systems has been operational with surface & subsurface sensors, 4 coastal buoys, one CAL-VAL buoy system, one subsurface ADCP mooring, one Wave rider buoy (DWR), one Arctic mooring and 2 tsunami buoy systems for continuous data collection. The buoy data are shared with the international community through GTS. During the reporting period, 8 cruises have been taken up which took 136 days ship time and a sailing covering 11283 nautical miles to carry out 26 deployments, 24 retrievals and one field operation.

Stringent steps are being adopted to improve the reliability of buoy systems in-line with the International-standards by using best practice methods. The moored buoys proved their stability by withstanding intense forcing due to recent Ockhi cyclone and transmitted data showing the success of the engineering design.

INCOIS sustained its effort to maintain exiting observational plan to support research to improve existing services and start new services from the gained knowledge. Details of existing and new observation plans are given below.

Fig. 3.6 Locations of deployment of various observation systems in the Indian Ocean.

3.5.1 Automated Weather Stations (AWS)

INCOIS maintains a network of 34 AWS onboard vessels owned by different government agencies such as MoES, Shipping Corporation of India (SCI), Fishery Survey of India (FSI), National Hydrographic Office (NHO) and Geological Survey of India (GSI). During the period January 2018 to October 2018, INCOIS carried out 71 preventive maintenance, 19 breakdown maintenance and calibrations of AWS sensors (Wind Sensors–11, Barometric Pressure-11, AT/RH Sensors-13, Long Wave Radiation Sensors-06, Short Wave Radiation Sensors-12, Rain Gauge Sensors-17) to ensure continuous availability of quality data.

3.5.2 Wave Rider Buoy Network

INCOIS maintains a network of 16 wave rider buoy for monitoring the state of the ocean as well as the online/offline validations of the ocean state forecasts. Regular calibration of the systems at recommended intervals are done to maintain the quality of the data from the buoys. The INSAT tracking mechanism for buoys which was developed indigenously at ESSO-INCOIS helped in successful retrieval of 10 buoys drifted away from the locations of their initial deployment during the period. These buoys were later redeployed in the respective locations.

3.5.3 Argo floats

INCOIS deployed 15 Argo floats in the Indian Ocean during this period. These included 12 standard floats (temperature and salinity sensors only), 2 Argo floats equipped with temperature, salinity, chlorophyll, backscattering and dissolved oxygen sensors and one ICE float equipped with temperature and salinity measurement sensors. Indian contribution to this international project has increased to a total of 454 floats, of which 139 are active and transmitting data in near real time.

3.5.4 Coastal ADCPs

During the reporting period, 17 ADCP moorings were maintained along the coast of India. One new mooring was deployed during September, 2018 off Gujarat in the continental slope. In the east coast, 4 moorings are active in the continental shelf and 6 mooring are active in the continental slope as of March 2018. In the west coast, 7 moorings are active in the continental slope. Out of these 16 moorings, 4 shelf moorings and 1 slope mooring in the east coast and all the 7 slope moorings in the west coast are equipped with sufficient number of ADCPs to measure current profiles for the full depth of water column.

3.5.5 Equatorial current meter array

At present two moorings are active, which were deployed on October, 2017 along equator at 83°E and 77.4^{0}E. The two new moorings are equipped with two 75 kHz ADCPs to measure currents in the top ~900 m and two rotor current meter (RCM) at ~1000 and ~4000 m to measure the single-point currents. One scientific cruise will be conducted during January, 2019 for the service of this mooring.

3.5.6 XBT/XCTD/Drifting buoys

During the period, 4 transects were conducted (2 along Chennai-port Blair and 2 along Port Blair-Kolkata) to collect 21 XBT's and 12 XCTD's profiles. In addition 48 XBT and 16 XCTD profiles were collected along the west coast from Tamil Nadu to Gujarat during SK-351 and SK-352 during summer monsoon season 2018. In addition, 4 drifters were deployed in the Indian Ocean region during this period and at present 6 drifters are active.

3.5.7 Coastal HF Radar network along Indian coast including Andaman Islands

All the five pairs of the High Frequency Radars are operated by NIOT along the Indian Coast and the data are being made available to scientific community through INCOIS.

Current Status of various observations systems deployed in the Indian Ocean

Type of Platform	Target	Commi-ssioned till October, 2018
Argo Floats *	200	323
Drifters*	150	108
Moored Buoys	16	22
Tide Gauges	36	35
High Frequency(HF) Radars	10	10
Current Meter Array	10	11
Acoustic Doppler Current Profiler(ADCP)	20	20
Tsunami Buoys	7	9
Wave Rider Buoy	16	19

3.6 Process Specific Observations in the Bay of Bengal and Arabian Sea

During the reporting period, INCOIS conducted three scientific cruises onboard Sagar Nidhi; one in the summer monsoon season in the Bay of Bengal (Bay of Bengal: 5 July-5 August, 2018, 3-13 April, 2018) and another during the winter season in the Arabian Sea (12 January, 2018-12 February, 2018; 30 days). The objectives of the two cruises were to document the planetary boundary layer characteristics in the Bay of Bengal during summer monsoon using radiosonde.

One of the major achievements during this cruise was the nine day time series (27 Jan-4 Feb, 2018) measurements of the microstructure of temperature, conductivity and shear using Vertical Microstructure Profiler (VMP-250) at every 3 hour interval in the upper 300 m of northern Arabian Sea (19^0N, 67^0E) and estimation of horizontal gradient of temperature though 10-km transect of underway CTD. The analysis further shows that, the rate of dissipation of turbulent kinetic energy (ε; 10^{-5}-10^{-7} W kg^{-1}) trapped in thin surface layer (15 m) during morning hours due to stratification associated with net surface heat flux into the ocean and during night, the high e layer penetrates into the deeper depth (60 m) due to net surface heat loss from the ocean. A region of relatively high value of ε (~10^{-8}) is observed in the depth range between 190 to 230 m throughout the observation period, which is approximately one order magnitude higher than the region above. The presence of double diffusion due to the interleaving water mass of different temperature and salinity must be the plausible explanation for this.

3.7 Ocean Modelling and research

3.7.1 Ocean Modeling and Data Assimilation

INCOIS completed setting up of high resolution ROMS, viz. WC-HOOFS (for the west coast of India), SEA-HOOFS (for the southeastern Arabian Sea) and BB-HOOFS (for the Bay of Bengal) as part of the HOOFS project. Monthly climatology of fresh water discharge from seven rivers to the Bay of Bengal (Ganga, Brahmaputa, Irrawaddy, Mahanadi, Godavari, Krishna and Cauvery) are now incorporated in the Indian Ocean configuration of ROMS with 1/12 degree spatial resolution. A Local Ensemble Transform Kalman Filter (LETKF) based data assimilation scheme has been developed and interfaced with the present basin-wide operational ROMS set-up (~ 9 km horizontal resolution) that assimilates in-

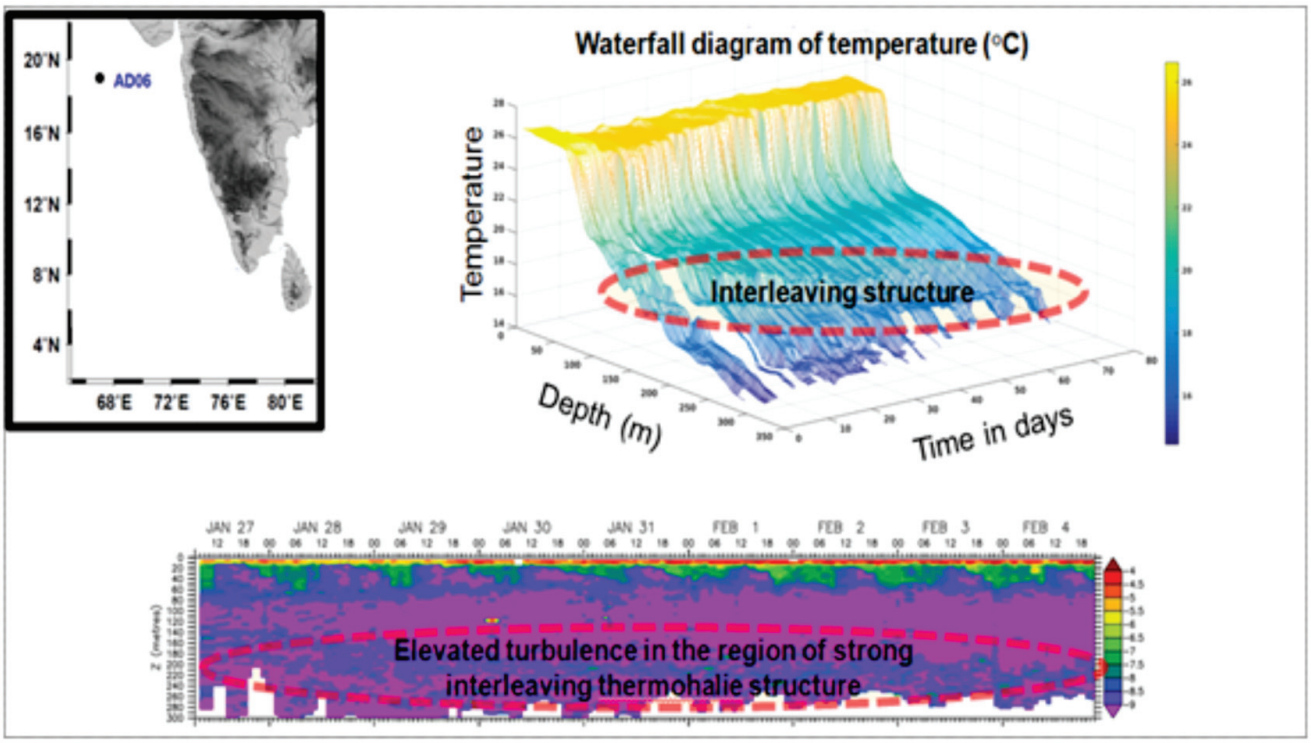


Fig. 3.7 (Top left panel) the location (19^{0}N, 67^{0}E) of VMP time series (top right) time series of waterfall diagram and (bottom panel) time series of turbulent kinetic energy (åW kg^{-1}) during SN-128 cruise.

situ temperature and salinity from RAMA moorings, NIOT buoys and Argo floats. The new system, LETKF-ROMS also assimilate satellite track data of sea-surface temperature from AMSRE. As part of Monsoon Mission, INCOIS has upgraded the ocean model component of existing INCOIS-GODAS from MOM4p0d to MOM5p1d.

In order to transform the existing PFZ advisories into PFZ forecast, a coupled physical-biogeochemical model in regional scale is developed which is capable of simulating ocean features leading to PFZs. This approach not only ensures that there is no data gap in either SST or Chl-a, but also makes data available in forecasting mode. The use of model data provides an additional advantage towards transforming the existing service from advisories to forecast. The modeling framework involves an online coupling of the Regional Ocean Modeling System (ROMS) physics/dynamics integrated with an ecosystem model at very high spatial resolution (1/48^0; approximately 2.25 km spatially averaged).

INCOIS is now configuring a modeling system to provide projections of sea level change along the entire coastline of India. In this regard, a suite of ocean models based on Modular Ocean Model (MOM5.1) is being set-up. This system consists of a high resolution global model with uniform 1/8^0 horizontal resolution and a Indian Ocean regional model with very high resolution (uniform 1/20^0 in horizontal and 50 vertical layers with 1-1.5 m in the top 30 m of the water column) to capture the coastal variability. The very high-resolution Indian Ocean configuration of MOM is also coupled with biogeochemical module. The simulations of Physical and Biogeochemical parameters by this model are being validated.

3.7.2 Operational forecasting system based on Indian Ocean Hybrid Coordinate Model (HYCOM)

A state of the art operational forecasting system based on HYCOM model with data assimilation (DA) is established at INCOIS, which is the first of it's kind in the country. The Indian Ocean model is the highest resolution operational system with DA available for the basin compared to any operational agency in the world. The core of the system is a 1/16o eddy resolving HYCOM, nested to a 1/4o Global HYCOM which provides lateral boundary conditions to the high-resolution model. The system uses data assimilation scheme based on Tentral Statistical Interpolation (T-SIS) scheme. A five-year hindcast for the period 2012 to 2016 has been carried out using both setups. The five-year hindcast results show that both Indian Ocean and global model simulated SST, SSS, SLA, currents and vertical structure of the ocean well, when compared with observations and other models. Sea-level and currents, show a notable better performance for the new setups at INCOIS over NRL-HYCOM and INCOIS-GODAS.

3.7.3 Web Based Services

Web-based applications are one of the most important activities of INCOIS which is vigorously used by users getting ocean data, information and advisory services such as potential fishing zone, ocean state forecast, Indian Argo, Indian Ocean Global Ocean Observing System, etc. The web based online delivery system facilitates the user with multi-lingual and WebGIS capabilities to query, analyze, visualize and download the ocean data, information and advisory services on different spatial, temporal resolutions and for their regions of interest. (Fig. 3.8)

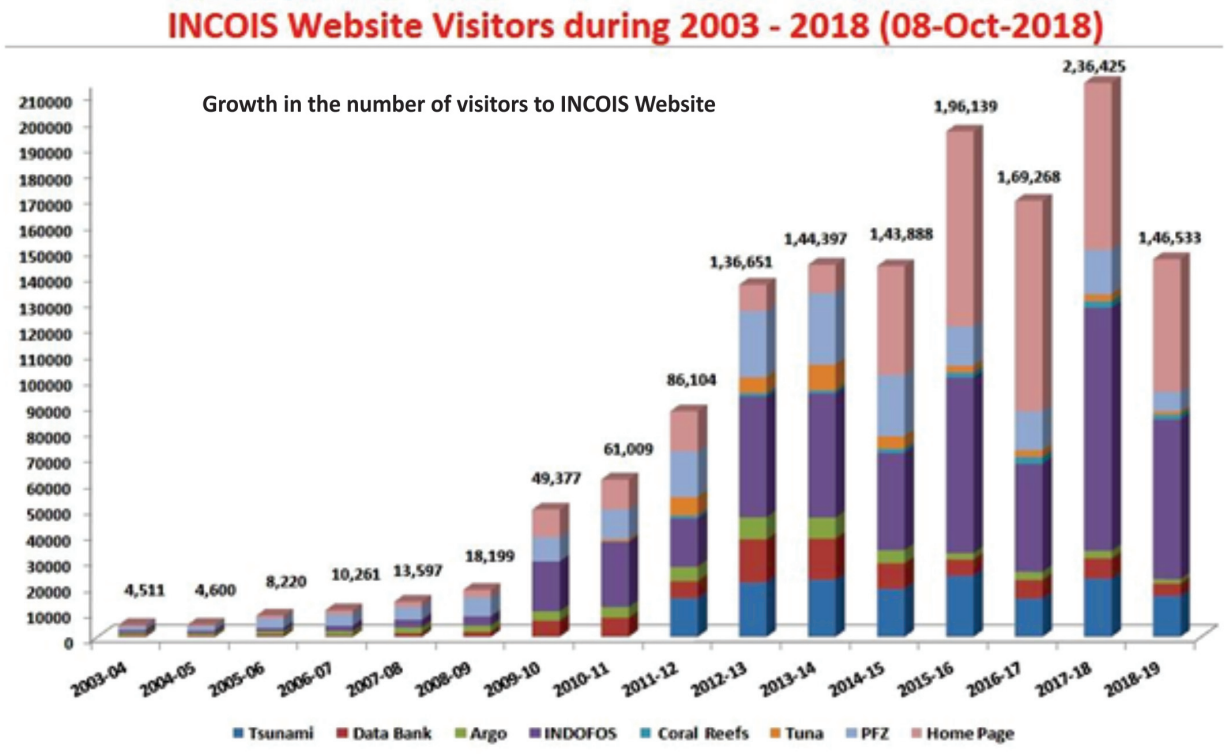


Fig. 3.8 Number of Visitors of INCOIS website during 2003-2018.

3.8 Studies on Marine Living Resources (MLR)

The MLR activities are broadly divided into two major projects viz. (i) Marine Ecosystem Dynamics of the eastern Arabian Sea (MEDAS) and (ii) Resources Exploration and Inventorisation System (REIS). While the MEDAS is a front-end mission mode collaborative project that explores the process studies governing the biogeochemistry and biological oceanography, the REIS is a back-end project that document the marine biodiversity and resource inventorisation. The details are as follows:

3.8.1 Marine Ecosystem Dynamics of Eastern Arabian Sea (MEDAS)

MEDAS, the first ever mission mode basin-scale time-series project covering entire eastern Arabian Sea, is one of the major in-house activities of Centre for Marine Living Resources and Ecology (CMLRE), Kochi implemented jointly with National Centre for Coastal Research (NCCR), Chennai and CSIR-National Institute of Oceanography (NIO), Regional Centre, Kochi. Understanding the complexity and interplay of upwelling and winter convective mixing leading to distinct nutrient replete/deplete conditions resulting in short/long-food chain is crucial for ecosystem management. MEDAS aims to explain the extent of influence of these environmental conditions on the biogeochemistry and food web dynamics that regulates the greenhouse gases and fishery oceanography. MEDAS is envisaged with a basin scale time series approach by monitoring seven/ten transects (10m to 2000m) between Cape in the south (8^0N) and Okha in the north (22^0N) on a monthly/seasonal basis **(Fig. 3.9)** integrating with seasonal estuarine surveys, as time series surveys in oceanographic processes would be an ideal way to derive the structure and function of the ecosystem at various levels. Out of a total of ten time series cruises planned to address the MEDAS objectives for one annual cycle (December 2017 – January 2019), seven cruises have been accomplished till October 2018 including five cruises onboard FORV *Sagar Sampada* and two onboard ORV *Sagar Kanya.* A total of 193 ship days spent and repeatedly occupied 64 (88) stations on monthly (seasonal) basis.

Preliminary understanding based on density stratification and related from the surveys conducted during winter monsoon (December-March) showed that the southern shelf system is more stable than the convective mixing influenced northern system. The biological and biogeochemical responses to nutrient replete/deplete conditions are being

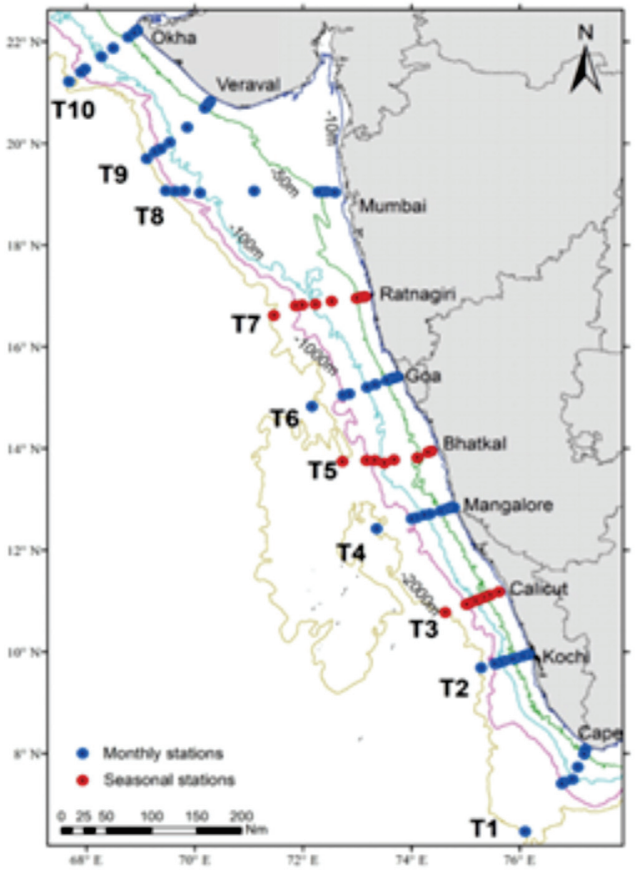


Fig. 3.9 Map depicting the time-series basin scale MEDAS study domain.

addressed comprehensively by considering all trophic levels to derive the structure and function of food web dynamics.

3.8.2 Resource Exploration and Inventorization System (REIS)

A total of 5 cruises were undertaken onboard FORV *Sagar Sampada* in the eastern Arabian Sea and the Andaman Sea and inventorised the marine biodiversity. The surveys have yielded numerous new records and new species to the inventory of Indian Ocean fauna. The CMLRE Referral Centre currently holds a total of 1219 voucher specimen, including 447 fishes, 470 polychaetes, and 222 echinoderms. Taxonomic identification of invertebrates collected from the Andaman and Nicobar waters yielded 5 new records of shrimps *(Haliporustaprobanensis, Acanthephyracarinata, Nematocarcinusbituberculatus, Nematocarcinustuerkayi and Plesionikaorientalis)* and one new record of echinoderm Ophialcaeatuberculosa. In addition, taxonomic identification of collections from the southeastern Arabian Sea (Cape to Goa) yielded 2 each new records of brachyuran crabs *(Euclosianaunidentata and Kasagiaarbastoi)* and echinoderms *(Astrothoraxwaitei and Ophientremascolopendrica)*. Five species of deep-sea eels and one species of polychaete from Andaman waters have been described as new to Science.

Compilation of published records of marine faunal species from the Indian waters based on check-lists and observational literature sources was attempted owing to previous erroneous estimates. Altogether from the survey of 714 literature sources yielded 13,259 species across 24 animal phyla. Phylum Arthropoda with 3976 taxa was the largest taxonomic rank, followed by Chordata (3196), Mollusca (1870) and Cnidaria (1113).

Based on the Trophodynamic approach, annual potential yield (2012-17) from the fishery resources of Indian EEZ (except for Lakshadweep and Andaman & Nicobar) has been revalidated to 5.12mt. Multispecies cetacean line-transect survey with 25 x 150 long-range binoculars or "Big-Eyes" and Celestron 7x50 Cavalry Binocular and a Nikon D750 camera was carried out between Okha and Kochi spanning shallow shelf waters (< 150 m) to deeper outer-shelf/slope waters. A total of 13 cetacean species viz., *Stenellalongirostris* (spinner dolphin), *Stenella attenuate* (pantropical spotted dolphin),

Spotted dolphin, Stenellaattenuata Gray, 1846

Spinner dolphin, Stenellalongirostris Gray, 1828

Fig. 3.10

Grampus griseus (Risso's dolphin), *Globicephalasp.* (Pilot whales), and *Balaenopteraedeni / B. omurai* (Bryde's whales/ Omura whale), *Tursiopssp*. (Bottlenose dolphin), and *Balaenopteramusculus* (Blue whale) as well as some unidentified cetaceans were spotted during the survey. Underwater survey at Agatti waters, Lakshadweep Islands reveals high biodiversity of coral associated fauna, some of which are new records to Indian waters and new species to science.

3.9 Coastal Research

The coastal areas are subjected to stress due to climate change and developmental activities. Recognizing the importance of diverse and productive ecosystems along the Indian Coast, the role of Integrated Coastal and Marine Area Management (ICMAM) has been upgraded as National Centre for Coastal Research (NCCR) to undertake multi-disciplinary research to understand the critical coastal parameters, processes and phenomena, which have significant societal, economic and environmental benefits. The centre would provide scientific and technical support to the coastal states for conservation and sustainable management of the resources to address blue economy in association with the coastal states, meeting the Sustainable Developing Goals (SDG 14). This would provide a strong institutional and scientific backing to solve the critical coastal issues and aid in the Nation building exercise.

3.9.1 Sea Water Quality Monitoring (SWQM) along Indian Coast

Coastal waters are monitored at selected locations along the Indian coast by collecting seasonal data of 25 parameters pertaining to physico-chemical, biological and microbiological characteristics of seawater and sediment. Sea water (surface, mid-depth and bottom) and sediment samples are being collected at each location at 0/0.5 km (shore), 2/3 km (near-shore) and 5 km (offshore) distance from the shore. The data collected under Coastal Monitoring and Prediction System (COMAPS) /SWQM programme, a status report on "Seawater quality at selected locations along India coast" was prepared and released for public use on 27th July, 2018 on the occasion of Foundation Day of the Ministry.

The report indicated that the nutrient concentrations showed an increasing trend in most of the locations and high nutrients concentrations were observed even up to 5 km offshore at some locations. Increasing concentrations of nutrients in the coastal waters is of concern as it leads to ecological disturbances affecting the coastal ecosystem processes and services. Further, the microbial loads in seawater and sediment also showed increasing trends in total viable counts (TVC), faecal coli forms (FC), *Escherichia coli* and *Streptococcus faecalis* counts in most locations. Water Quality Index (WQI) has been developed to understand and characterize the seawater quality and it was observed that the WQI for Port Blair and Kavaratti alone showed 'Good' condition.

3.9.2 Prediction of seawater quality in Coastal Waters

Seawater Quality is predicted for the 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 fecal indicator bacteria (FIB). Similar work is also being extended to Puducherry and Puri coastal waters.

3.9.3 Marine Litter

As a part of the Swachh Bharat Abhiyan of Government of India, NCCR organized an awareness and cleanliness around the beaches along the Indian coasts.NCCR as one of agencies responsible for "Coastal Clean Sea Campaign" of UN and the nodal agency for "Marine Litter Program" of SACEP conducted beach cleaning activities to create awareness among the public about the importance and need to preserve our coastline. NCCR and Indian Coast Guard (ICG), Eastern Command, Chennai organised a beach cleaning activity at Elliot Beach, Chennai on 15th September 2018 in connection with the ICC Day.

The data on percentage composition of debris in different beaches during the cleanup program suggest that the presence of non-degradable materials of plastic is relatively high. Plastic litter originated from the tourism and fishing sector dominates all beaches. Biomedical products are observed in urban beaches.

3.9.4 Marine Ecotoxicology and Ecological Risk Assessment

Marine Ecotoxicology and Ecological Risk Assessment programme seawater quality criteria for SW-III (Industrial cooling, Recreation – non-contact and Aesthetics – dissolved manganese) and SW-V (Navigation and Controlled Waste Disposal) for 7 heavy metals (Cu, Hg, Cd, Pb, Zn, As, Cr + pesticide Monochrotophos) have been developed in the form of safe levels for coastal waters of Chennai and Gulf of Mannar and have been provided to CPCB, MoEF&CC for notifying them as standards (Table-3.1), which is under active consideration.

Table 3.1 Seawater quality criteria for metals and pesticides developed by NCCR

Metals (µg/l)						Pesticides (ng/l)	
Cd	Cu	Hg	Zn	Pb	As	Cr	Monocrotophos
3.03	4.1	0.38	10.6	4.6	3.5	8	89

Fig. 3.11 Typical Shoreline change Maps

Further, NCCR has derived SWQC for coastal waters of Chennai and Kochi for the metals Viz., Nickel, Selenium, Copper, Zinc, Lead and the pesticide, Chlorpyrifos. Currently toxicity bioassay tests for Diesel oil, Anthracene and Benzopyrene are being standardized on marine organisms.

3.9.5 Shoreline Management

Shoreline change rate for entire Indian main land coast is analysed using Indian satellite images. The analysis included long-term, short-term and annual rates. The shoreline analysed from satellite imageries provided different data products such as state map, district map and 1:25,000 scale map. The state wise analysis (1990-2016) suggests that more than 40% of erosion is noticed in four states/UT i.e. West Bengal (63%), Pondicherry (57%), Kerala (45%) and Tamil Nadu (41%).

Land loss and land gain analysis revealed that West Bengal coast has lost about 99 sq/km of land during last 26 years. As a part of regular updating of shoreline change maps, analysis of 2017 shoreline is completed. Shorelines extraction is completed and analysis is in progress for the following years 1990, 2000, 2010 and 2017 of the Andaman islands. Shoreline extraction for the Lakshadweep islands has been initiated.

3.9.6 Ecosystem Based Services for the Management of Coastal Areas

Ecosystem modelling studies are being carried out with two projects namely MEDAS (Marine Ecosystem Dynamics of Eastern Arabian Sea) for the West coast shelf waters in association with CMLRE and for Pulicat Ecosystem (SE coast) in association with Andhra University (Visakhapatnam) and IIT (Delhi).

Benthic communities are an important component in coastal and shelf water ecosystems, initial results suggest that the macrofaunal community are dominated by polychaetes (74%), followed by crustaceans (10%), molluscs (2%) and the rest of the groups termed as "others" (14%). The mean macrobenthic biomass for the study region was 3.1±4.5. The infaunal diversity and biomass was higher at 30 to 50m depth range and decreased towards 100m depth contour. Higher macrobenthos biomass was found at selected stations of off-Mangalore, off-Goa and off-Okha.

3.9.7 Coral Reef Monitoring and Restoration in Gulf of Mannar

A new initiative to monitor, map and restore the Coral Reefs in Gulf of Mannar (GoM) has been started and a dedicated field research station will be established in Rameswaram for this purposes. The reefs are fringing or patchy reefs thriving in shallow water and are found encircling almost all islands. After the massive coral bleaching event during 1998, the live coral cover reduced to 36.98% and during the 2010 bleaching event, the coral cover decreased to 33.2%, which later recovered to 37.31% in 2011.

A team of scientists stationed at Rameshwaram will undertake extensive underwater survey around the islands of GoM. Presently survey has been carried out around the Hare Island and Manoli & Manoli Putti Island of Mandapam. The data on the coral coverage, species and benthic faunal communities were collected by using LIT methods and the locations geotagged for further monitoring purposes.

3.9.8 Centre of Excellence in Coastal Research

On 2nd November 2018, a foundation stone was laid in Visakhapatnam for setting up a Centre of Excellence in Coastal Research, which

Fig. 3.12 Foundation Stone Laying Ceremony at Vishakapatnam

can address the societal needs of the country through scientific and research programmes. (Fig. 3.12) The centre would provide scientific and technical support to the coastal states for conservation and sustainable management of the resources. The centre will carry out cutting edge coastal research and offer scientific, advisory and outreach services, formal and informal education for better management of coastal areas through scientific solutions. The facility will have state-of-the-art infrastructure that includes environmental analytical laboratories, laboratories for experimental and field related process studies and observational facilities to address challenging questions at the rapidly changing land-sea interface.

3.9.9 Coastal hazards

NCCR and the Govt of Tamil Nadu have signed an MoU for the operationalization of the Chennai Flood Warning System (C-FLOWS), which has been developed for the city of Chennai **(Fig.3.13)**. The Chennai Flood Warning System, a project initiated by the office of the Principal Scientific Advisor (PSA) was developed as a multi-institutional project involving IIT-Bombay, IIT-Madras, IRS-Anna University, and the MoES institutes IMD, NCMRWF and INCOIS. The integrated system involves coupling models of Regional weather forecast, Hydrological/ Catchment, Hydraulic regime of Rivers, Urban Drainage/overland flow, Tide and Storm Surge. The System will be tested for the upcoming NE Monsoon before making it operational.

Fig. 3.13 Dashboard for the Chennai Flood Warning System

3.10 Ocean Technology

3.10.1 Deep Sea Technologies/Deep Sea Mining Slurry Pumping Tests up a Vertical Riser at Sea

Sea trials were conducted from onboard ORV Sagar Nidhi during Dec 17 – Jan 18, to assess the pulsatile slurry flow behaviour in a flexible vertical riser system, with crushed natural manganese nodules. An experimental slurry pumping system with flexible riser unit was deployed from the ship to depths of 180-400 m (Fig. 3.14).

The slurry pumping unit consisted of twin-piston solids pump adapted for sub-sea applications, screw feeder with hopper for controlled feed of the crushed nodules, a hydraulic power pack unit, instrumen-tation and control and power system. The sea trials were undertaken at varying flow rates and slurry concentration.

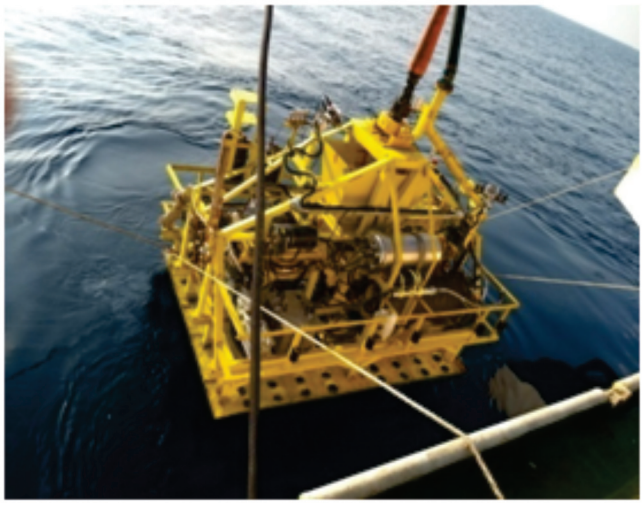


Fig. 3.14 Launching of Pumping system from onboard Sagar Nidhi

Testing & Installation of Winch-AHC System with Umbilical

NIOT has procured an Active Heave Compensated Deep sea winch system with 7000m sub sea cable. This winch is fully electrically operated system capable of operating in sea state up to 6, and will be used for launching and retrieval of deep sea systems at 6000 m. The Factory Acceptance Tests of different components was carried out during July 2018 at Norway/Denmark. The winch system was delivered and installed onboard ORV Sagar Nidhi in October 2018.

3.10.2 Development of Manned & Unmanned Underwater Vehicles

Manned Submersible

NIOT is involved in design and development of 6000 m depth rated manned submersible. It combines the advantages of Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV). It houses three human beings in 1 atm pressure Personnel Sphere made up to Titanium Alloy which can withstand the external pressure of 600 bar i.e., 6000 m water depth. System concept report was prepared in the critical areas pertaining to 6000m depth rated system including personnel sphere, life support systems, on-board energy storage, control hardware and navigation. Development of personnel sphere interior is undertaken in a mock up acclimatization personnel sphere of 2.1 m diameter with seating arrangements, pipelines and life support system. Studies towards design, manufacture, quality assurance, certification and qualification of the personnel sphere were taken up and also to identify the possibilities of manufacturing the personnel sphere in India. Experimental setup to study the life support systems for the manned submersible is being developed.

Underwater search operation of DRDL and NSTL object in the Bay of Bengal

Polar Remotely Operated Vehicle (PROVe) was deployed (Fig. 3.15 (a)) for the national mission of search operation of missing object of Defense Research and Development Laboratory (DRDL), Hyderabad and Naval Science and Technology Laboratory (NSTL), Vishakhapatnam. Underwater search operation was carried out using PROVe to identify the object lying on the seabed at a depth of 90m off Vishakhapatnam in Bay of Bengal using Shipping Corporation of India (SCI) vessel Saraswati during March 2018. DRDL objects were seen clearly with ROV mounted high definition cameras. Some of the sea floor images with natural debris are given below (Fig. 3.15 (b)).

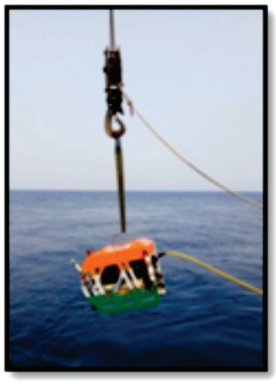
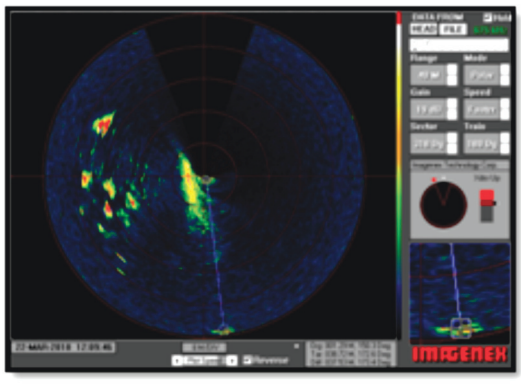


Fig. 3.15 (a) PROVe deployed off Visakhapatnam



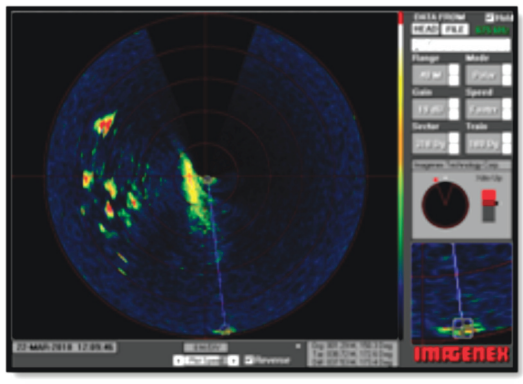


Fig. 3.15 (b) Underwater images at 80 m water depth

Wireline Autonomous Coring System

A wireline autonomous coring system (WACS) was developed in association with Williamson & Associates, USA. For long term reliable operation of hydraulic system in deep waters, system is completely revamped to avoid sluggish operation in deep water. The Steel armoured umbilical cable was re-terminated with penetrator assembly and tested in the west coast deep waters up to 3000 m water depth onboard Sagar Nidhi during February 2018. Land based drilling was carried by NIOT and drilled up to 23 m on the cemented hole. The system is ready for deep water sea trial.

3.10.3 Coastal Engineering

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

Further to the gain of beach width of 60m formed near the northern side, a submerged steel wedge was successfully installed as a near shore submerged reef in the northern side. It is a triangular steel wedge, of 800 tonnes, with dimension 50m x 60m x 2.5m and was successfully installed at 2.5 m water depth off Puduchery coast as part of Beach Restoration project on August 23, 2018 (Fig. 3.16). The Beach Restoration project in Puducherry has been successfully completed. Demonstration of submerged reef at Puducherry has resulted in formation of wide beach.

Establishing desalination plants in the Islands of UT Lakshadweep

NIOT has taken up the task of establishing Low Temperature Thermal Desalination (LTTD) plants with a capacity of each generating 1.5 lakh litre of potable water per day in Amini, Androth, Chetlat, Kadamat, Kalpeni, and Kiltan Islands of UT Lakshadweep at a cost of Rs. 187.87 crores in a timeframe of 2 years. The contract agreement was signed and the work has commenced.

Fig. 3.16 Puducherry Beach Restoration

Coastal protection demonstration in Kadalur Periakuppam

Based on extensive field work and numerical model studies, a segmented submerged dyke comprising of 1.76 Km long segments, height of 3.5m with gaps of 60m at 4 m water depths (CD) was developed in-house which has been successfully installed off Kadalur Periyakuppam. Beach has been restored along the coastline (Kadalur Periyakuppam, Chinnakuppam, Alikuppam) on the landward side of submerged dyke. Beach restoration has been demonstrated successfully in Kadalur villages and the project completion report has been submitted to Government of Tamil Nadu.

3.10.4 Energy & Fresh Water OTEC Powered Desalination Plant at Kavaratti

The foundation stone for the new OTEC Powered Desalination Plant at Kavaratti was laid by Honorable Union Minister for Ministry of Earth Sciences Dr. Harsh Vardhan on 22nd October 2018 in presence of Honorable Administrator of U.T. Lakshadweep Shri Farooq Khan and Honorable Member of Parliament from Lakshadweep Shri Mohammed Faizal. This plant will be the second plant in Kavaratti Island to be set up by NIOT and funded by MoES. Memorandum of Understanding (MoU) for the same has been signed with U.T. Lakshadweep Administration on 21st May 2018 at MoES, New Delhi. This plant will work on the energy from Ocean Thermal Gradient and will not need any electricity from the island grid except during startup.

Fig. 3.17 Inauguration of OTEC Plant

3.10.5 Ocean Science and Technology for Islands

The Atal Centre for Ocean Science and Technology for Islands in Port Blair was inaugurated by Hon'ble Minister for Science & Technology, Environment & Forest and Earth Sciences, Dr. HarshVardhan, on 15.09.2018 (Fig. 3.18). The activities are focused towards offshore open sea cage culture for marine fishes, deep sea microbial technology aimed at the production of novel bioactive compounds from actinobacteria and other deep sea

Fig. 3.18 Inauguration of the Atal Centre

microorganisms, isolation and production of biomolecules from macroalgae and seawater quality monitoring.

3.10.6 Microbial Biotechnology

A streptomyces strain NIOT.Ch.40 (Streptomyces olivaceus) isolated from deep-sea sediments (2000 m) of Bay of Bengal was found to exhibit antimicrobial and cytotoxic activities. The cytotoxic effect of strain NIOT.Ch.40 against the cancer and normal cells was quantified by the ability of the viable cells to reduce 3- (4,5-dimethyl- 2- thiazolyl) -2,5-diphenyl-2H-tetrazolium bromide. HPLC elute labeled C.40-9.2 was found to be the major compound with antibacterial and anticancer activity against colon cancer cells.

Twenty four halophilic eubacteria were isolated and identified based on their biochemical and 16S rDNA sequences from the volcanic Barren Island. Salinosporamide-A, a naturally occurring proteasome inhibitor was isolated from the marine actinobacteria *Salinisporatropica.* Salinosporamide-A belongs to the class b-lactones, a novel cancer treatment option suitable for oral administration. A total of 123 cultivable actinobacteria were isolated from deep sea core sediments of Barren Island. Of these 123 isolates, 17 were confirmed as *Salinospora sp.*

3.10.7 Open Sea cage culture

The 9 m diameter open sea cage with multipoint mooring system is re-moored at new location off Olaikuda village near Rameshwaram. Shallow water fish culture cages were designed and deployed at Vennangupattu creek near Marakkanam, Tamilnadu for culturing of Asian seabass fish for societal developmental activities in collaboration with Central Institute of Brackishwater Aquaculture (CIBA). Automatic feeder for feeding the fish cultured in cages was developed and testing is under progress.

3.10.8 Ballast Water Treatment Technologies – Test Facility

The baseline study for the establishment of land-based Ballast Water Treatment Technologies – Test Facility (BWTT-TF) has been successfully completed by collecting samples for 44 months till December 2017. The initial outcome of the study indicated that the physicochemical and biological parameters from open sea as intake water was satisfactory in all seasons for testing the ballast water treatment system as per the guidelines of International Maritime Organization for Ballast Water Management. Based on the baseline investigation, it was decided to draw seawater from the open sea by way of construction of trestle. The design of the storage tanks, control tanks, and test tanks was completed based on the recommendations of engineering experts.

3.10.9 Marine Sensors, Electronics & Acoustics Marine Sensors

System upgradation with NIOT-BEL Transducer array: The Modular Buried Object Detection Sonar (BODS) has been upgraded by incorporating a transmitter array jointly developed by NIOT, in collaboration with Bharat Electronics Ltd (BEL), Bangalore under an MoU. A patent has already been granted to NIOT for the transducer technology in the year 2016, and the technology was transferred by NIOT to BEL.

Design and fabrication of improved Tow body with additional features: An improved new tow body is designed and fabricated by the group with Glass Reinforced Plastic. Additional provision for fixing hydrophones in two different directions is also incorporated in the new tow body.

Sea trial was conducted in the Royapuram Harbor in Tamil Nadu, India [Lat. 13.13^{0}N, Lon. 80.30^{0}E]. Multiple buried sea bed layers were observed at some regions of the test site and the corresponding image is shown below. Layer detection up to 6m below the sea bed was also observed with the modified sonar system.

3.10.10 Ocean Electronics

Wireless Expendable CTD (WXCTD) : A wireless expendable CTD system which is mainly used for the upper ocean thermal profile data collection has been developed. The compact WXCTD system measures sea water temperature and salinity up to 500m depth and transmits the observations to vessel by wireless communications. 4 units have been fabricated in-house and rigorous laboratory /field tests have been conducted for communication and reliability. The product is registered for Indian patent.

3.10.11 Ocean Acoustics

Ambient noise measurements in Polar regions and Arctic Data Analysis: The autonomous ambient noise measurement system was successfully deployed (Fig. 3.16.3) as an independent mooring on 16/07/2018 at 200 m depth, near the IndARC mooring, in the Kongsfjorden, Arctic (Lat:78^{0}56.719´N and Long:012^{0}01.845´E). The system consists of two hydrophones, buoyancy steel floats, tilt sensor, acoustic release and sinker weight. The data acquisition system has the sampling rate of 25 kHz, for a duration of 3 minutes, in every one hour (24 data set per day).

Participation in key comparison calibration of National Physical Laboratory (NPL) UK: NIOT successfully completed the key comparison calibration of hydrophones in the frequency range 250Hz to 500kHz, organized and carried out by NPL UK, under the auspices of the Consultative Committee on Acoustics Ultrasound and Vibration (CCAUV) which is a part of the International Committee of Weights and Measures (CIPM). NIOT received hydrophones from NPL, UK during April 2018 and the calibration was carried out during May and June 2018.

Laboratory Quality Management system for the NABL accredited Acoustic Test Facility has been made online based on the requirements of ISO/IEC 17025: 2017 standard and was released by Dr.M.Rajeevan, Secretary, MoES on 25.9.2018. It encompasses online approval process, database for laboratory management system documents, customer requests, equipment, training record for laboratory personnel, internal audit process and day to day maintenance of records.

3.10.11 Transfer of Technology (ToT)

NIOT signed the following agreements for Transfer of Technology (ToT) on 27th April, 2018 through NRDC.

- Robo coastal observer to CT control technology, through NRDC
- Remotely Operable Vehicle to L&T heavy industries.
- Patented transducer (patent no 278301) to Bharat Electronics Limited (BEL) and is in production level.
- Ocean drifter and expandable CTD to Indian industries – M/s. Norinco, Mumbai, M/s. Astra Microwave, Hyderabad and M/s. Azista Industries Pvt. Ltd., Ahmedabad on 31.8.2018.

3.11 Ocean Survey and Mineral Resources

3.11.1 Geoscientific surveys of the Exclusive Economic Zone (EEZ)

Ministry of Earth Sciences (MoES) launched a program 'Geo-Scientific Studies of the Indian EEZ' for mapping the entire EEZ by using state-of-the-art technologies of multibeamechosounder (MBES) and other associated underway geophysical surveys. National Centre for Polar and Ocean Research (NCPOR) is the nodal organization for implementation of the program.

NCPOR has thus far completed 57 cruises exclusively for Multibeam Swath Bathymetry survey to achieve the assigned targets and covered a total area of approx. 15,39,371 km^2 of EEZ area off the mainland and Andaman Island region. The coverage comprises ~82% of the deep water blocks within the Indian EEZ.

During 2018-19, ten survey cruises were undertaken in eastern offshore region onboard ORV SagarKanya (two cruises) and RV-MGS Sagar (8 cruises). A total area of approx. 2,11,700 km^2 was surveyed using MBES. During the process, geophysical data using Sub-bottom profiler (SBP), gravity and magnetic data of about 60,600 kms along track were also acquired. 26 successful gravity cores and 74 CTD/SVP station data were also gathered. Data processing, integration and mosaicking were undertaken using hydrographic data processing software with the standardized data processing procedures. 25 slope-confined submarine canyons and various features such as 'Plunge Pools' and 'Cyclic Deposits' were mapped and identified for the first time in the Palar Continental Margin by utilizing high resolution swath bathymetry and acoustic sediment profiling.

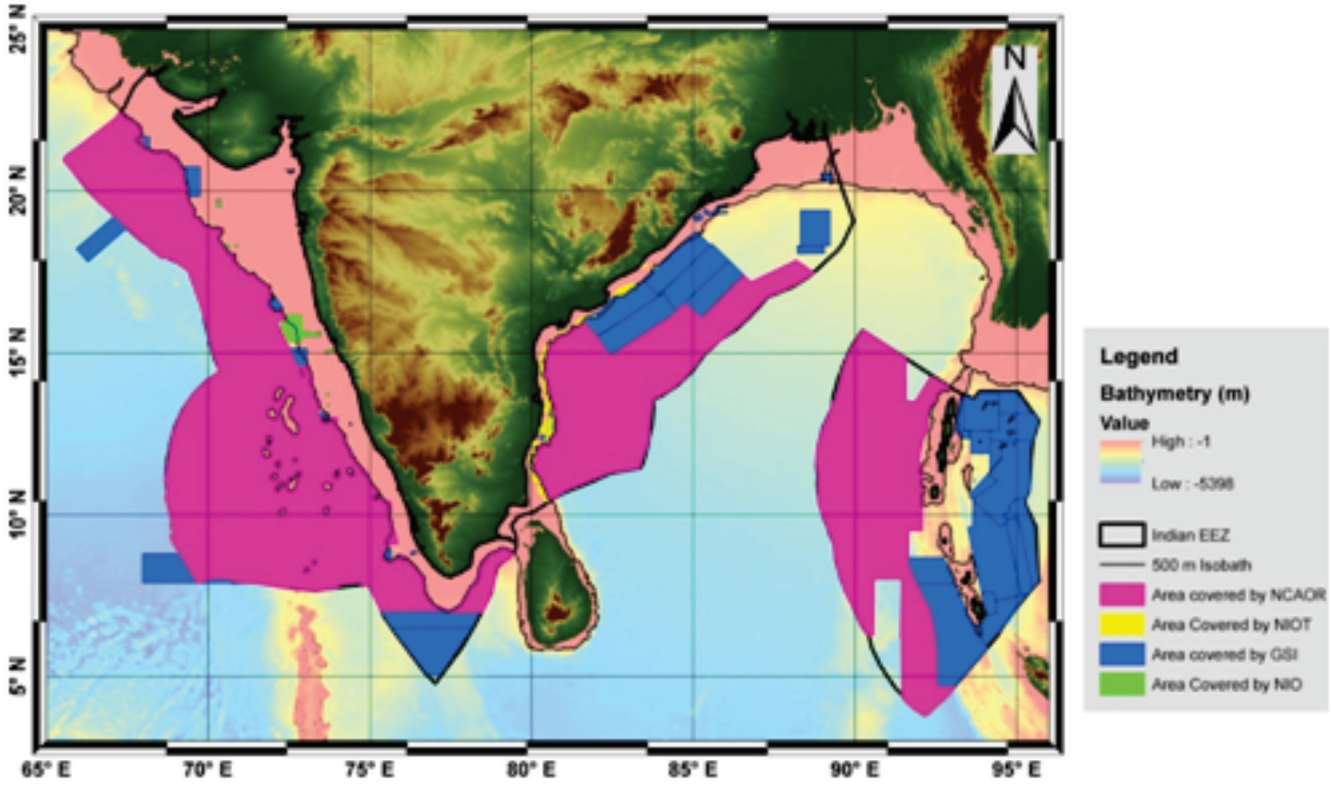


Fig. 3.19 Map showing total area covered in DW regions

3.11.2 Studies on Hydrothermal Sulfides

Seafloor hydrothermal sulphide formations are integral aspects of seafloor accretion and cooling at mid-oceanic rides and are typically found along faults, fissures and volcanic structures within large rift valleys. Over time, the build-up of particulate sulphides, collapsed chimneys and other vent debris form a mound of metal sulphide-rich material with high concentration of base metals (Cu, Pb, Zn) and many noble metals (Au, Ag, Pd, Pt) in them.

After signing of contract with ISA in September 2016, NCPOR undertook survey cruises onboard RV-MGS Sagar during January-March 2017 and analysis of various geoscientific data/samples collected during the cruise provided significant clues regarding few active plume locations in the region. In order to carry out further exploration activity in the region, three months cruise was undertaken onboard MGS Sagar from 5th January – 31st March 2018 in the contract area in Central Indian Ridge (CIR) and South West Indian Ridge (SWIR).

In collaboration with Pacific Marine Environ-mental Laboratory (PMEL) of National Oceanic and Atmospheric Administration (NOAA), a total of 800 nautical miles (~1480 km's) in 26 track lines were surveyed using six sets of MAPR. Analysis of the Miniature Autonomous Plume Recorder (MAPR) data could identify plume signatures in three locations and further processing in conjunction with other data sets is under progress.

The various survey, sampling and analysis carried out so far, could provide convincing clues on presence of 5 to 6 hydrothermal plumes in the contract area. Further studies could narrow down the plume area, bringing close to the possible vent location. Development of environmental baseline data also is in progress, following the guidelines of the International Seabed Authority (ISA).

■

CHAPTER 4 | Polar and Cryosphere Research (PACER)

4.1 Scientific Studies in Antarctica

4.1.1 Polar Cryosphere and Ice core Studies

Microbial communities and their potential for degradation of dissolved organic carbon in cryoconite hole environments of Himalaya and Antarctica

The retrievable heterotrophic microbes in cryoconite hole (cylindrical melt-holes on the glacier surface) water from three geographically distinct sites in Antarctica (namely Larsemann Hills, Amery Ice Shelf and central Dronning Maud Land), and a Himalayan glacier found belonged to phyla Proteobacteria, Bacteroidetes, Firmicutes, Actino-bacteria and Basidiomycota and had the ability to degrade a variety of compounds such as proteins, lipids, carbohydrates, cellulose and lignin that are documented to be present within cryoconite holes. Microcosm experiments (22/ days) show that 13–60% of the dissolved organic carbon in the water within cryoconite holes is bio-available to resident microbes.

Chemical characteristics of hydrologically distinct Cryoconite holes in coastal Antarctica

Major ions and total organic carbon in the hydrologically isolated, closed cryoconite holes showed significantly higher enrichment (6-26 times and 9 times, respectively) over the conservative tracer ion Cl– possibly due to sediment dissolution and microbial synthesis during isolation period. In contrast, depletion of major ions and organic carbon were observed in the open, hydrologically connected holes due to their discharge from the cryoconite holes through interconnected streams. The study suggests that the contribution of cryoconite holes to the nutrient and microbial transport to downstream environments vary with the extent of hydrological connectivity.

Influence of gaseous and particulate species on neutralization processes of polar aerosol and snow

The inter-conversion of nitrogen and sulfur species between the gas and particulate phases and their interaction with alkaline species influences the acidity of the aerosols and surface snow in Ny-Ålesund, Svalbard. The results suggested that nitrate-rich aerosols are formed when PAN (peroxy acetyl nitrate) disassociates to form NO2 and HNO3 which further hydrolyzes to form pNO3– (particulate nitrate). The acidity of the aerosols and snow evaluated through cation/ anion ratio (C/A) indicated alkaline conditions with C/A > 2. The bicarbonates/carbonates of Mg2+ played an important role in neutralization processes of surface snow while the role of NH3 was dominant in aerosol neutralization processes. Such neutralization processes can increase the aerosol hygroscopicity, causing warming.

4.1.2 Polar Remote Sensing

Analysis of Melt Duration and Onset dates over Antarctic ice shelves using multiple scatterometers (2000-2017)

Active microwave measurements, particularly from scatterometers, were used to

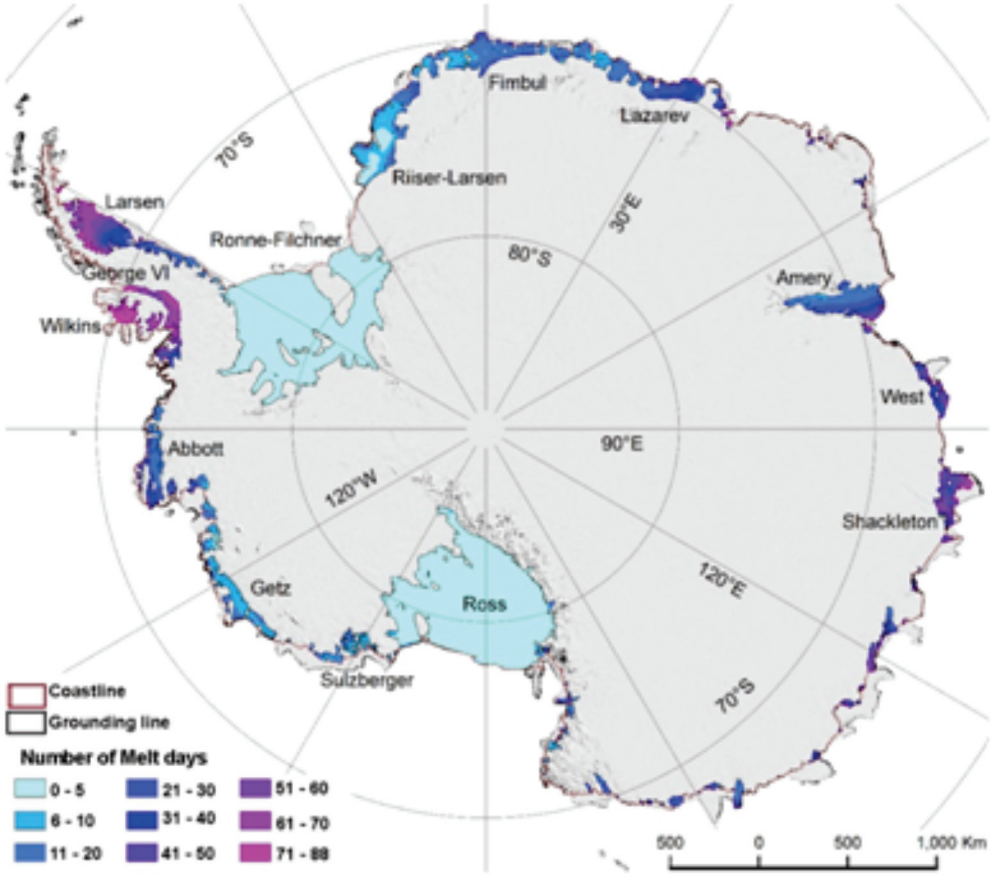


Fig 4.1 Average extent of melt duration (days) over the Antarctic shelves during austral summer (2000-2018)

detect melt duration and onset date. The average melt duration indicated prolonged melt duration (> 51 days) over the east and west Antarctic Peninsula (Fig. 4.1). Ronne-Filchner and Ross ice shelves depicted lowest duration (< 5 days). During El Nino events extensive melting on the western Ross shelf was noted. On the northern shelves of Riiser-Larsen, Fimbul and Lazarev the duration ranged from a minimum of 5 days to <40 days. The outer limits of Amery ice shelf showed high melt duration (<40 days) compared to the interior (<20 days). Other shelves on the southwest coast depicted high melt duration (55 days on average). On the periphery of Amundsen and Bellingshausen seas, we found melt duration of 25 days. Positive Southern Annular Mode and the deepening of the Amundsen Sea low and shifting of its central low pressure towards the Ross Sea shelf over the study period are some factors that have influenced the melt duration on the shelves from Antarctic Peninsula to Ross Sea sector.

The melt onset date over the Antarctic ice-shelves indicated significant shifting in the austral summer over the period of 2000-2018. Most of the areas over Larsen-C ice-shelves indicated that in first decade (2000-2010) experienced a significant shift in the melt onset date which shifted to first or second week of December instead of first or second week of November.

4.1.3 Polar Environmental Impact Assessment

Persistent Organic Pollutants (PoPs) in Terrestrial Environment of Schirmacher Hills

The occurrence of organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) in mosses, soil and water from the Schirmacher Hills, Dronning Maud Land, Antarctica (latitude 70°43´50" S–70°46´40" S, longitude 11°22´40" E–11°54´25" E) were studied and new information on direct PCB release in the region, and the degradation kinetics of PCB congeners were obtained. Near-shore lake water and moss (submerged growth under lake water) were sampled. OCPs and 28 PCB congeners were analysed using Gas Chromatograph. The total concentration of all 28 analyzed PCBs in moss samples is in the range 9.46 – 288.03 ng/g dw which are higher, by up to 10 times, than in other Antarctic locations.

Hydrochemistry of Land Locked Lakes Around, Bharati Station, Larsemann Hills, East Antarctica

The water samples collected from 12 different lakes around Bharati station (Fig. 4.2) were analysed for physical, physio-chemical, trace and ionic constituents. The pH of the examined lake water shows alkaline condition (7.74 to 11.41), may be due to the effect of alkaline earth followed by atmospheric precipitation in the form of snow and sea spray. Significant positive correlation is observed between major cations and anions along with few trace elements. It is concluded that the hydro-chemistry of the lakes in the promontory of Larsemann Hills is controlled by the lithology, precipitation, evaporation and the effect of sea spray.

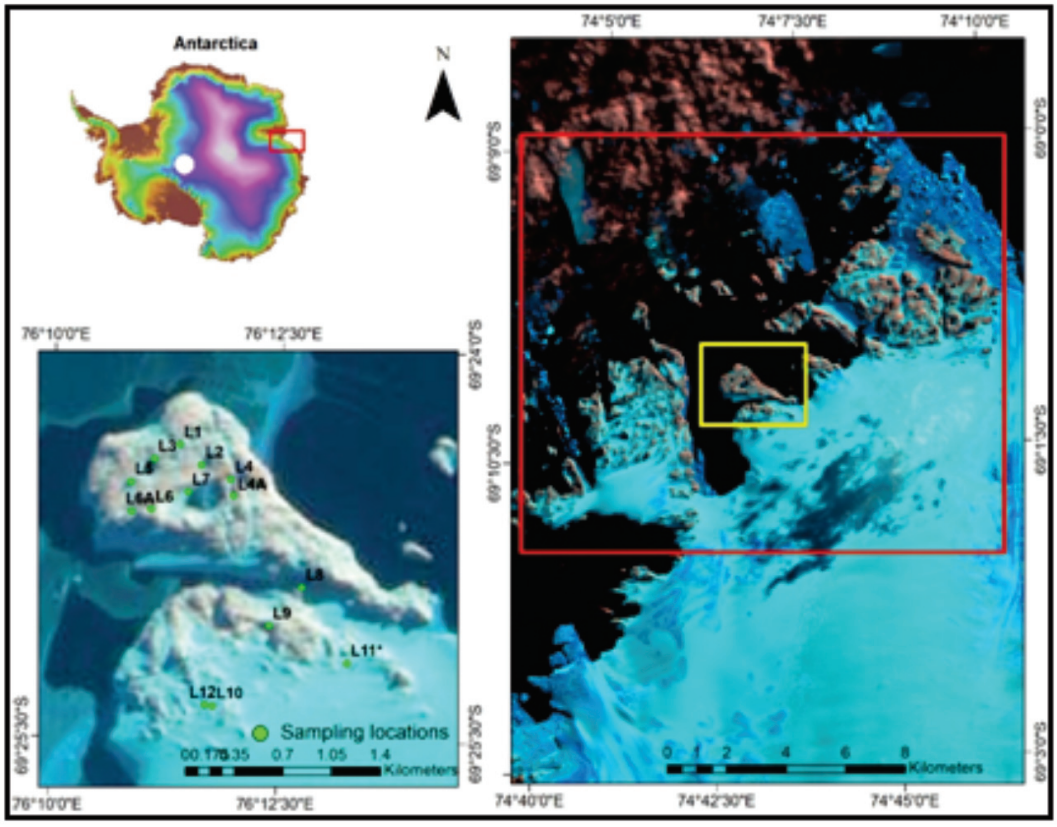


Fig 4.2 Location map of the study area

4.1.4 Polar Micropaleontology and Past Climate

The research focuses on reconstruction of past-climate using biological proxies (foraminifera-diatom-coccolith), geochemical proxies (stable isotopes-organic geochemistry-elemental concentration) and physical proxies (grain size variation in sediments-environmental magnetism) along with the modern biogeochemistry of Antarctic lakes and Southern Ocean. A brief report from each study area is given below.

Climate mediated changes in F. Kerguelensis and T. lentiginosa sizes during the Glacial-Interglacial periods: Southern Ocean Paleoceanography

Southern Ocean diatom size variability has been proved useful to infer recent and past oceanic conditions at the glacial–interglacial timescales. A sediment core from Southern Ocean (550 01'S latitude and 450 09'E longitude) covering the lat 153 kyr and covering marine isotopic stage (MIS) 6 i.e., the penultimate Last Glacial Maxima was studied to measure the apical length of F. Kerguelensis and radius of T. Lentiginosa. The records revealed that F. Kerguelensis and T. Lentiginosa have smaller valve sizes in sediments representing the glacial periods (MIS 4 and 6) in contrary to the interglacial period (MIS 5). It was seen that smaller size of these diatoms during glacial periods corresponds to increased sea ice presence and lower Antarctic temperature.

Response of Southern Indian Ocean coccolitho-phores to climate change: evidence from laboratory culture experiments

Laboratory controlled experiments on 26 Gephyrocapsa ceanic (Fig. 4.3) strains collected from Indian Ocean, North and South Pacific Ocean; North and South Atlantic Ocean and Equatorial Ocean was carried out at five different temperatures viz., 100C, 150oC, 200C, 250C and 300C. Samples were collected for Scanning Electron Microscopic studies and for calculation of coccolith mass. The preliminary results show diverse response of G. ceanic strains to different temperatures.

Fig 4.3 G. Oceanic coccosphere [strain (RCC1314)]

Paleolimnological records of regime shifts from marine-to-lacustrine system in a coastal Antarctic lake in response to post-glacial isostatic uplift

-Low altitude coastal lakes along the Antarctic margin often contain both marine and lacustrine sediments as a result of relative sea level (RSL) changes due to deglaciation. The sediments also record changes in regional climate. A sediment core from a coastal lake in Larsemann Hills, East Antarctica viz., Stepped Lake – SL (Heart Lake), records distinct changes in diatom abundance during the mid-Holocene (8.3 to 4.6 ky BP). The diatom community shows shift with the major part of Holocene (8.3 to 5.5 ky BP) dominated by sea-ice and open-ocean diatoms while the core-top sections (5.5 to 4.6

ky BP) transitions to lacustrine diatoms (S. inermis). These observations confirm that the basin was marine, and later became isolated as a result of post-glacial isostatic uplift after 4.7 ky BP.

4.1.5 37th Indian Scientific Expedition to Antarctica

The 37th Annual Indian Scientific expedition to Antarctica (ISEA) was launched to carry out various scientific projects under cryosphere and ice core studies, remote sensing studies, lacustrine studies, and environmental studies. Out of 48 proposals received, a total of 31 research proposals were recommended for the 37th ISEA by the Expert Committee. The National Co-ordination Committee for Polar Programme (NCPP) assessed the recommendation of Group of Experts, where the list of participating institutions and expedition team were finalized. Dr. Yogesh Ray (NCAOR) was selected as Voyage Leader, Dr. Shailesh Pednekar (NCPOR) as Bharati Leader and Shri Sunny Chug (IMD) as Maitri Leader. Shri Sudarshan Patro (IIG) was designated as the Deputy Leader for Bharati. A total of 116 persons consisting of 54 scientists (including 04 Norwegian scientists at Maitri under the MADICE project) and 62 logistic support staff from 28 different national organizations were deployed between November 2017 and January 2018.

National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO) successfully installed and commissioned an additional antenna for augmentation of Data Reception System (DRS) and Data Communication System (DCS) (Fig 4.4).

Fig. 4.4 Construction of DRS-2 antenna at Bharati

4.2 Scientific Studies in Arctic

4.2.1 Characterization of Polar Aerosols

Extensive measurements of the micro-physical and optical parameters of aerosols have been made over the Svalbard region of Arctic since July 2010. The continued effort pursued through the successive Expeditions has led to the generation of continuous long term data from the Arctic and brought up several new aspects on the physical and optical properties of aerosols, associated processes, and their radiation interaction over the Polar region.

4.2.2 Hydrography of Kongsfjorden

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. Indian researchers have been conducting systematic measurements with respect to the hydrography of Kongsfjorden, an Arctic fjord since 2011. As a part of Long term monitoring program, several field campaigns pertaining to hydrology, biology, chemistry and environmental studies, were conducted in 2017-18. High resolution physical and biochemical measurements collected inside Kongsfjorden since 2014 using the 'IndARC' multisensor subsurface mooring suggest ~30% increase in the Atlantic water (AW) volume and consequent increase in the temperature.

Regional Ocean Modelling Systems (ROMS) simulated sea level and currents due to tides for the Kongsfjorden-Krossfjorden region showed good comparisons with observations (Fig. 4.5). Model showed weak (strong) barotropic and internal tides inside (outside) the fjords (< 2 cm/s) (Fig. 4.9). Weak tidal currents was recorded inside both the fjords, however, the mouth and the open ocean side of the fjords experienced strong tidal currents.

4.2.3 Cryospheric studies

Vestre Broggerbreen glacier is monitored from last five years and Feiringbreen glacier (cross the fjord; opposite to Vestre Broggerbreen glacier) from last two years in Spitsbergen, Svalbard Arctic. The winter balance of Vestre Broggerbren glacier is 0.51±0.1m we for year 2016-17 which is significantly higher (25%) than

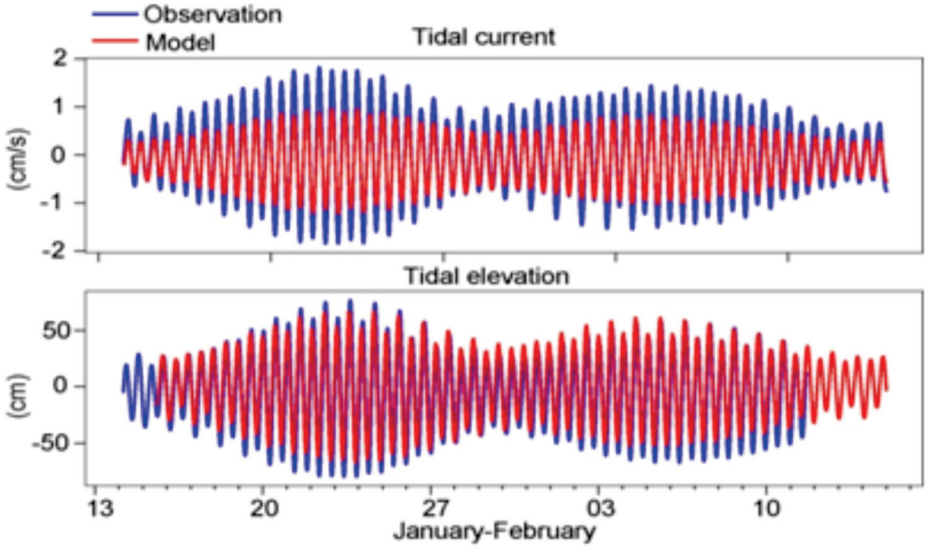


Fig 4.5 Comparison between the model and observed tides.
Tides experience strong spring-neap variability. Amplitudes of tidal currents are weak inside the fjord.

previous year winter balance (0.40±0.1 m we). The average snow depth was slightly higher than previous year and range of snow depth was observed from 43cm in lower ablation to 200 cm in upper accumulation in Vesstre Broggerbreen during early spring 2017. However in summer there was no snow in ablation except few patches close to lateral moraine but in accumulation it was varies from 80cm to 160cm in both the glaciers Vestre Broggerbreen and Feiringbreen.

4.2.4 Operations and management of Arctic Station 'Himadari'

- The Indian research station 'Himadri' was manned for over 120 days
- A total of 32 researchers visited the station and another 2 have sailed in RV Lance under 19 different scientific projects.
- The Gruvebadet station was made fully operational with instruments like Radiometer profiler, Micro rain radar, Aethalometer, Nephelometer, Multistage impactor, Net Radiometer etc. collecting data round the year.

4.3 Himalayan Studies

4.3.1 Glaciological studies of benchmark glaciers in Chandra Basin, Western Himalayas

In order to understand glacier impact on hydrology and climate of Himalaya region, six benchmark glaciers (Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Gepang and Kunzam) of Western Himalaya have been monitoring since 2013 on long term basis. Field station Himansh at Sutri Dhaka, Chandra basin is used as base for all operational activities to carry out Glaciological studies in the Himalaya (Fig.4.6).

Fig 4.6 A synoptic view of station Himansh including field activities over studied glaciers in Chandra basin

4.3.2 Mass balance estimate of six benchmark glaciers revealing a huge ice mass loss and significant glaciers thinning in Chandra basin

Mass balance measurements at six studied glaciers revealed an interesting response of ablation processes. Glaciers of Chandra basin have experienced an overall negative mean annual mass balance of 1.02±0.20m we (Sutri Dhaka: -0.87±0.17m we; Batal:-0.42±0.08m we; Samudra Tapu: -1.12±0.21m we; Bada Shigri: -0.56±0.11m we; Gepang Gath: -1.05±0.20m we and Kunzam: -0.28±0.04m we) for the year 2016-17 (Fig 4.7). Ablation processes shows the high melting in clean type glaciers than debris covered glaciers. The water terminated glaciers has experiencing much higher melting rate than land terminated glaciers. However solar radiation is the dominant factor to control the ablation rate followed by altitude, precipitation, debris cover etc.

4.3.3 Geospatial observations of topographical control over the glacier retreat, Miyar basin, Western Himalaya, India

A total of 29 glaciers covering an area of

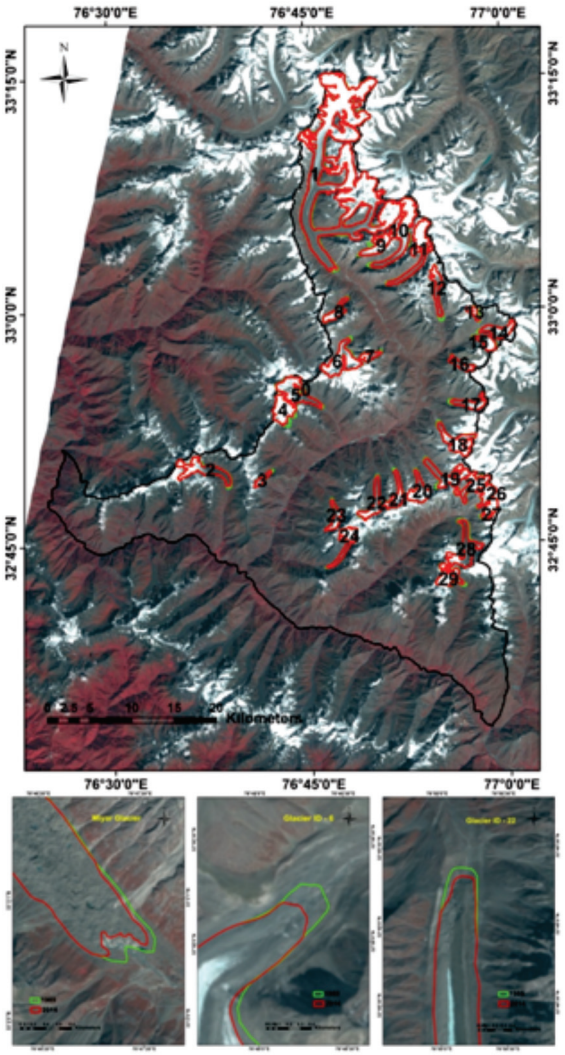


Fig 4.8 Glaciers retreat and terminal fluctuation in Miyar basin for the period 1989-2014.

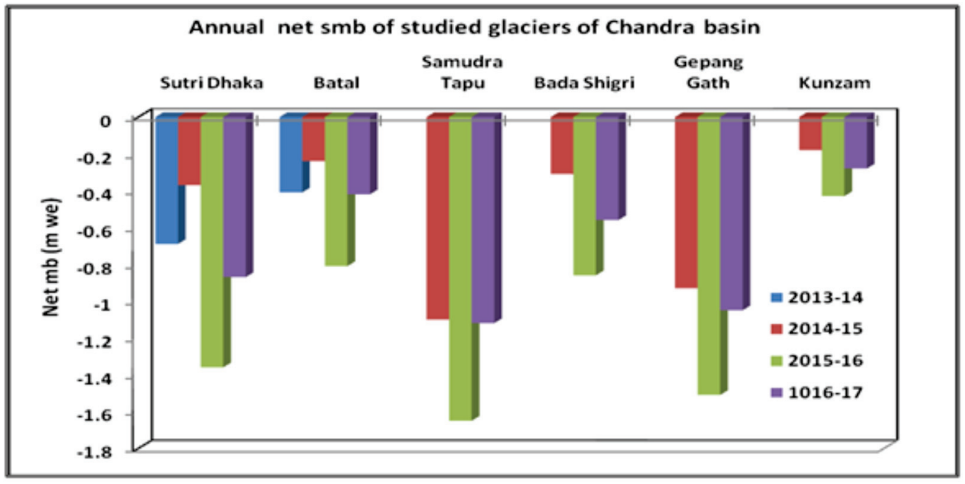


Fig. 4.7 Annual surface Mass Balance of six representative glaciers of Chandra basin, Western Himalaya during last four years (2013-17)

~227 km2 were monitored in Miyar basin and estimated for the retreat pattern of these glaciers for the period 1989-2014 (Fig. 4.8) using satellite data of Landsat series (TM, ETM and OLI). Observations revealed that there was significant loss (4%) in area (9 km2 ± 0.7 km2) for studied glaciers in this basin during 1989-2014. Large glaciers having higher slop and debris were showing lower retreat than small glaciers having gentle slope and low debris.

4.4 Southern Ocean Studies

4.4.1 El Nino Southern Oscillation (ENSO) teleconnections and heat flux anomalies in the southern high latitudes

During El Nino, anomalous pole ward moisture transport and a high pressure cell induces a suppressed latent heat flux anomaly (Fig. 4.9) in the south Pacific, which in turn induces thinner mixed layer in the ocean and warm/cools the SST. The presence of a high pressure anomaly enhances the downward short wave radiation and makes the mixed layer shallower resulting in a well developed SST anomaly. In the South Atlantic exactly the opposite is noticed and the situation reverses during a LaNina. Apart from the surface heat fluxes ocean transport of heat by means of ocean currents, known as advection also plays an important role in maintaining SST; this however was not prominent in the present study, indicating the overwhelming role of turbulent heat fluxes in generating sea surface temperature anomalies. The study shows that the tropical phenomenon ENSO has an explicit influence on the heat fluxes of the southern high latitudes.

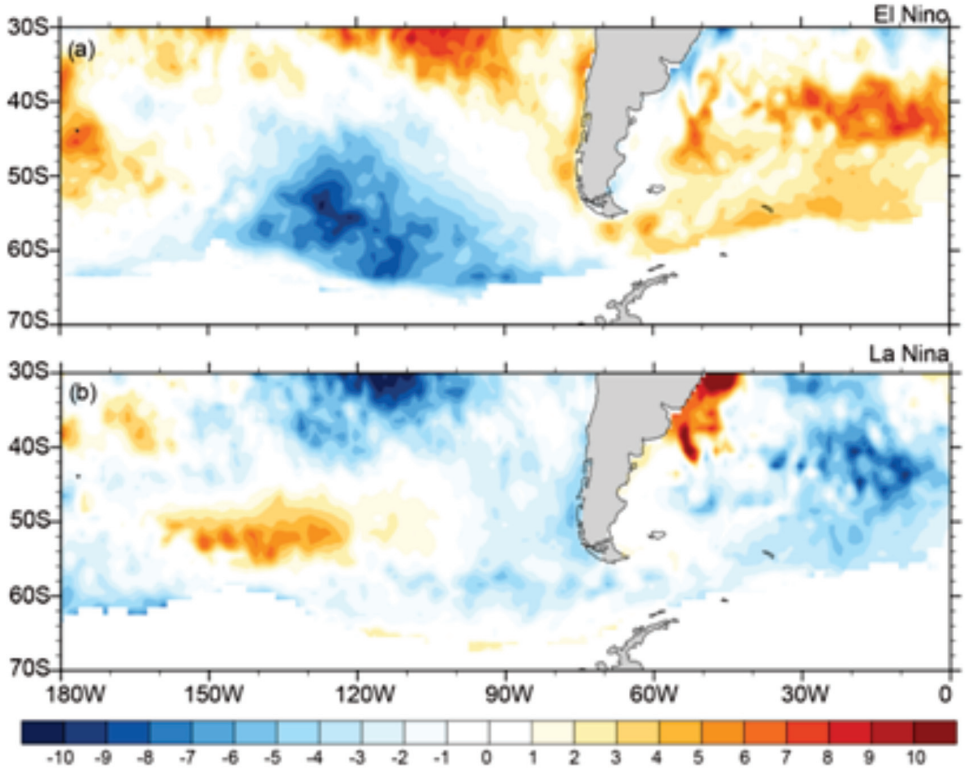


Fig. 4.9 Summer time (DJF) averages of Latent heat flux anomaly (Wm-2) obtained from ECMWF ERA reanalysis for (a) El Nino and (b) La Nina Years.

4.4.2 Processes controlling the frontal variability of organic carbon in the Indian Ocean sector of Southern Ocean

The processes controlling the organic carbon variability across the fronts were studied using Total Organic Carbon (TOC) and Apparent Oxygen Utilization (AOU). TOC was higher in warmer Subtropical Front (STF) waters compared to the Polar Front (PF) waters, with a range of 80µM to 121µM. The observed TOC also decreased with depth. The drop in TOC with depth was more evidently beyond 120-200m, likely due to the decrease in net production and higher heterotrophic processes beyond the euphotic depth. Also, the significant TOC-AOU correlation beyond 120m across the fronts, especially the STF and Subantarctic Front (SAF), was attributed to heteroterophic biological processes especially remineralisation via bacterial respiration. The present study revealed that the variability of TOC is not entirely a response of biological processes but has a major contribution from physical factors like mixing and temperature gradient driven processes.

4.4.3 Nitrogen uptake by phytoplankton in surface waters of the Indian Ocean sector of Southern Ocean during austral summer

Nitrogen uptake rates; measured using the 15N tracer technique, in the surface waters (ca. 0-1 m) of different frontal zones (the subtropical front (STF), sub-Antarctic front (SAF), Polar Front-1 (PF1) and Polar Front-2 (PF2) in the Indian sector of the SO were studied to understand the preferential nitrogen uptake by phytoplankton, and the influence of the physical forcing (if any) on this biological response. Results indicate southward decrease of sea surface temperature (SST), whereas surface salinity did not show any significant trend. Nutrients (NO3– and SiO44–) concentration increased southward from STF to PF; while ammonium (NH4+), nitrite (NO2—) and phosphate (PO43–) remained comparatively stable. Analysis of nutrient ratios indicated potential N-limited conditions at the STF and SAF but no such scenario was observed for PF. In terms of phytoplankton biomass, PF1 was found to be the most productive followed by SAF, whereas PF2 was the least productive region. Results indicated potentially near equal contributions by new production (53%) and regenerated production (47%) to the total productivity by phytoplankton. Nitrate uptake rate increased with increasing latitude, as no systematic spatial variation was discerned for NH4+ and urea. Like N-uptake rates the f-ratio also increased towards PF region indicating comparatively higher new production in the PF than in the subtropics.

4.4.4 Inter-annual variability of Chlorophyll-a and Diatoms in the frontal ecosystem of Indian Ocean sector of Southern Ocean (IOSO)

The variability of Chlorophyll-a (Chl-a) and diatoms in the frontal ecosystems of the IOSO have been investigated along with the SST, winds, photosynthetically active radiation (PAR) and nutrients datasets for the period of 1998-2012. Combined analysis of in-situ, model and satellite observations indicate that the variability of Chl-a and diatoms were primarily influenced by light and wind. The Chl-a was higher at the SAF followed by the STF and the PF. The diatom concentration was higher at the SAF followed by the PF and STF. Maximum concentration of Chl-a and diatoms commonly observed at the SAF region are probably due to the moderate PAR, SST and wind. Dominance of diatoms at the PF may be attributed to their adaptability for low light conditions

4.4.5 Indian Scientific Expedition to Southern Ocean (2017-18)

The 10th Indian Southern Ocean expedition (ISOE-10) was launched on 9th December, 2017 onboard chartered Ice Class Research Vessel SA Agulhas. The expedition team consisted of 42 participants representing 8 different research institutions/universities of India and 1 participant from Scripps Institute of Oceanography, USA.

During the expedition, multi-disciplinary observations such as i) water sampling and profiling using CTD, ii) Underway CTD (UCTD) and XCTD along the ship track, iii) Lowering- ADCP, iv) Microstructure profiler v) Radiometer, vi) Inherent Optical Profiler (IOP), vii) Radiosonde launching, viii) ARGO and SOCCOM floats deployment, ix) Multiple Plankton Net and x) Bongo net were carried out across different frontal regions of IOSO and in the Prydz Bay (Fig. 4.10) to understand the complex process of physical, biogeochemical and air-sea interactions and their role in the ecosystem of IOSO.

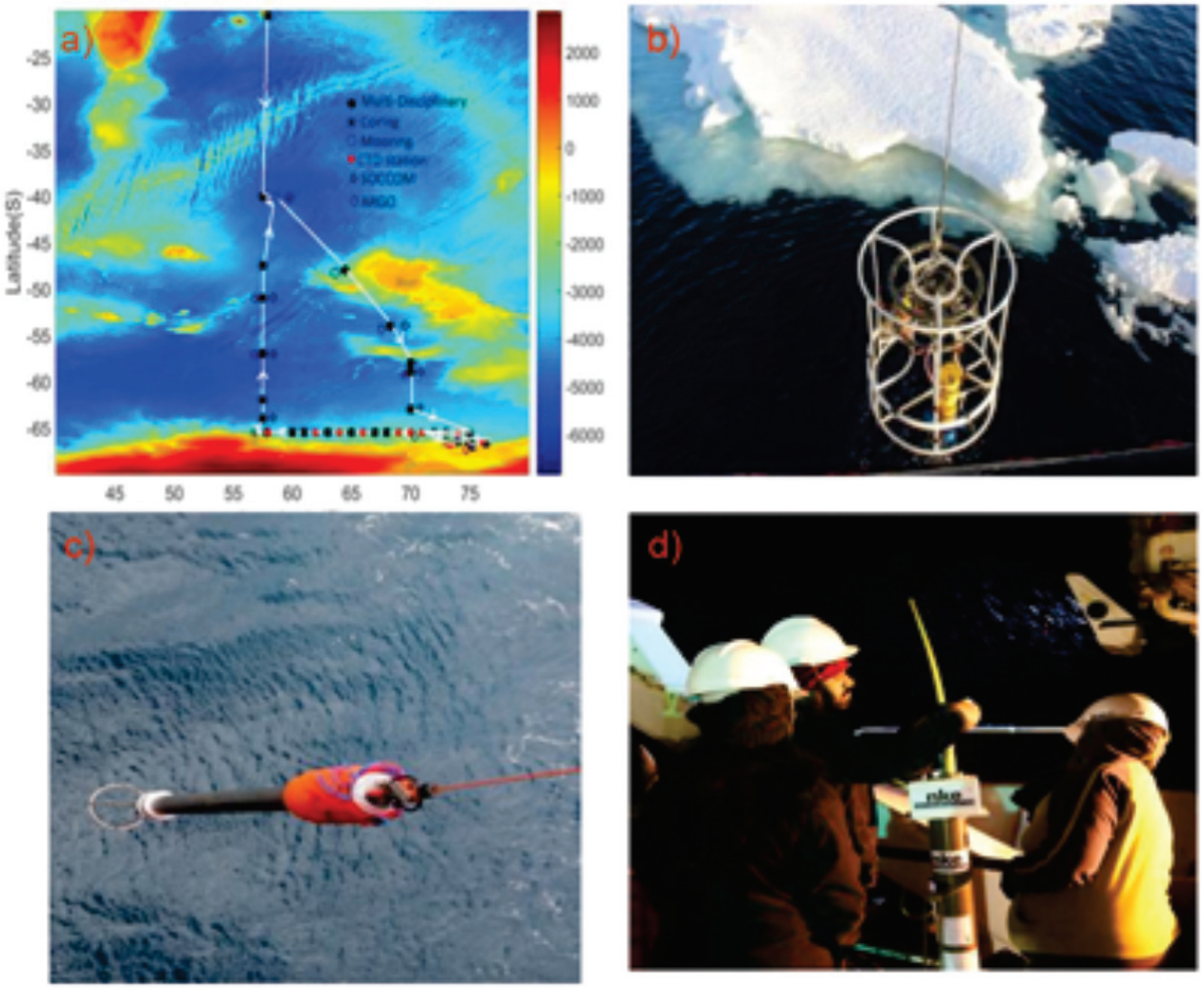


Fig.4.10 Showing the cruise track along the CTD and multidisciplinary observations, b: LADCP fixed with a CTD rosette, c: Microstructure profiler operation and d: Deployment of ARGO floats in the expedition

4.5 National Polar Data Center (NDPC)

National Polar Data Center (NPDC) is an authoritative platform for managing and sharing data of Indian Polar Research (Fig. 4.11). It covers data from a broad spectrum of disciplines, including oceanography, glaciology, resources and environ-mental science, biology & ecology, atmospheric science, etc. Polar date sets received from different institutes of India have been migrated into polar data portal. The Scientists/ Scholars/ Researchers could fill the online metadata form along with / without processed data by choosing the expedition (s) such as Antarctica, Arctic and Southern Ocean and save it. NPDC has become a nodal centre of" India's Data-sharing Network of Earth System Science".

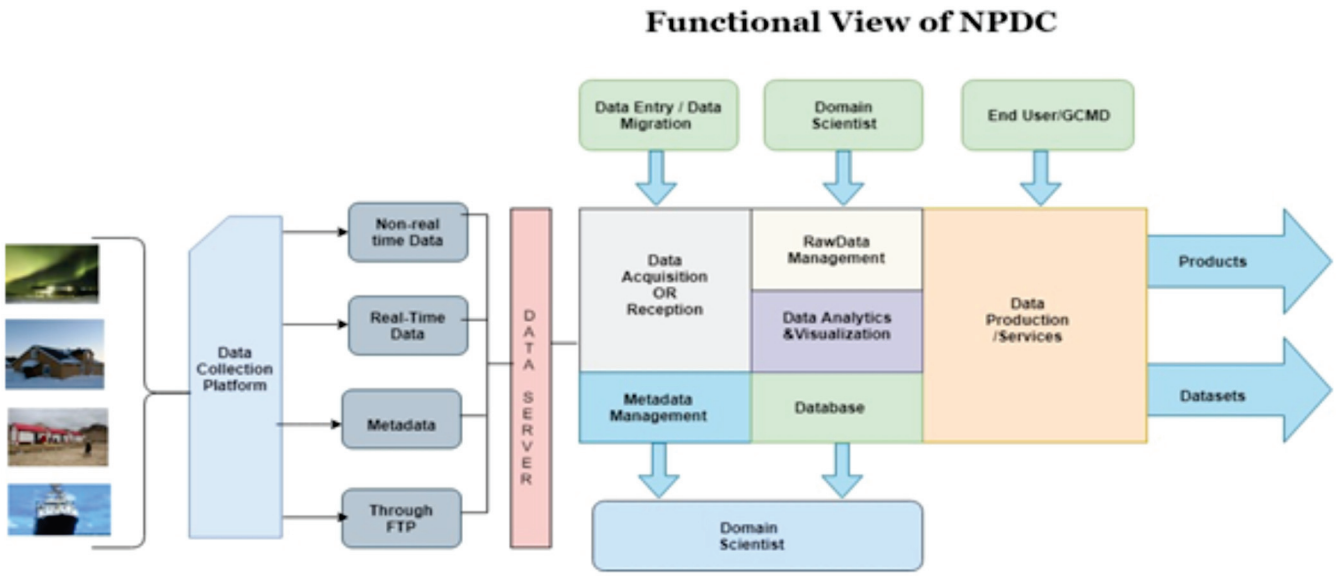


Fig.4.11 Functional view of NPDC

CHAPTER 5 Seismology And Geosciences Research (SAGE)

5.1 Observational Seismology, Earthquake Monitoring and Services

The national seismological network, being operated and maintained by the National Centre for Seismology (NCS), located a total of 268 earthquake events during January 1st, 2018 - December 31st, 2018 in and around India (Lat. 6-38^{0}N & Long. 68-98^0 E). While most of the events were of small in size (M $\leq$ 5), 36 events fall in the category of moderate to strong earthquakes, in the magnitude range 5.1 - 6.2 (Fig. 5.1). 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.

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

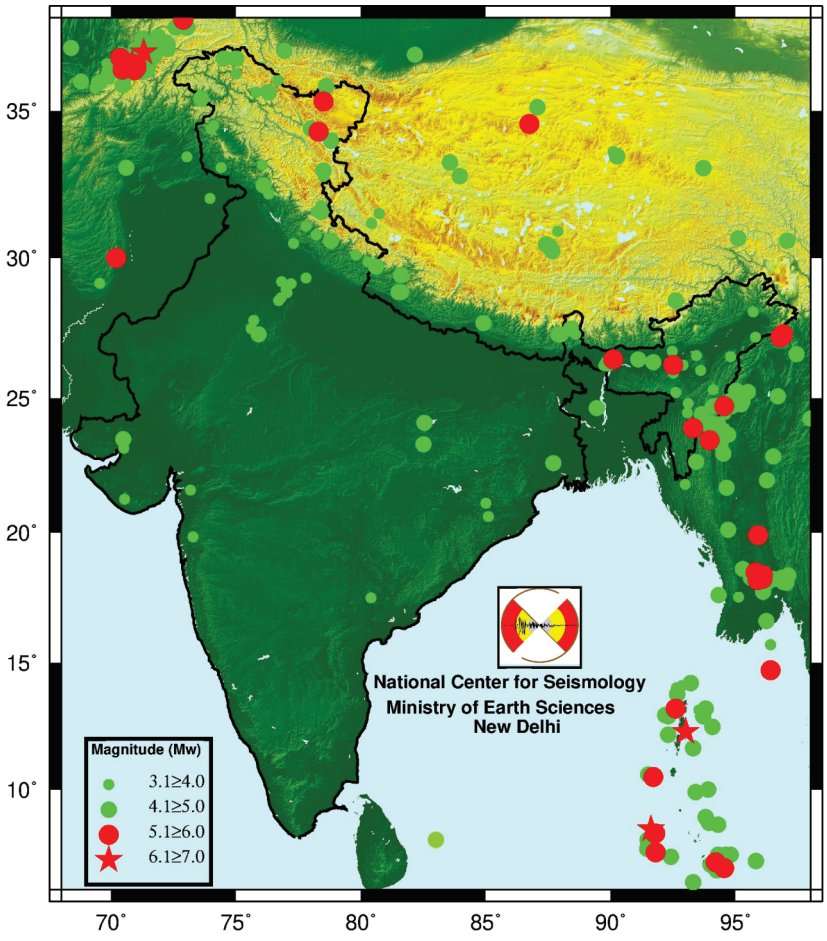


Fig. 5.1 Seismicity during January to December, 2018

5.1.1 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 up-gradation completed with up-gradation of 38 stations and installation of 2 new stations. The second phase of augmentation and upgradation of National Seismological Network (NSN) under Optimum Seismological Network (OSN) programme, comprising installation of 31 new and upgradation of 7 existing seismological observatories, has successfully been completed. The

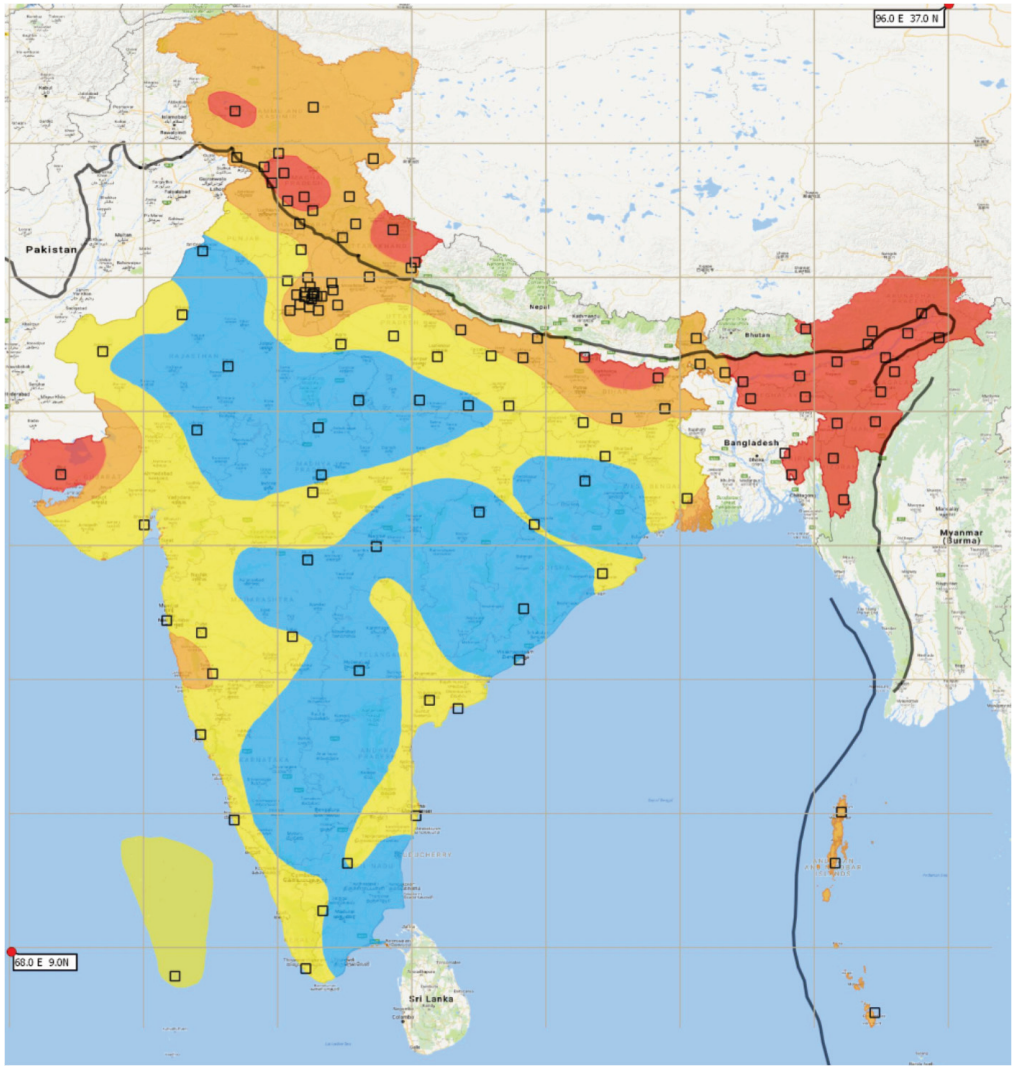


Fig. 5.2 Location map of 115 seismological observatories of the national network

National Seismological Network now comprises of 115 seismological observatories spread across the country and the earthquake detection capabilities are improved to a minimum threshold earthquake magnitude of 3.0. Location map of 115 observatories of the national network is shown in (Fig. 5.2).

These observatories are being integrated with Operational Centre through VSAT communication facility, established under the Integrated Seismic and GPS Network (ISGN). ISGN comprises of 2 numbers of VSAT Hubs and 126 numbers of VSAT terminals; and two data centers, each at INCOIS and NCS.

5.1.2 Microzonation of selected cities

The Seismic Microzonation work related to Geophysical investigations has been initiated for the four selected cities, namely, Chennai, Bhubaneswar, Coimbatore, and Mangalore. In addition, microzonation for the 8 more cities, considered to be important from seismic point of view, is being taken up separately on priority through academic and research organizations in India. The list include, Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad.

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

Under the scientific drilling project in Koyna region, which aims at understanding of physics of the earthquakes and developing the predictive model, rare geophysical datasets have been obtained up to depth of 3 km from downhole measure-ments in pilot borehole. These data have provided critical inputs for design of deep borehole observatory in the Koyna Seismogenic Zone. Plans are being worked out to conduct seismic studies in the pilot borehole, which would be followed by installation of seismometers for long-term monitoring.

5.2.1 Physical and mechanical properties in Koyna seismogenic zone

The Koyna pilot borehole KFD1 passed through 1247 m of Deccan basalt and continued into the granitic basement up to 3000 m. Downhole geophysical logs acquired in the borehole provided crucial information about the physical and mechanical properties of the rock formation, fracture/ fault zones, in-situ stress regime, fluid flow zones and temperature regime. Anomalous physical and mechanical properties at various depths in the basement section, potentially associated with highly fractured zones, have been delineated (Fig. 5.3). Anisotropy analysis of dipole sonic log data reveals stress perturbations across the majority of anomalous zones. High concentrations of helium gas obtained from real-time gas monitoring during drilling confirm their connection with active fault (s). The measured temperature at 3 km depth is 78^{0}C. The datasets provide critical inputs for the design of the deep borehole observatory planned in the region.

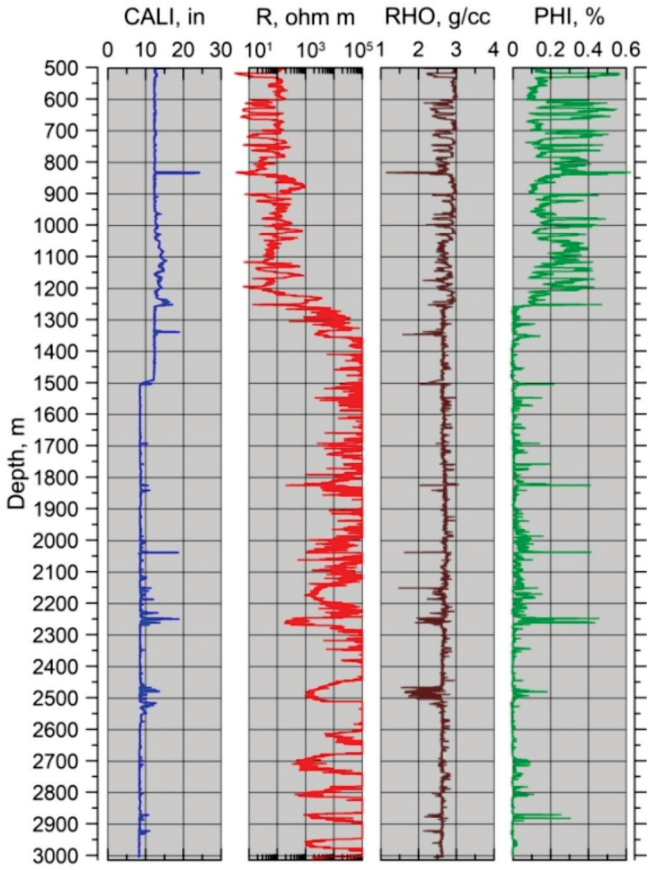


Fig. 5.3 Plot showing geophysical logs (CALI: caliper, R: resistivity, RHO: density and PHI: porosity) obtained in the Koyna 3 km deep borehole KFD-1.

5.3 Geological and Geophysical studies

5.3.1 Scientific Proposals for Andaman Drilling Endeavour (SPADE) Workshop: September 17-18, 2018

With an objective to develop scientific proposal (s) for drilling and investigating the Indian Ocean near Andaman subduction zone an international workshop was organized by NCPOR on 17-18 September, 2018 at Goa. The workshop was focused around three main themes: **1) Tectonics of oblique convergence in the Andaman subduction zone –** understanding the convergence-transpressional transition, the generation and propagation of seismicity, the

effect of subduction of large sediment piles on slab processes, history of volcanism in Andaman arc, growth of continental crust beneath the arc, the timing and nature of back-arc spreading and the relationship between the thermal structure of the oceanic crust and the development of magnetic anomalies. **2) Recovering Asian monsoon archives from the Andamans and Indian margins –** long-term, high resolution records of Indian monsoon circulation from the Paleogene to present, including the influence of the Himalayan orogeny and its consequential signatures of uplift, weathering, erosion, sediment deposition. **3) Recovering depth-transects from open-ocean, bathymetric highs –** assessment of dust transport pathways, timing of gateway restrictions and surface, intermediate, and deep water circulation over time.

A total of 33 scientists including, earth scientists, marine biologists and climatologists from India and abroad participated and talked about their science plan for possible drilling during the workshop.

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

A long term scientific program to explore possible reasons behind the largest geoid low on earth, also known as the Indian Ocean Geoid Low (IOGL), was initiated by NCPOR a few years back. The IOGL, centered near to south of Sri-Lanka, is the largest geoid low in the globe and investigations of IOGL are expected to help in understanding the dynamics of the earth's interior. Even though various hypotheses have been proposed to explain possible causes of IOGL, a conclusive explanation remains unreached. The 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, IOGL.

In a recently concluded ocean expedition onboard ORV *Sagar Kanya*, 17 OBS instruments have been deployed in Indian Ocean to make an array, recording data at 100 sps **(Fig. 5.4)**. These broadband passive OBS instruments will be recording the local, regional and teleseismic

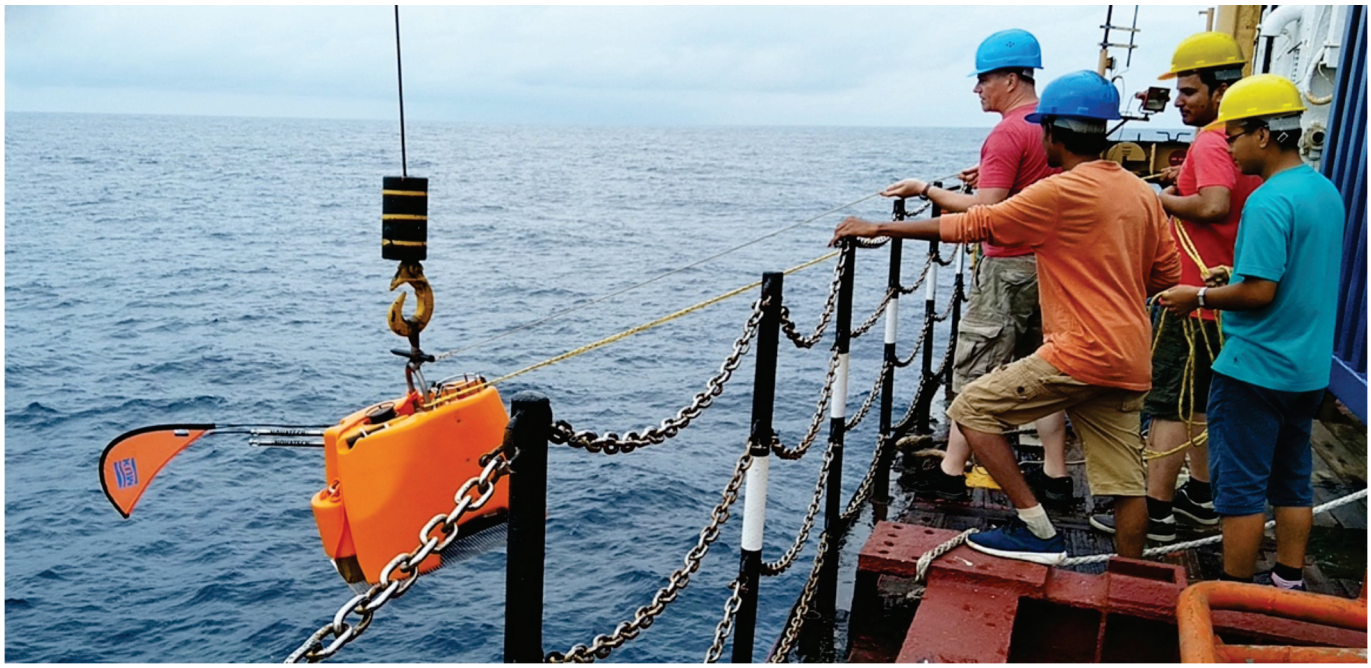


Fig 5.4 Deployment of a passive ocean bottom seismometer in the IOGL region onboard ORV Sagar Kanya

earthquakes for a period of one year or so and these new marine seismological observations will provide high resolution images of the Earth's interior, which are expected to unfold the enigmas of the largest geoidal low, the Indian Ocean Geoid Low.

5.3.3 Mantle structure beneath the Indian Ocean Geoid Low: Insights from modeling

The lowermost mantle (D2 2 layer) structure beneath the Indian Ocean Geoid Low (IOGL) is important as it plays a crucial role in controlling the dynamics of lower mantle. For a better understanding of the seismic structure of the D3 layer, NCESS has modeled the compressional and shear wave velocities, especially, within the assumed D3 layer. The S40RTS global tomographic model for the S waves and the GyPSuM compressional global tomographic model for the P waves were utilized in the study. The corrected differential travel time residuals reflect the anomalies within the D3 layer (220 thick layer above the core mantle boundary). The corrected differential travel time residuals vary from -9.6 to 5.0 s for the shear wave and -4.7 to 3.3 s for the compressional wave. Modelling of the obtained differential travel time residuals indicate that the shear wave velocity perturbations in the D3 layer vary from 8.4% to -3.0% and the compressional wave velocity perturbations vary from 6.5% to -5.2%. Interestingly, the high compressional and shear wave velocity perturbations sample the IOGL region, while the negative velocity perturbations sample the adjoining geoid high region. The modelling results suggest the existence of high velocity material lying above the core mantle boundary (CMB) beneath the IOGL. This high velocity material may be attributed to the dehydrated Tethyan subducted slabs at the CMB.

5.3.4 The Makran waves: A mid-latitudinal low level jet induced surface waves in the Arabian Sea

The 'Makran waves' is a newly coined term to describe high frequency quasi periodic surface waves in the northern Arabian Sea, which are induced by a mid-latitude Low Level Jet (LLJ). The surface wind systems off the southern coast of Pakistan and the Arabian Sea, when they get further modified and redistributed due to presence of the Makran mountain ranges are known as Makran winds. Recent studies carried out by NCESS on the atmospheric variability over Arabian Sea identified the occurrence of northerly LLJ systems which can influence the wave pattern. It is observed that with intensification of the Makran winds, the prevailing wind system in the northern Arabian Sea weakens, resulting a gradual increase in the significant wave heights in the NW-NE sector. The measured wave data along the west coast of India shows convincing evidence of the presence of Makran waves, induced by the Makran winds. These waves are quite prominent during the pre- and post-monsoon seasons, with average significant wave heights of 2-3 m. However, a decreasing trend in the order of magnitude could be seen as one moves from the north to the south. These waves, though resemble the Shamal waves in periodicity, can be considered as unique, since they have distinct generation and propagation characteristics. Different stages during and after the development of a northerly LLJ event which occurred in December 2012 is illustrated in **Fig. 5.5**.

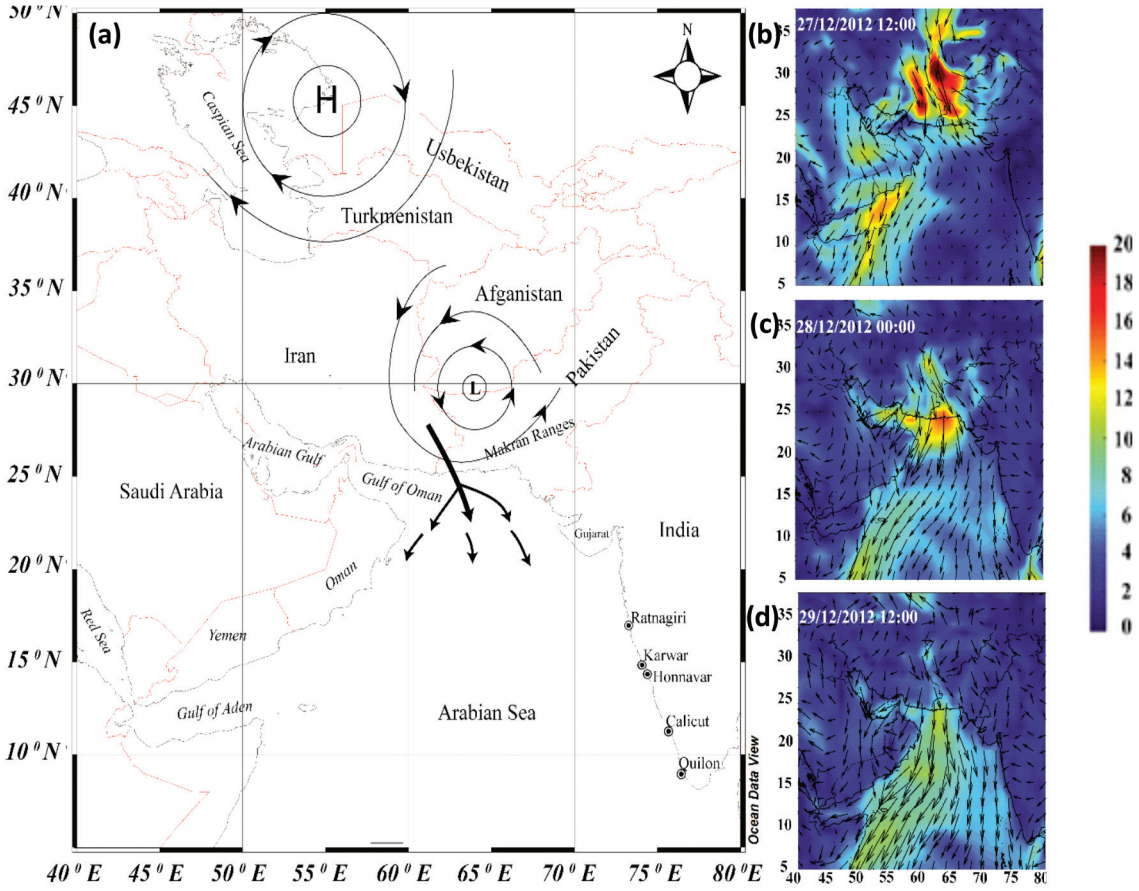


Fig. 5.5 (a) Development of the northerly LLJ and subsequent transformation as Makran winds, (b) Snapshot of the northerly LLJ at 850 hPa (c) surface wind after 12 Hours and (d) surface wind after 36 hours.

5.3.5 Infra-gravity waves in the northern Indian Ocean and its implications on the west coast of India

Ocean surface waves comprise the waves in different frequencies ranging from capillary waves (<0.1s) to Trans tidal waves (>24 hrs.). Of these, the infra-gravity (IG) waves having frequencies less (>30 s) than the wind-generated ocean surface gravity waves, but higher than the semi-diurnal tides, can have significant influence on the coastal hydrodynamics, particularly, the beach dynamics and sediment transport. These IG waves are generated by non-linear mechanism and they propagate freely in the deep ocean. Studies pertaining to the generation, propagation and dissipation of IG waves in the Indian Ocean are rather scanty, probably because of the limitations in getting measured data. The present study is taken up in this context to throw light on the IG waves generated in the Indian Ocean. The study, aims to investigate the spatial variability of the IG waves in the deeper parts of the north Indian Ocean which includes deep waters of both Arabian Sea (to the west) and the Bay of Bengal (towards east) that surround the Indian Peninsula.

One-year (Feb. 2015-Feb. 2016) pressure data from four Bottom Pressure Recorders (BPR) installed in the Indian Ocean **(Fig. 5.6)** by NIOT, Chennai at depths of more than 2000 m have

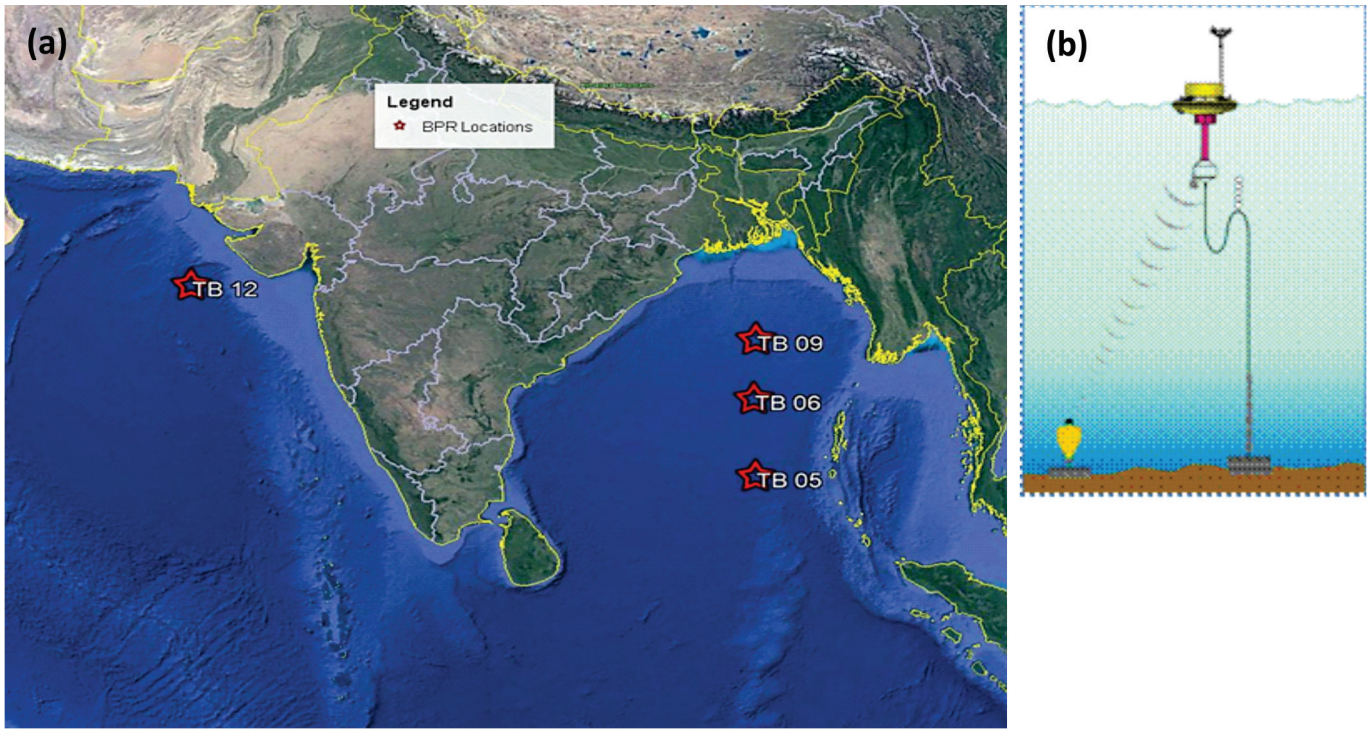


Fig. 5.6 Study area (a) Bottom Pressure Recorder (BPR) locations and (b) Anchored BPR & mooring for surface buoy

been used in the present study. The temporal variations in the sea surface elevations are derived from the recorded BPR data by applying the Fast Fourier Transformation Technique (FFT). Detailed analysis of data from these BPR stations in the northern Indian Ocean reveals that the two stations namely TB 05 and TB 12 located in the central Bay of Bengal and the northern Arabian Sea respectively, show a distinct increase in energy level, particularly between 30 sec and 20 minutes, whereas it is not so evident at the other two locations (TB 06 & TB 09).

5.3.6 Variation in rain drop size distribution and rain integral parameters during southwest monsoon over a tropical station

The variations of the rain parameters have been studied during the southwest monsoon period of 2012 over a tropical coastal station using continuous observations from Micro Rain Radar (MRR) and Optical Disdrometer (OD). These instruments were installed on the rooftop of the National Centre for Earth Science Studies (NCESS), Thiruvananthapuram ($8^0$31'22.25" N, $76^0$54'35.25" E, 20 m above MSL). The rain rate and radar reflectivity obtained from both MRR (observation at 200 m level) and disdrometer show correlation of ~90%. The comparison between integrand of rain rate integral (RD) obtained from disdrometer (blue) and MRR (red) for six rain rate bins are shown in Fig. 5.7. The peaks of disdrometer curves occur at lower diameters than MRR for the first three bins. But for last three bins (heavy rain rate bins) peak positions of disdrometer curves are ahead of MRR. The comparison between MRR and disdrometer is found to be fairly good for low rain rates and for rain >25 mm/hr. The drop size distribution (DSDs) compares well for rain drop diameters in the range 1-3 mm from disdrometer

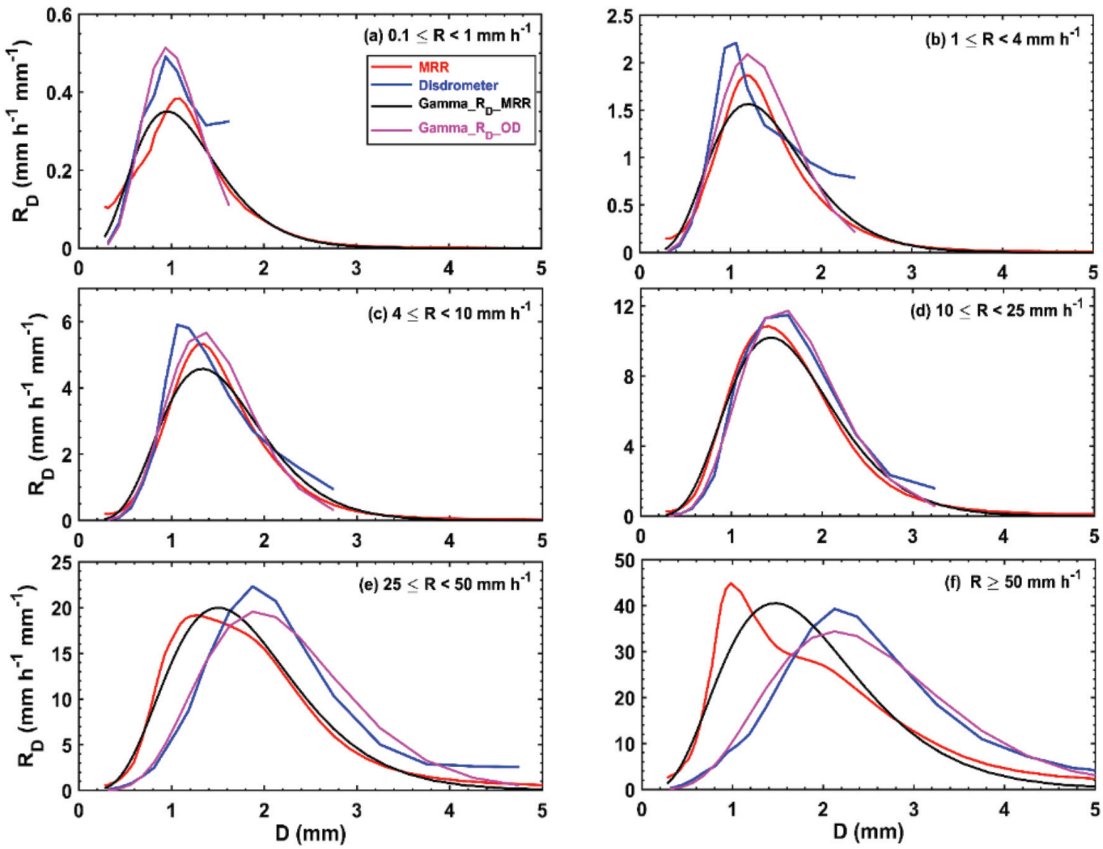


Fig. 5.7 Comparison of RD from disdrometer (blue) and MRR at 200 m (red) for six rain rate bins. Pink and black curves represent RD calculated using Gamma fit DSD for disdrometer and MRR respectively.

and MRR. Integrand of rain rate integral (RD) follows a bell-shaped distribution in which the peak position shifts between 1-2 mm drop diameters. For different rain categories the DSD spectra intercept at D~1-2 mm for both MRR and disdrometer observations. The total rain water content for bright band (BB) cases is significantly contributed by drop diameter, D~1.3 mm (1.1 mm).

5.3.7 Microphysical properties of stratiform rainfall over mid and high-altitude regions in Western Ghats

Understanding of the microphysical properties of the orographically elevated regions of Western Ghats is a major gap area. Analysis including, the in situ/remote sensing observations across mid (Braemore, Thiruvananthapuram ($8^0$45'N, $77^0$5'E) and high-altitude (Rajammallay, Munnar ($10^0$09'N, 77^0 02'E) regions has been carried out to fill up the knowledge gap to a certain extend. The two locations analysed are the mid altitude 400 m, (Braemore) and high altitude, 1820 m above MSL (Rajamallay) regions in southern Western Ghats.

The mean features of bright band (BB) over a mid and high land region over Western Ghats are identified using reflectivity gradient method. Fig. 5.8 left panel shows an example of the time-height cross section of radar reflectivity on 12th Aug 2017 at Rajamallay. Analysis indicates that the peak reflectivity at the BB layer is 20.05±7.5 dBZ and 19.95±10 dBZ for mid and high-altitude regions respectively. BB or melting layer is identified between 4.6 and 5.2 km layer in both the sites. The study revealed that orographic condition in the Western Ghats favours the

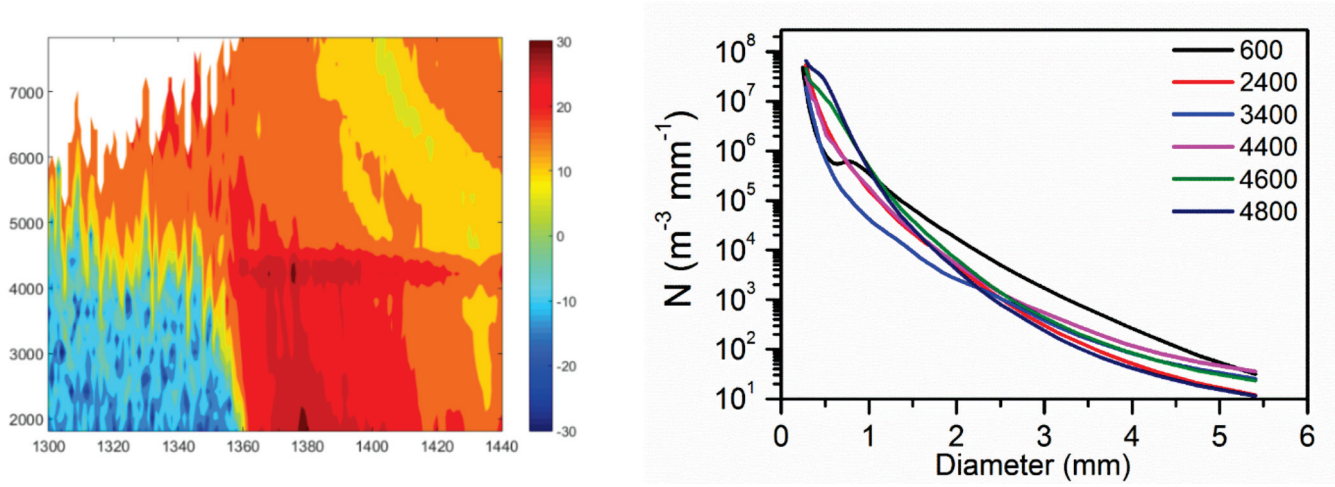


Fig. 5.8 Time-height cross section of radar reflectivity (dBz) and droplet spectrum

melting processes in the monsoon clouds at 4.6 km layer than the mid altitude areas. The internal dynamics between the shallow stable cloud layer present in the high land region with the melting layer creates a seeder - feeder effect, helping the formation of more stratiform cloud layers leading to an orographic enhancement in precipitation over Western Ghats.

5.3.8 Critical Zone Studies of Southern Western Ghats

The Critical Zone is the predominant interface in the global energy, water and carbon cycles. It is the heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air and living organisms regulate the natural habitat and determine the availability of life-sustaining resources. Critical Zone Observatories (CZOs) are terrestrial observatories that can document and inform prediction of the multi-scale and less visible transport of energy and material, and evolution of the Earth's critical zone.

Considering its extreme importance in sustaining economic development, as a first phase, NCESS has initiated setting up Critical Zone Observatories at three different hydroclimatic regions in the south India: 1) Munnar – Humid high-altitude observatory; 2) Silent Valley Twin Watershed – tropical east and west flowing humid to semiarid transition region; and 3) Trichy - Cauvery delta region (Fig. 5.9). Monitoring and instrumentation have already been initiated at Munnar and Silent

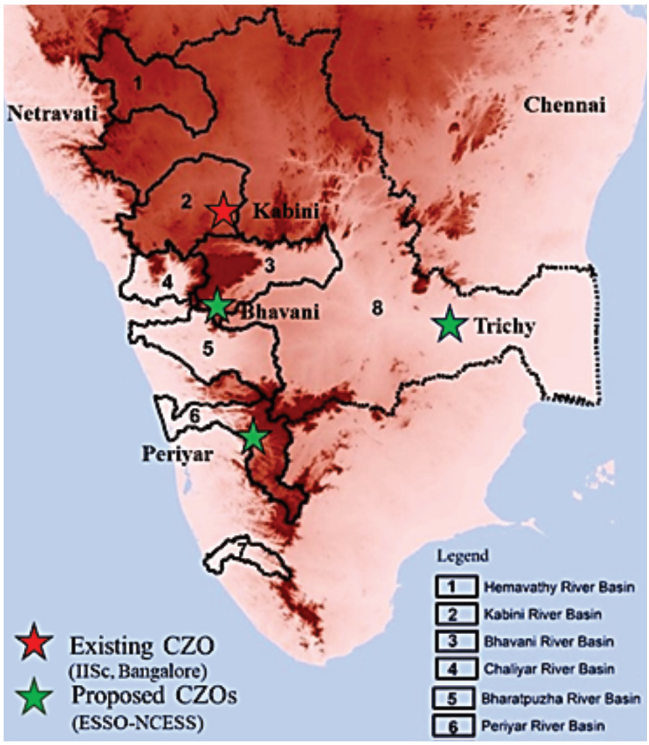


Fig. 5.9 Locations of the Critical Zone Observatories of NCESS.

Valley CZOs. Sensors are in place to measure the soil water movement in the vadose zone and to understand the root water uptake by the canopies under different water regimes.

The effect of natural and anthropogenic stressors in the hydrologic system has been studied in an integrated way. For the purpose, two coupled models have been tested. These are (1) Coupling Vadose Zone Model (HYDRUS) and Groundwater model (AMBHAS) for better simulations of recharge to groundwater in the cases of extreme rainfall events and (2) Coupled surface hydrological model (SWAT) with groundwater model (MODFLOW) for understanding the interactions between the stream and groundwater recharge/discharge. Results showed that the coupled model has a better efficiency in simulating both stream flow and groundwater levels when tested for the Silent Valley CZO data. This shows the applicability of coupled models to study the surface sub-surface interactions and their importance in the context of forced changes in the hydrological system.

5.3.9 Holocene Land – Sea Interaction and Climate Variability

Unlike glacial-interglacial periods, Holocene remained deprived of witnessing drastic climatic perturbations. The recently proposed divisions of Holocene period viz. Greenlandian, Northgrippian and Meghalayan ages has been based on globally observed climatic shifts. Such climatic shifts had remarkable impacts on Indian Summer Monsoon (ISM) intensities leading to severe drought and/or heavy rainfall over the Indian subcontinent. These climate variabilities are often well recorded in sedimentary archives. Among the sedimentary archives, lake sediments are one of the best archives that are used widely for decoding the past ISM variabilities. In lakes, sediments get accumulated from their watersheds which in turn archive the ambient climatic changes. Considering the importance of lake sediments in paleoclimate studies, NCESS has under taken systematic studies of lakes sediments of the West Coast of India. In the first phase, two important lakes viz. Sasthamcotta Lake and Vellayani Lake were investigated to address the Holocene climate perturbations in SW coast of India which is often considered as the gateway of ISM over India. Two shallow cores with lengths of 1.5 m and 10 m were raised respectively, from the Sasthamcotta and Vellayani Lakes for detailed paleoclimatic study using multi proxy tools. Selected organic rich samples from both the sections were subjected to AMS radiocarbon dating. The studied sections of the Sasthamcotta and Vellayani lakes together demonstrate a continuous climatic history since middle Holocene.

The geochemical variations in the Vellayani lake core showed ISM strengthening during 6500 yr BP with a gradual declining towards late Holocene, which is corroborated well with solar insolation, GISP2 ice cores and Indian Ocean sediment core records. Interestingly, the Vellayani freshwater lake core, embed a few marine-brackish water fossil faunae of Villorita sp., Terebrae sp., Nassarius sp. along with foraminiferal (eg., Ammonia Sp.) fossils, especially in the middle – bottom part of the core indicating the prevalence of marine influence with gradual freshening (Saline-Brackish environment) towards last millennia. During post 2000 yr BP, the southern arm of the Vellayani basin might have isolated from marine influence due to cut-off of the arm due to rapid alluvial sedimentation from hinterlands under heavy rainfall conditions.

CHAPTER 6 Research, Education, Training And Outreach (REACHOUT)

To fulfil the primary mandate of the Ministry of providing the nation with best possible services in providing skilful weather forecast and climate information, ocean state, earthquakes, tsunamis and other phenomena related to earth systems, it is essential to holistically address scientific understanding of the individual components of the earth system (the atmosphere, ocean, solid earth, biosphere) as well as interactions between them and their response to the natural and human induced changes through various R&D programs. This also requires a large number of trained manpower, knowledgeable in atmospheric, oceanic and geosciences that can be inducted into the country's R&D and operational organizations. The Research, Education and Training Outreach (REACHOUT) program which takes care of the above activities consists of the following five sub-programs:

I. R&D in Earth System Science (RDESS)
II. Outreach and Awareness
III. BIMSTEC Centre for Weather and Climate (BCWC)
IV. International Training Centre for Operational Oceanography (ITCOocean)
V. Program for Development of Skilled manpower in Earth System Sciences (DESK)

The following sections deal with the activities carried out under each of the sub-programsprograms of REACHOUT program.

6.1 RESEARCH & DEVELOPMENT IN EARTH AND ATMOSPHERIC SCIENCE (RDESS)

Proposals from various academic/research organizations and universities in the different fields of Earth system Science are supported with an intention that it would help in improving our understanding of the earth system. Activities which are supported include focused research in areas of national importance; Building indigenous development, Human resource development through opening of Centers of excellence, initiation of academic programmes, establishment of MoES Chairs; Setting up of specialized labs as national facilities; National and international collaboration, National coordinated projects and setting-up of Earth Science & Technology Cells (ESTCs). During the current financial year a total number of 39 proposals have been sanctioned as shown in the table below:

	Atmospheric Sciences	Ocean Sciences	Geoscience	Seismology	Cryosphere & Hydrology
Number of proposals recommended for funding during the year	4	7	16	7	5

The progress of some of the ongoing projects is described below:

6.1.1 Atmospheric Research including Climate Change

- **Development of a mid-IR Cavity Ring-Down Spectrometer for High-Precision Real-Time Continuous Monitoring of Multiple Trace Gases and Stable Isotopic Species in the Atmosphere** by S. N. Bose National Centre for Basic Sciences, Kolkata **- Completed.**

Under the project, a mid-IR Cavity Ring-Down Spectrometer was developed for High-Precision Real-Time Continuous Monitoring of Multiple Trace Gases and Stable Isotopic Species in the Atmosphere and Wavelength modulation spectroscopy (WMS) technique was developed using the Quantum Cascade Laser (QCL) for atmospheric sample measurements. Under the project 6 papers were published in very good journals and 3 scholars have completed their Ph.D under the project.

- **Aligned Carbon Nanotubes as Porous Materials for Selective Carbon-Dioxide Adsorption and Desorption: Effect of Pressure and Charge** by IIT Kanpur **– Completed**

The main aim was to develop materials which help in removal of CO_2 from flue gas to curtail the greenhouse gas effect. It was concluded that chemically modified porous materials are promising candidate for CO_2 separation from flue gas. In addition to this, simulation software was developed as a by-product of this project, which will be used for future studies. Under the project 7 papers were published and 2 M.Tech. students graduated and one Ph.D. student registered for Ph.D.

6.1.2 Geosciences

- **Evaluating structural control on gold mineralization in Gadag region (Karnataka) – a study based on fabric quantification and kinematic analysis** by IIT Kharagpur **- Completed**

Under this project, the structural control on the gold mineralization in the Gadag region, Western Dharwar Craton was studied using the field, magnetic and microstructural data. Six publications have emanated from this project and 8 students have completed their MSc dissertations.

- **Physical properties of elemental solid, their compounds & oxides & mineral phase of extreme conditions of pressure and temperature: an experimental and theoretical study** by IISER, Kolkata **- Completed**

A Laser Heated Diamond Anvil Cell (LHDAC) facility has been developed at IISER, Kolkata and is running for achieving pressures up to about 150 GPa and above, temperatures about 3000 Kalvin. A dedicated micro-Raman spectrometer system has also been developed for observation of phase changes at extreme P&T.

- **Advancing integrated Wireless Sensor Network for real-time Monitoring and Detection of Disasters** by Amrita University **- Completed**

A landslide monitoring and detection system has been developed using emerging wireless sensor network technology with enhanced geological Deep Earth Probes (DEPs) at an active landslide site in Chandmari, Sikkim. This system consists of embedded DEPs containing sensors such as moisture sensors, pore pressure sensors, geophones, GPS, tilt meters, inclinometers, and strain gauges to

monitor the changes in moisture content, pore pressure, rainfall, movement, and vibrations inside the earth. Based on the knowledge discovery from this analysis, a multi-level warning system is developed to issue real-time landslide warnings.

6.1.3 Hydrology & Cryosphere

- **Quantification of physical and chemical flux of discharging groundwater to sea in coastal areas of the Bay of Bengal** by IIT, Kharagpur. Under this project, studies have been carried out to delineate the hydrodynamic and chemodynamics of groundwater-seawater interactions at selection coastal aquifers adjacent to the Bay of Bengal. Data were collected and geophysical method and geological mapping have been used to generate reactive transport models of hydrogeochemical evolutions along delineated groundwater discharging flow paths.
- **Modelling of soil moisture in a changing climate using the potential of probabilistic hydro-meteorological approach** by IIT-Kharagpur. A copula based probabilistic model is developed which captures the temporal variation in soil moisture by using a combined hydro-meteorological index (CHM index) derived from different hydrometeorological variables using supervised principal component analysis (SPCA).
- **Seasonal Hydrologic Predictions based on Regional Forecasts of Monsoon Rainfall with CWRF and Statistical Downscaling** by IIT, Bombay. Under this project, studies were made to simulate and predict Regional monsoon rainfall scenarios over India at fine resolutions with a coupled dynamic-statistical downscaling model viz. Climate Weather Research and Forecasting (CWRF) model applied to predict ISMR from a global coupled climate model.
- **Near-Real-Time Urban Flood Forecasting System** by IIT, Bombay. The project is aimed to design urban flood forecasting system in Mumbai, considering distributed rainfall forecasting using rainfall data and numerical weather forecasting model, real-time hydrodynamic system for tidal forecasting, integrated urban flood model and a forecasting system.
- **Establishing a Critical Zone Observatory (CZO) in the Ganga Basin** by IIT-Kanpur. A critical Zone Observatory (CZO) has been established in a watershed of the Pandu basin in the Gangetic plains where an array of field instruments has been set up to monitor hydro-meteorological parameters, determine soil characteristics and chemistry, and geochemical fluxes.
- **Measurements and Modeling of Evapotranspi-ration and other Hydrological Processes in Lesser Himalayas** by National Institute of Hydrology, Roorkee. This project is aimed at understanding the Hydro-climatic processes in the lesser Himalayan region by monitoring evapotranspiration (ET) by using the latest available technology of eddy covariance tower and ET modeling.

6.1.4 Seismology

- **Deep Seismic Profiles in Kachchh by National Geophysical Research Institute, Hyderabad**

Seismic reflection data were acquired along two profiles (line 1 of 70 km i.e., Mouvana-

upto small island in little Rann; and Line -2 of 100 km i.e., Rann-Enthal Talav) with a spread length of 15 km using 50 m receiver and 100 m of shot intervals. Preliminary observations show that the geologically mapped Kutch Mainland Fault strike extends further 10-15 km towards east. The present study also suggests that South Wagad fault is most seismically active in the shallow region.

- **Active Fault Study around Kishtwar Area, Jammu & Kashmir by Jammu University**

A systematic Active Fault study around Kishtawar area was carried out to establish a new understanding of tectonic environment of the area and particularly the tectonic geomorphology of Kishtwar basin. The result shows that active faulting in Kishtwar area is induced by the local extensional tectonics which is due to the right stepping of Kishtwar strike-slip fault.

- **Present day subsurface configuration and geodynamics of the Kumaon Himalaya: an integrated geophysical and geological investigation by Wadia Institute of Himalayan Geology (WIHG), Dehradun**

Crustal thickness and Poisson's ratios were estimated at 13 broadband seismological stations established in a profile along the Kali river valley, Kumaon (Central) Himalaya with the help of receiver function analysis (RF) & H-K stacking method. The study reveals that the crustal thickness beneath the Indo-Gangetic plain is ~38 km which gradually increases up to ~41 km at the northernmost station located in the Higher Himalaya.

- **Investigation on Crustal Stress, Seismic Velocity and Porosity in Rock and Deformation Modeling by ISM (IIT), Dhanbad**

Well log data from six wells (three from Assam Gap and three from Belt of Schuppen) were analyzed and compared. Rock strength parameters such as uniaxial compressive strength, internal frictional angle, cohesion, dynamic and static Young's modulus which are key inputs for any geomechanical study have been calculated for the Upper Assam basin. Two research papers have been published so far in the international journals.

6.1.5 Solar Multi-Effect Desalination System

Solar Multi – Effect Desalination (MED) System is a stand-alone desalination system developed by IIT, Madras with funding from MoES. Figure 6.1 gives the photographic view of Solar Multi-Effect Desalination (MED) system which operates with solar energy at Vivekananda Kendra, Kanyakumari. This system will produce 10,000 litres of water per day with the quality of 5 ppm as dissolved salt.

Fig.6.1 Pictorial view of Solar Multi-Effect Desalination system.

6.1.6 Ka band Cloud Radar

The project on design and development of Ka band radar is funded with a view to establish radar technology for advanced study of clouds especially pre precipitation stage of cloud and its profile. This radar can be used for measuring the atmospheric turbulence and for hydrometeor classification. The stated objective of technology

establishment has been addressed and a Scanning polarimetric Radar in Ka Band (35.6 GHz) with 2.2 kW Transmiter and a beamwidth of 0.3 degree is being developed. The Radar Platform is ready and antenna steering has been tested to its full functionality. The Electronic Unit is also ready and is being integrated..

6.1.7 Earth System Science and Technology Cells (ESTC)

One of the ESTCs at M.K. Bhavnagar University on "Marine Ecology of West Coast of India" that involved nine universities/Institutes has been successfully concluded in 2018. Some of its salient results are as follows.

a) Decline of hydrocarbon, major heavy metals like nickel, copper, lead, iron and chromium in the sediments and increase of PH and salinity are observed over Alang-Sosiya Ship-Breaking and Recycling Yard (ASSBRY) at Alang, Gujarat between 2010 and 2015. It is also observed that implementation of government policies in association with the ship breakers association has resulted in reasonable improvement in quality of the water. .

b) New species of Crabs and Lichen have been found for the first time in the Gujarat coastal region.

c) 30 research papers have been published in peer reviewed journals.

A new ESTC on "Marine Biotechnological Studies" has been established at Sathyabama Institute Science & Technology (SIST) Chennai, with National Institute of Ocean Technology (NIOT) and Centre For Marine Living Resources and Ecology (CMLRE) of Ministry as collaborating Institutes.

6.1.8 Human Resource development & Capacity Building

- Establishment of "MoES Chair on Climate Science and Policy" at TERI School of Advanced Studies for 3 years has been recommended.
- MoU for continuation of activities under DN Wadia MoES Chair Professor established at IIT Kanpur was extended for 5 years.
- An annual grant to National Institute of Advanced Studies (NIAS), Bangalore was approved, for period of five years to support inter-disciplinary research and socio-economic impact assessment of operational services and products by MoES institutes.

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

6.2.1 Exhibitions

During the year, the Ministry participated in 15 Exhibitions. The Ministry’s pavilion at the Indian Science Congress-2018 has been adjudged as ‘Exhibitors of the Year’


Indian Science Congress 2018 at Manipur University, Imphal, Manipur

Ministry's pavilion at ISC 2018 has been adjudged as 'Exhibitors of the Year'



Competitions for "Earth Day" celebrations on 22nd April 2018

6.2.2 Earth Day Celebration-2018

The theme for the "Earth Day" celebrations on 22nd April 2018 was as **"Go Green – Go Clean".** Various competitions like drawing and painting, debate, essay writing, etc. for various age groups was organized at 44 centers across the country including schools, college and universities. Popular lectures were also delivered by eminent scientists/local scholars on Earth Science related topics. About 6000 children participated in these events. Prizes at National level were distributed on Ministry's foundation day.

6.2.3 Ozone Day 2018

"Ozone Day" was celebrated across the country on **Sept. 16th, 2018** and the event was organized at 2 centers. About 500 children participated in this event. Children were given awards for Painting Competitions for Earth day 2018 on the occasion of Foundation Day at Vigyan Bhawan, New Delhi.

6.2.4 Participation in International Earth Science Olympiad

Ministry had sponsored the participation of Indian contingent in the 12th International Earth Science Olympiad, organised during 8-17 August 2018 at Mahidol University, Kanchanburi. Campus, Thailand. Children from **38** Countries participated in the event. **Indian team won one Silver Medal and one Bronze Medal.**

Indian team with mentors and observer at 12th International Earth Science Olympiad (IESO) at Mahidol University, Kanchanburi. Campus, Thailand

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

In order to provide a platform to scientists, engineers, technologists, experts, social scientists and user communities to interact and discuss the various aspects of Earth System Science, 76 Seminar, Symposia, Conference, etc. were supported. These events were supported in the field of climate change and impact on health; coastal dynamics; aquaculture; environmental pollution and its effects on agriculture and human health; marine ecosystem; disaster management; agro meteorological services, space technology and applications; geological science; snow and avalanches processes; mathematical modelling and simulation; etc.

6.2.6 MoES Foundation Day

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27th July 2018 at the Vigyan Bhavan, New Delhi. Professor Ashutosh Sharma, Secretary, DST was the Chief Guest. The foundation day lecture was given by

Dr. Asahiko Taira and Professor Ashutosh Sharma addressing the gathering on MoES Foundation Day

Dr. Asahiko Taira, President, Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

In order to provide due recognition to major scientific contributions made by eminent scientists/engineers in various fields of Earth System Science and also considering the need to encourage young researchers for coming into the mainstream of Earth System Science, the Ministry has instituted the Life Time Excellence Award and National Earth System Sciences Awards.

This year the Life Time Excellence Award was awarded to Professor K. S. Valdiya, Honorary Professor, JNCASR, Bengaluru for his significant contribution in the field of isotope geoscience. The National Awards for Ocean Science & technology was presented to Dr. Satheesh Shenoi, Director, INOCIS, Hyderabad and Dr. R. Venkatesan, Scientist-G, NIOT, Chennai. Dr. B. V. Krishna Murthy, Retd. Director, SPL, ISRO received the National Award for Atmospheric Science & technology. The National award for Geoscience & technology was presented to Prof. Sekhar Muddu, IISc, Bengaluru and Prof Sunil Bajpai, Director, BSIP, Lucknow. Dr. Kusala Rajendran, IISc, Bengaluru received the newly instituted National award for women scientist. The Young Researcher Awards was presented to Dr. Mala S. Bagiya, IIG, Mumbai and Dr. Praveen Kumar, INOCIS, Hyderabad for their outstanding work in Earth Science & Technology. In addition, certificates of merit were also presented to the scientists from MoES. **The winners of Gold Medal and Bronze Medal** of 11th International Earth Science Olympiad (IESO) were also awarded during the function.

6.3 BIMSTEC - CENTER FOR WEATHER AND CLIMATE (BCWC)

BCWC was established at NCMRWF following a Memorandum of Association (MoU) signed among MoES, India and BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Member countries. The activities of BCWC include conducting Training Workshops, capacity building, enhancing observing system for BIMSTEC region for both process understanding and forecast skill improvement. BCWC is continuing these activities in order to meet the regional leadership and cooperation role committed by Government of India under BIMSTEC Cooperation.

6.4 INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANOGRAPHY (ITCOocean)

The ITCOocean continued its operations using the state-of-the art facilities of INCOIS, Hyderabad. During this period around 225 scientists were trained of which 149 are from India and 76 from 36 other countries. A total of 9 courses were conducted which covered various topics like remote sensing of marine phytoplankton, Discovery and use of operational ocean data products and services, Data visualization, Fish catch time series using R etc. Also there were training sessions conducted exclusively for officers from Indian Coast Guards and trainees from Indian Air Force. The ITCOocean building along with facilities for faculty, students was inaugurated by Hon'ble Minister Dr. Harsh Vardhan on 22nd December at INCOIS.

6.5 DEVELOPMENT OF SKILLED MANPOWER IN EARTH SYSTEM SCIENCES (DESK)

Replacing the Centre for Advanced Training (CAT-ESSC) Program, MoES has formally approved the new project DESK (Development of Skilled manpower in Earth System Sciences) on 30th June 2018 to create a large pool of trained and dedicated multidisciplinary earth system and climate research manpower in the country. DESK will (a) Implement JRF/SRF program of the Ministry and their initial training, (b) Organize short and medium duration courses/workshops on specific or targeted areas of skilled manpower development (c) To strengthen research and education support for science of the climate and climate change and to establish linkages amongst the education, research and operational organizations in the country. A set of new committees for organizing short term training programs and workshops has been constituted. Several workshops will be taken up immediately under DESK.

CHAPTER 7 | International Cooperation

In its constant endeavour to provide the best possible weather, climate and ocean service, Ministry of Earth Sciences (MoES) regularly partners with national and international institutes for scientific collaboration in all fields related to earth sciences to broaden the scope of research through trans-national joint projects and joint developmental work. The international collaborations not only help in delivery of high-end research for societal benefit but also ensures optimum usage of infrastructure, data and manpower resources. Some of the successful collaborations undertaken in the past and which are currently underway include joint development work with USA, UK, Norway etc.

7.1 Cooperation with NOAA, USA

MoES and National Ocean and Atmospheric Administration (NoAA) entered into a Memorandum of Understanding in 2008 on Earth Sciences and Observations. Under this, 10 joint research and development activities as Implementation Agreements (IA) 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. NOAA-MoES Science Colloquium was held during 11-13 June 2018 at NIO, Goa. This was followed by the business meeting between NoAA and MoES where in the progress of the ongoing projects, areas of future collaboration and renewal of IAs was taken up.

Some of the significant outcomes are placed below:

- **Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) :** The field work and the research conducted under the RAMA IA have greatly contributed to our understanding of the importance of the Indian Ocean in the regional and global climate system. The data derived from the array have also provided essential support in the development of operational climate forecast models, weather and climate prediction, ocean data assimilation, ocean state forecasts, reanalysis efforts and satellite validation. The second IA on RAMA was signed on 13th June 2018 to continue the activities of the RAMA IA.
- **Technical cooperation for the study of dynamical short range, extended range and seasonal prediction for Indian summer monsoon rainfall :** Under this IA, systems have been set up for seasonal, extended-range and short range dynamical predictions with specific emphasis on monsoon variability. India now has the capability for sub-seasonal and seasonal predictions and improved climate forecasts. A modified version of the same modeling system is also used for climate change studies and will be the basis for an Indian entry in the CMIP6 inter-comparison

exercise. During 2018 the Monsoon Desk facilitated setting up of the Global Land Data Assimilation System for Seasonal & Extended range prediction systems, provided source code of GFS Semi-Lagrangian model (with very high spectral resolution of T1534 in the horizontal) for short range prediction, testing weakly coupled data assimilation system. In addition the hindcast GFS T1534 runs were also shared with the IITM scientists.

- **Improving Tropical Cyclone Prediction Over the Indian Ocean :** Under this IA, the high-resolution operational HWRF was implemented at the IMD in 2012. IMD and other institutes in India have worked together in close coordination with NOAA to improve the HWRF system further. A Very high resolution HWRF with the storm following nest set to a resolution of 2 km has been implemented. This IA was extended for an additional five-year period, effective from 18 June 2018.

7.2 Cooperation with United States Geological Survey (USGS)

A Memorandum of Understanding (MoU), was signed between MoES and USGS on 1st November 2018, to enable the sharing of expertise available with both organizations and adoption of the latest state-of-the-art technology in the field of Earth Sciences. The cooperation under this MoU is envisaged through various modes viz. exchange of technical information, visits, training, and cooperative research consistent with ongoing programs of both MoES and USGS.

7.3 Cooperation with UK Met Office (UKMO)

Consortium Agreement : Under the Consortium Agreement signed in 2016 with UKMO core partners for weather and climate forecasts, data assimilation components of the latest operational version (PS40) of the UK Met Office "Hybrid 4D-Var" system has been implemented in the new Mihir HPC for the high resolution (12 km) global NCUM which is made operational in May 2018. A 4D-Var regional data assimilation system for the 4 km resolution regional NCUM (NCUM-R) was tested with various satellite, radar and conventional observations. The model with the latest science settings was used to give forecast in the BIMSTEC region and Amarnathji Yatra. The Annual board meeting was held in Australia in February 2018, wherein the future strategies for joint developmental work were discussed.

Statement of Intent with UK Met Office : In order to jointly develop weather and climate science for efficient delivery of climate services, MoES and the UK met office signed a Statement of Intent on 22nd March 2018 for cooperating on Seamless ensemble coupled model development across scales, Model & Observations evaluation of monsoon processes & hazards and Risk based forecasting & high impact weather/seasonal events. A two day workshop was held during 20-21 March 2018 at Prithvi Bhavan, wherein the scientists from MoES and UK Met office identified specific work packages on various topics to enable efficient delivery of climate services.

7.4 Cooperation with Natural Environment Research Council (NERC)

MoU on Cooperation in Earth Sciences: The MoU, signed in February 2013 between MoES and NERC has been extended by a further period of five years. The progress on the ongoing three IAs signed under this MoU is as follows

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

Three projects involving Indian and UK scientists were undertaken under this IA namely **South West Asian Aerosol Monsoon Interaction (SWAAMI) Experiment, Bay of Bengal Boundary Layer** Experiment **(BOBBLE), and Monsoon dynamics and thermodynamics from the land surface, through convection to the continental-scale (INCOMPASS)** with an aim to study different aspects of physical processes affecting the monsoon. A review of these three projects was done during July 26th 2018 at IISc Bangalore under the Chairmanship of Prof. J. Srinivasan and Dr. K. Krishnamoorthy. They recommended that the three supersites established as part of the project should be maintained by MoES for their long-term sustainability and the aircraft data should be shared with other researchers at the earliest.

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

Five projects funded under this IA are at various stages of implementation. The projects are meant to capture the contribution made by primary and secondary aerosols to the air pollution in Delhi during summer and winter conditions and to understand interactions between boundary layer dynamics and long-range transport of air pollution to the local air quality of Delhi. Two process orientated observational campaigns were carried out during winter 2017-18 and summer 2018 using a range of instruments. A similar campaign is again planned during 2018-19 winter season. The data collected is being analyzed and the results will be presented during the review meeting in March 2019.

7.4.3. 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 of the project "Up-scaling catchment process for sustainable water Management in Peninsular India (UPSCAPE)" is to provide an understanding of the impacts of the smaller scale interventions in the river basin on the larger scale hydrology and water resources, in the Cauvery river basin in the Peninsular India. A systems approach is being applied to identify and quantify the dominant interactions and feedbacks between human activities and the hydro-meteorological system in the Indo-Gangetic Plain under the project "Coupled Human and Natural Systems Environment (CHANSE) for water management under uncertainty in the Indo-Gangetic Plain". The third project entitled Sustaining Himalayan Water Resources in a changing climate (SusHi-Wat) aims to investigate how water is stored in, and moves through, a Himalayan river system (the inter-linked Beas and Sutlej catchments) in northern India at daily to decadal timescales, using a combination of state-of-the-art modelling, field studies, satellite-based remote sensing and observation.

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

MoES and the NERC,UK collaborative "India-UK Virtual Joint Centre on Water Security" (IUKWC) has now over 650 registered members, a 54% increase from the number of members at the same time last year. The IUKWC has hosted four Science Workshops to date, with two this year, that have brought together UK and Indian Scientists to discuss the current state of knowledge in the area 'Integrating precipitation forecasts and climate predictions with basin scale hydrological modelling in the Himalayas', and 'Advancing Drought Monitoring, Prediction and Management Capabilities'. Under the Research Exchange scheme, 3 exchanges were funded in 2018 in the areas 'linking drought to heatwaves'; 'monitoring range of antibiotics in river catchments' and 'Integrating remotely sensed observations of surface water storage with climate forecast'. A project on 'Synergistic utilisation of EO-based soil moisture observations: Applications in the UK and India' was carried out jointly by Dr. Manika Gupta, Department of Geology, University of Delhi and Dr. Emma Tebbs, King's College London, UK. The first User Engagement Initiative on the topic of 'Improving Freshwater Monitoring Frameworks for Data and Research Management' was held in Kochi, Kerala and a total of 47 participants.

7.5 Cooperation with Belmont Forum Countries

Under an MoU signed in February 2013, between MoES and the Belmont forum Countries (a group of the world's major and emerging funders of global environmental change research and international science councils) to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges, MoES is participating in 4 Collaborative Research Areas (CRA) namely Coastal Vulnerability, Food Security, Biodiversity and Climate Predictability and Inter-regional linkages. Till date, MoES has supported 10 projects involving over 15 Indian scientists from MoES institutes as well as other Indian Universities/ institutes. India has committed to participate in the CRA on Ocean sustainability proposed by Sweden and the call for proposals has been announced on 12th November 2018. Mid-term review of the projects funded under Climate Predictability and Inter-regional linkages was done at Kyoto in October 2018 on the sidelines with the WCRP event. The end-term meeting of the Belmont Forum Food Security and Land Use Change CRA was organized on 8th December 2018, at Washington D.C.

7.6 Belmont Forum Secretariat

Belmont Forum Secretariat has been established to coordinate the activities and to maintain a certain degree of continuity in the operations of the Forum. The Secretariat was hosted by ANR France for 3 years till the end of 2017 at an annual cash contribution of 20 kEuro or 0.2 FTE by the members of Belmont Forum. The 13th Plenary meeting was held at Sao Paulo, France and it has been unanimously decided by the members that the Belmont Forum Secretariat for the next 3 years will be hosted by Inter-American Institute for Global Change Research, Uruguay.

7.7 Cooperation with BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Countries

Following the signing of the Memorandum of Association to establish the BIMSTEC Centre

for Weather and Climate (BCWC) at National Center for Medium Range Weather Forecasting (NCMRWF) during the BIMSTEC Summit on March 04th, 2014 at Nay Pyi Taw, Myanmar, the BCWC has been formally established at NCMRWF on 28th March 2014. The BCWC organized the first Governing Board (GB) Meeting, Scientific Advisory Committee (SAC) Meeting and Workshop on "Severe Weather/Climate Disaster Warning for BIMSTEC Region" during 30-31 July 2018. The meetings and workshop was attended by participants from Bangladesh, Bhutan, Nepal, Myanmar, Sri Lanka and Thailand. India was declared as the Chairman of Governing Board for the first term.

7.8 Cooperation with Research Council of Norway (RCN) : Under the MoU with RCN

Following a joint call in Feb 2015, 5 projects under Climate System in Polar regions and 3 projects under Geohazard theme have been supported in October 2015. These projects are in various stages of implementation. Major progress in the projects includes (i) NCPOR-NPI team carried out geophysical surveys during the 2017-18 field seasons in Antarctica and also drilled a 153 m ice core at the summit of Leningradkollen ice rise in coastal Antarctica. The geophysical data and the ice cores are being processed and analysed. (ii) Arctic climate variability during the Mid-Pliocene Warm Period was studied using various proxies in the sediment samples collected from the various IODP Expeditions in the Arctic Ocean and Eastern Arabian Sea. (iii) Various CMIP5 models were used to study intra-seasonal variability of the Indian summer monsoon (ISM) and the tele-connection between ISM and the changing wind patterns. (iv) Diatoms in the marine sediment cores from two Arctic fjords were analysed to reconstruct the Sea Surface temperature and Sea Ice during Holocene.

7.9 Cooperation with UNESCO/IOC

Following the cabinet approval on 15th December 2017, the International Training Centre for Operational Oceanography at INCOIS Hyderabad was upgraded to UNESCO Category 2 (C2C) center. 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. The MoU was signed in May 2018, and Category-2 Centre of UNESCO has been established with the state-of-the art facilities at INCOIS, Hyderabad. So far, over 996 scientists including 804 from India and 192 from 36 other countries have been trained at this centre in various aspects of operational oceanography. Training sessions exclusively for officers from Indian Coast Guards and Indian Air Force were also organized. At present, the other infrastructure facilities like building and training hostel are being established.

7.10 Cooperation with International Seabed Authority (ISA)

Polymetallic Nodules : 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). Under the exploration

contract, geo-statistical assessment is under progress. Environmental data have been acquired. Components for the deep sea mining system are being integrated. Research and development in extractive metallurgy is continuing.

Polymetallic Sulphides : Under the fifteen year Contract of Government of India with International Seabed Authority for exploration on Polymetallic sulfides signed in September, 2016, the work on exploration of hydrothermal sulfides is continuing. Marine geophysical surveys were carried out and work on environmental baselines is being carried out.

7.11 Cooperation with Japan

A Memorandum of Cooperation between Ministry of Earth Sciences and Japan Agency for Marine Earth Science and Technology (JAMSTEC), Japan was signed on 11th November 2016. A joint workshop was held at Indian Institute of Tropical Meteorology, Pune from March-1-2, 2018. Collaborative projects of mutual interests were discussed for prediction of monsoon, understanding the biogeochemistry of the north Indian Ocean, Monsoon and Southern Ocean (including sea ice around Antarctic) interactions, and ocean observations. Dr. Taira, President, JAMSTEC delivered the Foundation Day Lecture and had discussion with MoES along with his team on 27th July 2018.

"A Memorandum of Cooperation between The National Centre for Polar and Ocean research (NCPOR), Ministry of Earth Sciences and The National Institute of Polar Research (NIPR) of Japan, the Research Organisation of Information and Systems on Polar Research, to strengthen cooperation in the study of Polar Sciences and related logistics, was finalized during the 13th India-Japan Annual Summit and signed during the visit of Hon'ble PM of India to Japan on 29th October 2018."

7.12 Cooperation with International Conti-nental Scientific Drilling Programme (ICDP), Germany

An MoU on the Membership of the ICDP between MoES and the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, for a period of five years was signed on 30th August 2016. As per MoU, MoES is paying annual contribution of US$ 200,000 to GFZ. The MoU is facilitating 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 also provides technical/ operational support, facilitate capacity building in terms of manpower training in key scientific areas. India is also represented on two panels of ICDP, viz, Assembly of Governors and Executive Committee. During the current year analysis of (i) chemical and noble gas isotope composition of formation gas samples has been collected from depths up to 3 km, and (ii) in-situ hydrofrac test data obtained in the Koyna Pilot Borehole was carried out with technical support of ICDP.

7.13 Cooperation with International Ocean Discovery Program (IODP), USA

MoES joined International Ocean Discovery Program (IODP) consortium in 2009 as an Associated Member through MoU with National Science Foundation (NSF), USA. The said MoU was extended for a period from 1st October 2013 to 30th September 2019. As a part of the MoU, Indian scientists have been participating on

various IODP expeditions. As per MoU, MoES is paying annual contribution of US$ 1M to NSF. A total of 40 Indian Scientists who sailed on different expeditions exposed facets of scientific drilling in a variety of geological settings around the world so far. Also, by virtue of being a member of IODP, India is represented on three panels of IODP, viz; JOIDES RESOLUTION Facility Governing Board, IODP Forum and Science Evaluation Panel. During the current year, 3 Indian scientists participated in 3 IODP expeditions IODP 381 (Corinth Active Rift Development), IODP 372 (east of the coast of New Zealand) and IODP 374 (Ross Sea West Antarctic Ice Sheet) and had unique hands-on experience in the scientific ocean drilling. IODP forum meeting was also held at Goa during 19-21 September, 2018 with approximately 35 international participants.

7.14 Cooperation with Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)

RIMES is an international and intergovernmental institution, owned and managed by its Member States, for building capacities in the generation and application of user-relevant early warning information. Currently, 48 countries collaborate under RIMES. The 10th RIMES Council Meeting was held at Bangkok, Thailand during 11-13 November 2018. INCOIS has operationalized the Ocean State Forecast System for Maldives, Seychelles, Sri Lanka, Comoros, Mozambique, Mauritius and Madagascar. Real-time Observation System has been deployed in RIMES countries. INCOIS has also conducted Training courses in Ocean State forecast for RIMES member states.

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CHAPTER 8 | Awards, Honours and Publications

Awards and Honours

- Prof. Ravi S. Nanjundiah has been elected as a Fellow of the Indian Academy of Sciences (IASc) and the Indian Meteorological Society (IMS).
- Dr. M. Ravichandran has been elected a Vice President of SCAR (Scientific Committee on Antarctic Research).
- Dr. R. Krishnan has become a Member of Joint Scientific Committee of WCRP for the 4-year period up to 2022 among 8 others. He is also the Coordinating Lead Author for "Chapter 8: Water Cycle Changes" of the IPCC Working Group I Sixth Assessment Report.
- Dr. Thara Prabhakaran contributed as Member of WMO Expert team (ET) for weather modification for the WMO peer reviewed report entitled, "Peer Review Report on Global Precipitation Enhancement Activities WWRP 2018 - 1".
- Dr. Swapna Panickal was selected as a Lead Author for Chapter 4 on Future Global Climate: Scenario Based Projections and Near-term Information for IPCC Working Group I Sixth Assessment Report (IPCC AR6).
- Dr. Roxy Mathew Koll was elected as the CLIVAR/IOC-GOOS Indian Ocean Region Panel Co-Chair, for the period 2018-2021 by CLIVAR/IOC-GOOS Scientific Steering Group.
- Dr. Roxy Mathew Koll is also selected as a Lead Author, Chapter 6: Extremes, Abrupt Changes and Managing Risks of the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.
- Dr. M. A. Atmanand, Director NIOT, has been elected as the first Indian from India for the Administrative committee (AdCom) of IEEE Oceanic engineering society (OES) from 2019 to 2021.
- Dr. R. Venkatesan has become a member of Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology.
- Dr. G. A. Ramadass has been elected as the Chairman, IEEE OES India.
- Dr. G. Latha has become a member of the working group on data management under "International Quiet Ocean Experiment (IQOE)" of SCOR.
- Mr. Tata Sudhakar has been elected as the Chair of Institute of Electronics and Telecommunica-tion Engineers for the period 2018-2021.

Patent awarded

- An Indian Patent (No. 289579 dated 14th November 2017) is awarded for the Energy and Freshwater team for the invention titled "An apparatus for the continuous generation of potable drinking water", for the term of 20 years from the 12th day of April 2012 in accordance with the provisions of the Patents Act, 1970.

PUBLICATIONS

A total number of 406 research papers were published in 2018 by MoES centres under its various programs, the details of which are given below. The total impact factor (1009.5) in this year is much higher than the previous year (862 in 2017), which means research papers in this year were published in journals with higher impact factor.

	ACROSS	OSMART	PACER	SAGE	TOTAL
Total no. of Publications	232	78	40	56	**406**
Cumulative Impact Factor	**630.029**	**140.424**	**94.032**	**145.066**	**1009.551**

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Other Publications

Research Reports/Books

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CHAPTER 9 Administrative Support

9.1 Citizen's Chapter

The Chapter 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 grant 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 Chapter 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 hazard 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 communities while making recruitment or forming Selection Committee set up for filling up of vacancies in Group A, B, C including MTS has been ensured.

9.3 BUDGET AND ACCOUNTS

(Rs. In crore)

Sl. No.	Major Head of Account	2016-17 Actuals			2017-18 Budget Estimates			2017-18 Actuals		
	REVENUE SECTION	**Plan**	**Non-Plan**	**Total**	**Revenue**	**Capital**	**Total**	**Revenue**	**Capital**	**Total**
1	3403- Oceanographic Research	367.74	44.60	412.34	576.60	0.00	576.60	531.01	0.00	531.01
2	3425- Other Scientific Research	35.65	7.44	43.09	52.60	0.00	52.60	48.54	0.00	48.54
3	3451- Secretariat Economic Services	0.00	29.24	29.24	35.46	0.00	35.46	33.35	0.00	33.35
4	3455- Meteorology	420.91	381.22	802.13	939.82	0.00	939.82	873.18	0.00	873.18
	Total (Revenue)	**824.30**	**462.50**	**1286.80**	**1604.48**	**0.00**	**1604.48**	**1486.08**	**0.00**	**1486.08**
	CAPITAL SECTION									
5	5403 - Capital Outlay on Oceanographic Research	7.89	0.00	7.89	0.00	16.00	16.00	0.00	9.96	9.96
6	5455 - Capital Outlay on Meteorology	66.59	0.00	66.59	0.00	99.00	99.00	0.00	45.43	45.43
	Total (Capital)	**74.48**	**0.00**	**74.48**	**0.00**	**115.00**	**115.00**	**0.00**	**55.39**	**55.39**
	Total (Revenue +Capital)	**898.78**	**462.50**	**1361.28**	**1604.48**	**115.00**	**1719.48**	**1486.08**	**55.39**	**1541.47**

9.4 Report of the Comptroller and Auditor General of India

The number of Action Taken Notes (ATNs) pending for Ministry of Earth Sciences taken from various C&AG reports are given in the following table:-

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	2013	One (Para No. 8.1 of Report No. 22 of 2013- Irregular Introduction of Pension Scheme and Diversion of Funds)	NIL	NIL	NIL	NIL
2	2014	NIL	NIL	NIL	One (Para No. 5.2 of Report No. 27 of 2014- Irregular Payment of Gratuity)	NIL
3	2015	One (Para No. 6.1 of Report No. 30 of 2015- Unfruitful Expenditure due to non-functional website)	NIL	NIL	NIL	NIL
4	2016	One (Para No. 6.1 of Report No. 12 of 2016- Non-Establishment of desalination plants and wasteful expenditure).	NIL	NIL	NIL	NIL
5	2017	NIL	NIL	NIL	Two (1) Para No. 7.2 of Report No. 17 of 2017 - Irregular plementation of promotion scheme and (2) Para No. 7.1 of Report No. 17 of 2017 - Non –recovery of fuel charges due to improper contract management).).	NIL

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	
6	2018	One (Para No. 8.1 of Report No. 2 of 2018 - Avoidable expenditure towards rent of bonded warehouse)	One (Para No. 8.2 of Report No. 2 of 2018 - Irregular Protection of Pay - NIOT Chennai)	NIL	NIL	NIL

9.5 STAFF STRENGTH

S. No.	Group of posts	MOES	NCMRWF	CMLRE	NCCR	IMD	NIOT	NCPOR	INCOIS	IITM	NCESS	NCS	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(15)
1.	GROUP A	89	72	17	16	465	91	47	47	180	72		1096
2.	GROUP B	69	18	04	03	3900	54	17	27	64	28		4184
3.	Group C (including MTS)	64	27	15	06	2692	23	23	-	70	59		2979
	TOTAL	**222**	**117**	**36**	**25**	**7057**	**168**	**87**	**74**	**314**	**159**		**8259**

MOES = MINISTRY OF EARTH SCIENCES
NCMRWEF = NATIONAL CENTRE FOR MEDIUM RANGE WEATHER FORECASTING
CMLRE = CENTRE FOR MARINE LIVING RESOURCES AND ECOLOGY
NCCR = NATIONAL CENTRE FOR COASTAL RESEARCH
IMD = INDIA METEOROLOGICAL DEPARTMENT
NIOT = NATIONAL INSTITUTE OF OCEAN TECHNOLOGY
NCPOR = NATIONAL CENTRE FOR POLAR AND OCEAN RESEARCH
INCOIS = INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION STUDIES
IIITM = INDIAN INSTITUTE OF TROPICAL METEOROLOGY
NCESS = NATIONAL CENTRE FOR EARTH SCIENCES
NCS = NATIONAL CENTRE FOR SEISMOLOGY

Representation of Persons with Disabilities in Government of 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 Post	VH	HH	OH	VH	HH	OH	Total	Un Identified Post	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

GROUP	Representation of SCs/STs/OBCs(as on 1.1.2018				Number of appointment made during the calendar year 2017											
					By Direct Recruitment				By Promotion				By Deputation			
	Total No. of emplo-yees	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	-	-	-	-	-	-	-	-	-	-	-	-
GROUP B	43	8	3	2	-	-	-	-	-	-	-	-	-	-	-	-
GROUP C Including MTS	58	22	4	7	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	150	39	11	14	-	-	-	-	-	-	-	-	-	-	-	-

9.6 PROGRESSIVE USE OF HINDI

OFFICEAL LANGUAGE ACT AND RULES

The Hindi Section of this Ministry is working under the supervision of Joint Secretary and to assist him there is One Joint Director (OL), One Assistant Director (OL) and two Senior Translators and One Junior Translator along with 2 data entry operators. Hindi Section is responsible for entire translation work and Implementation of Official Language policy of the Govt. of India in the Ministry and its attached and subordinate offices and their field organizations. The important activities undertaken during the year are as under:

1. During the year, appropriate action was taken to ensure implementation of the provisions of the Official Language Act and the Rules framed thereunder.
2. For ensuring compliance with the provisions of the Official Language Act, 1963 and rules framed thereunder, checkpoints have been set up in the Ministry. Effective steps were taken for the adherence to these checks points.

REVIEW

i) The Annual programme for the year 2018-2019 for implementation of the Official Language Policy of the Union, issued by the Ministry of Official Language as well as orders issued by them were circulated in the Ministry and to all the attached/ subordinate Offices for compliance. Progress made in this regard was reviewed through the quarterly reports received from them and critically discussed in the Official language Implementation Committee.

ii) Regular meetings of the Official Language Implementation Committee to review the progress made in implementation of Official Language policy were held during the year. Emphasis was laid in the meetings to increase the progressive use of Hindi.

iii) A Meeting of Joint Hindi Salahkar Samiti of Ministry of Science and Technology and Ministry of Earth Sciences was held on 22 June 2018.

INCENTIVE SCHEMES

i) The scheme for awarding cash prizes to central Govt. Employees for noting and drafting in Hindi continued to be implemented during the year.

ii) Under Prithvi Vigyan Maulik Pustak Lekhan Yojna, the process of inviting entries is underway

iii) The Ministry observed Hindi fortnight from 14.09.2018 to 28.92018. During this fortnight various competitions were organized with a view to encourage the Officers / employees. The prizes were distributed by Secretary, Ministry Of Earth Sciences in a prize distribution ceremony held on 7th October, 2018.

OTHER ACTIVITIES

i) Workshops are being organized to impart training in noting and drafting in Hindi, to do work in Hindi on computers and also to guide how to fill up quarterly progress reports.

ii) Continuous efforts are being made to encourage progressive use of Hindi in official work not only in the Ministry but also in its attached and subordinate offices.

iii) In this year Committee of Parliament on Official Language has inspected 3 offices of IMD i.e. Meteorology Centre, Trivendrum on 25th January, 2018, Climate Research

Prize distribution ceremony of Hindi Pakhwara 2018

Services, Pune on 23rd February, 2018 and Cyclone Warning centre, Vishakhapatnam on 8th September, 2018.

iv) Hindi Section has conducted official language inspection of 10 sections in the Ministry.

v) Official Language inspection of CMLRE was carried out on 27th June, 2018 and a workshop was also conducted on 29th June, 2018. Official Language inspection of INCOIS was carried out on 13th November 2018.

vi) A roadmap on future activities of Hindi Section has been prepared which includes organising a scientific symposium on Ministry related subjects, starting a in-house magazine, organising Kavi Sammelan and other various events to give thrust to propagation of Hindi in the official domain of the Ministry.

9.7 Capacity Building and Human Resources development

During the year officers/staff of this Ministry (from the Headquarters) sent for different training/workshop/seminar programmes to update their knowledge and skills.

9.8 Implementation of the judgments/ orders of the CAT

All the judgments/directions/orders of Hon'ble CAT's or any other courts have been implemented or contested in proper form within the stipulated period of time.

9.9 Vigilance Activities and Achievements

Dr. M. P. Wakdikar, Sct. 'G' acted as CVO of the Ministry w.e.f 31.12.2014. Senior level officers have been appointed as VOs in attached/ subordinate offices and autonomous bodies of the Ministry. A preventive as well as punitive vigilance monitoring rigorously pursed through the CVO and VOs. Independent External Monitors appointed by the Ministry with the approval of Central Vigilance Commission (CVC) are monitoring the contracts exceeding Rs. 5 crores, in accordance with the guidelines of CVC.

9.10 Parliament Matters:

The Parliament Section, which caters to the correspondence with the Parliament Secretariats, replied Lok Sabha (56 Questions) and Rajya Sabha (46 Questions) during 2018.

9.11 Significant Audit Point Printed in the Audit Reports o 2018:

Two audit points have appeared in the audit reports of 2018.

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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 and also the Parliamentary Committee on Rajbhasha for their constant support, guidance and encouragement.

The various committees constituted by the Ministry which participated in the on-going activities and programmes are described below. We gratefully acknowledges the valuable contributions.

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, Bengaluru.
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, Goa.
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. INSA-Senior Scientist & J. C. Bose Fellow, Physical Research Laboratory, Ahmadabad.
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 NCCR chaired by Dr. Y. V. N. Krishna Murthy, Director, National Remote Sensing Centre, Hyderabad.
13. Research Advisory Committee of CMLRE chaired by Prof. T. Balasubramanian, Vice Chancellor, Chettinad Academy of Research and Science, Chennai.

14. Research Advisory Council of NCPOR, chaired by Dr. Shailesh Nayak, Director, NIAS.
15. Research Advisory Council of NCESS chaired by Dr. S. K. Tandon, Professor Emeritus, University of Delhi.
16. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof. Sulochana Gadgil.
17. Committee of domain knowledge experts chaired by Dr. Shailesh Nayak, Director, NIAS to look into all the atmospheric science programs constituting the Umbrella scheme ACROSS to facilitate adoption of latest technology and scientific tools for this scheme.

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सत्यमेव जयते

Government of India
Ministry of Earth Sciences