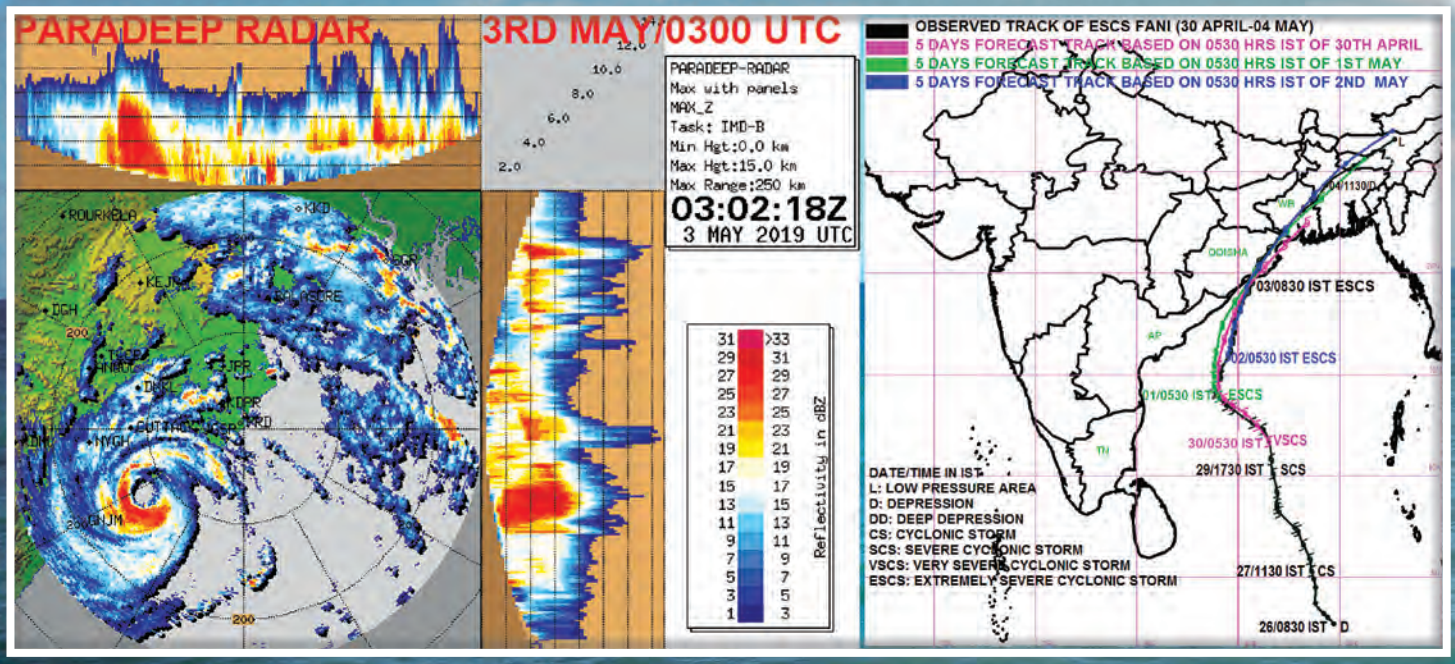
# ANNUAL REPORT

## 2019 - 2020

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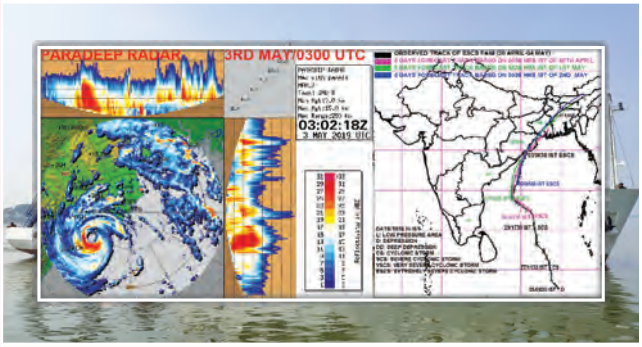
**Government of India**
**Ministry of Earth Sciences**

## FRONT COVER

# ANNUAL REPORT
2019 - 2020




Observed and forecast tracks of Extremely Severe Cyclonic Storm FANI along with the radar images from Paradeep.

Government of India
Ministry of Earth Sciences

## BACK COVER

Coastal Research Vessels Sagar Tara and Sagar Anveshika which were recently inducted to the MoES fleet of research vessels.

Instrumented research aircraft utilized for cloud seeding experiment in CAIPEEX campaign.

Government of India
Ministry of Earth Sciences


# ANNUAL REPORT
# 2019-20

**Ministry of Earth Sciences**
**Government of India**

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# 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 also has the mandate of making ocean survey and exploration for living and non-living resources and exploration of all the three poles (Arctic, Antarctic and Himalayas). The services provided by the ministry are being effectively used by different agencies and state governments for saving human lives and minimizing damages due to natural disasters. Several major milestones have been accomplished under the five major schemes of the MoES during the last year, which are illustrated below:

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

The meteorological observational network in the country was augmented to include the following:

i) Commissioning of 13 additional GPS based RS/RW stations with special emphasis to North East India. The stations, Jabalpur, Bhuj, Sriganganagar, Gopalpur, Shillong, Passighat, Dimapur, Imphal, Aizwal, Kavali, Ramagundam, Gadag and Bankura are now included in the RS/RW observational network. The GPS radiosounding network now consists of 56 stations with twice a day ascents/observations.

ii) Commissioning of a portable X-Band Doppler Weather Radar mounted on mobile platform at Sonamarg under the Integrated Himalayan Meteorology Programme (IHMP) for Western and Central Himalayas.

iii) Commissioning of 3 transmissometers - RVR (Drishti System) at Kochi, Thiruvananthapuram and Bhubaneswar airports.

iv) New sensors for Lightning Location Network have been installed at Vellore, Nellore, Bengaluru, Vijayawada, Hyderabad, Ananthapuramu, Shrivardhan, Ratnagiri, Vengurla,Ranchi, Raipur, Goa, Pudhucherry, Nainital and Madhubani. All these new sensors have been integrated with the central processor of lightning detectors at IITM, Pune.

v) The network of automatic rain gauges (ARG) in Mumbai metropolitan region has been augmented with the addition of about 30 ARGs in Navi Mumbai and Thane region.

A web-based data portal (mumbairain.tropmet.res.in) is developed for archiving and disseminating rainfall data over Mumbai

Metropolitan region. To disseminate rainfall data to public and stakeholders, a mobile app (Mumbai Weather Live) and a data portal (mumbairain.tropmet.res.in) are developed.

Intensive Observational Periods (IOPs) as part of CAIPEEX Phase-IV 2019 started on 1st April 2019 with the ground facility established at Solapurand Tuljapur stations documenting the background data of aerosol, clouds, precipitation, cloud condensation nuclei, ice nuclei, and other dynamical and thermodynamical data needed for the aircraft campaign. The airborne experiment at Solapur commenced on 29th July 2019, with an instrumented research (Beechcraft B200) and a seeder (Beechcraft C90) aircraft for cloud seeding and its scientific evaluation. The experiment took 240 hours of aircraft observations while flying and investigated the randomized and physical evaluation of clouds after seeding.

Various new types of observations viz., Atmospheric Motion Vectors (AMVs) from GOES-16, GOES-17 and NOAA-20 satellites are being assimilated in the data assimilation system. Capabilities have been developed for assimilation of AMVs from GK-2A, FY-2G, FY-2H; scatterometer winds from HY-2A and NOAA-20 radiance (ATMS & CrIS).

Under Monsoon Mission Phase-II, a modelling framework for thunderstorm/lightning prediction using 'dynamical lightning parameterization' (DLP) in WRF model has been set-up. The system is presently generating real time forecasts every day and the same are made available at http://srf.tropmet.res.in/srf/ts_prediction_system/index.php.

A very high-resolution Air Quality Early Warning System for Delhi has been developed to predict extreme air pollution events in Delhi and give warnings as per Graded Response Action Plan (GRAP). A very high-resolution (400 meters) operational air quality forecast using both satellite (3 km resolution) and surface (at city scale with 43 monitoring stations) chemical data assimilation integrated with dynamical down-scaling has been developed.

An area of about 100 acres of land has been acquired from the Madhya Pradesh State Government for establishing an Atmospheric Research Test Bed (ART) at Silkheda village in Sehore District of Madhya Pradesh (about 50 km from Bhopal). The ART programme is a highly focused observational and analytical research effort that will compare observations with model calculations in the interest of accelerating improvements in both observational methodology and monsoon prediction models.

A new website, https://mausam.imd.gov.in/ was launched by the India Meteorological Department on 27th July 2019. The new website will be an important tool for dissemination of information in an attractive & user-friendly manner and will meet the requirements of the general public. A new mobile app "Meghdoot" (a joint initiative of India Meteorological Department, Indian Institute of Tropical meteorology and Indian Council of Agricultural Research) was launched on 27th July 2019 to provide real-time location-specific, crop-specific and livestock-specific weather-based agro advisories across India in local language.

During the year, a total number of 102 new District Agro-Meteorological Field Units (DAMUs) were established. IMD also initiated Experimental block level Agromet Advisory bulletins for about 1200 blocks on each Tuesday and Friday in regional languages.

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

Indian National Centre for Ocean Information Services (INCOIS) started providing the Potential Fishing Zone (PFZ) forecasts to Gujarat and North Andhra Pradesh.

INCOIS collaborated with Airports Authority of India (AAI) to utilize the GAGAN (GPS Aided Geo Augmented Navigation) satellite system to transmit disaster warnings to fishermen. A low-cost GAGAN system-enabled GEMINI (**G**AGAN **E**nabled **M**ariner's **I**nstrument for **N**avigation and **I**nformation) device and electronically designed and manufactured in India was inaugurated on 09th October 2019 by the Honourable Union Minister Dr. Harsh Vardhan.

The coastal flood warning system for Chennai (CFLOWS-Chennai) which was developed as a multi institutional project was dedicated to the Nation on 03rd November 2019 by Honourable Vice President of India. The system has been handed over to the Tamil Nadu State Government for operational use. Based on request from the State Government to aid their disaster mitigation operations a mobile app and dashboard have been developed for the safety and security of the Coastal fishermen. It is presently being implemented by the Department of Fisheries in the state of Tamil Nadu as "Thoondil" and as "KadalChngayyai" in Kozikode, Kerala.

A coastal cleanup campaign was organized on the International Coastal Cleanup day of 21st September 2019 at 34 locations along the Indian coastal states and UTs with the assistance of 26 coordinator involving 6,984 volunteers. The major objective of the program was to create awareness among the public about the importance of the ocean environment and how to manage the coasts sustainably. A total of 35 tons of waste and 2,39,095 individual pieces of litter were collected within 2 hours of activities.

A total of 7 cruises were undertaken onboard FORV Sagar Sampada in the Eastern Arabian Sea and the Andaman Sea during the year so as to explore and inventorise the marine biodiversity of Indian seas. The surveys have yielded numerous new records and new species to the inventory of Indian Ocean fauna. The new campus of CMLRE at Puthuvypu, Kochi was dedicated to the Nation on 23rd Feb. 2019 by Hon'ble Union Minister Dr. Harsh Vardhan. The transit hostel with 10 rooms and canteen facilities was inaugurated on 1st Nov. 2019 by Dr. M. Rajeevan, Secretary, MoES.

The In-situ soil tester was deployed for seabed soil assessment in the PMN mining area in the CIOB at a depth of 5,418 m during April 2019. The newly procured deep sea winch and 7,000 m hybrid aramid umbilical cable was used. The seabed soil was assessed to be non-clayey and fairly strong to support the underwater weight (2.2 ton) of the soil tester.

A MoU was signed between NIOT and ICAR-CIBA, at Chennai for technical partnership in the promotion of aquaculture in the country. The Transfer of Technology agreements have been signed through NRDC for commercialization of Wave powered navigational buoy and commercialization of *E.faecalis* Multiplex PCR Detection Kit.

The new coastal research vessel (CRV) Sagar Tara joined MoES fleet of research vessels after successful and satisfactory harbour & sea trials on 16th August, 2019. Sagar Tara sailed out for her maiden scientific cruise with NIO-Vizag team & successfully completed sampling &

survey off-Paradip for Sea Water Quality Monitoring (SWQM) program of NCCR. The other new research vessel Sagar Anveshika was successfully launched on 31st August, 2019 at M/s Titagarh Wagons Ltd (TWL) Shipyard.

## 1.3 Polar and Cryosphere Research (PACER)

A voyage team of 25 personnel (scientific and logistic members) for the 39th Indian Expedition to Antarctica sailed off from Cape Town, South Africa on 24th December, 2019 onboard chartered vessel MV Vasiliy Golovnin. The team was comprising of scientists from Wildlife Institute of India, Dehradun; Ministry of Earth Sciences, New Delhi; University of Calcutta, Kolkata; Space Application Centre, Ahmedabad; National Hydrographic Office, Goa; NCPOR, Goa and Indian Institute of Technology, Bombay.

Indian research station 'Himadri' was manned for over 150 days since March 2018 till November 2019. Over 40 researchers visited the station, 7 sailed in *RV Lance* for mooring retrieval-deployment, and 4 sailed in *RV Clione* on Svalbard coastal cruise under 23 different scientific projects. Gruvebadet Atmospheric Laboratory, Ny-Alesund has also been operational for continuous monitoring of precipitation, clouds and aerosols, with instruments like radiometer profiler, micro rain radar, aethalometer, nephelometer, net radiometer and sunphotometer.

Various glaciological and geophysical measurements were carried out along the 2000-km-long coast in coastal Dronning Maud Land (cDML) to understand the response of the Antarctic ice shelves to global warming. A systematic long-term scientific investigation of Himalayan glaciers with objective "to understand the response of Himalayan Cryosphere to the changing climate and its hydrological impacts" has been carried out. Six selected benchmark glaciers (Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Gepang and Kunzam) of Chandra basin, western Himalaya have been monitored for their changes.

## 1.4 Seismology and Geoscience Research (SAGE)

A new website (https://seismo.gov.in) of National Centre for Seismology (NCS) was launched on 27th July, 2019. The website is GIS based with a host of features that provides earthquake information suited to individual's requirement (in the form of list/table, map overlaid with different layers etc). A mobile app was also launched for earthquake information "RISEQ" on PLAY Store (Android Users) and APP Store (IOS Users) which provide the latest earthquake information.

The Seismic Microzonation work related to Geophysical investigations has been taken up for the four cities, namely, Chennai, Bhubaneswar, Coimbatore, and Mangalore. During the current year, 4 Indian scientists participated in different International Ocean Discovery Program (IODP) expeditions i.e. IODP 379 (Eastern Amundsen Sea continental shelf), IODP 382 (Iceberg Alley and Sub-Antarctic Ice), IODP 383 (Dynamics of the Pacific Antarctic Circumpolar Current) and IODP 385 (Guaymas Basin Tectonics and Biosphere) and had unique hands-on experience in the scientific ocean drilling. A new state-of-the-art Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) facility was established at the NCESS, Thiruvananthapuram for in-situ trace element geochemistry and geochronology.

The discharge of groundwater to sea through coastal aquifers (Submarine Groundwater Discharge - SGD) has been recognized as

small volumetrically, but quite significant ecologically because SGD offers an important pathway of nutrients, carbon and other geo-chemical constituents to the ocean. NCESS has taken up a national program for the SGD flux determination. Fourteen institutes are participating in this national Program.

## 1.5 REACHOUT

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 were received in response to the above call, out of which 7 proposals have been approved for funding.

## 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.

An Implementation Agreement on Weather and Climate Science for Service Partnership India (**WCSSP India**) has been signed between MoES and UK Met Office on 7th February 2019. A science plan consisting of 3 work packages was finalized with a focus on enhancing our capabilities in modelling high impact weather and services that help reduce exposure to damaging weather and climate impacts. MoES was elected as a steering committee member of the Belmont Forum for a 3-year term starting 1st January 2020. A Memorandum of Understanding (MoU) on "Antarctic co-operation" between the Ministry of Earth Sciences and the Ministry of Foreign Affairs and Worship of the Argentine Republic was signed on 4th April 2019.

The First Workshop of Experts on Himalayan Science Council (HSC) was held during

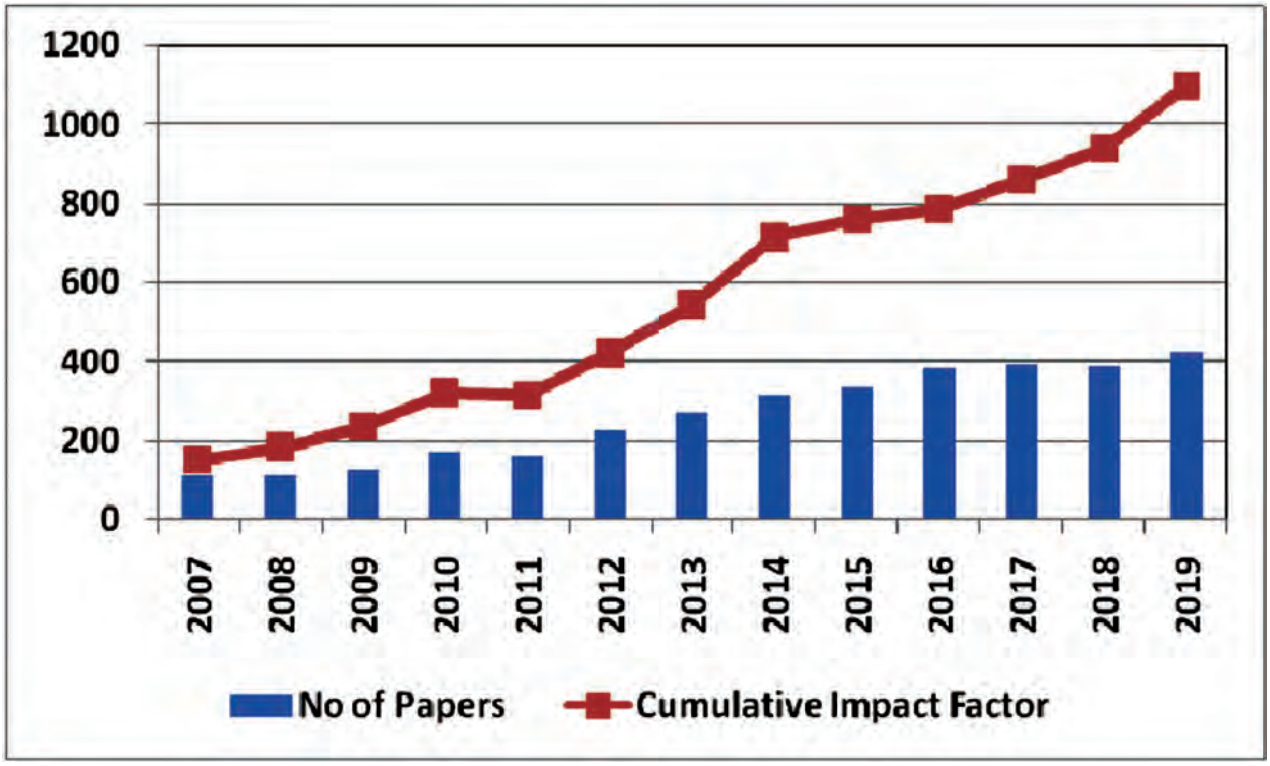


**Fig. 1.1 Number of research papers and cumulative impact factor year wise**

05-06 December 2019 in Goa, India at the invitation of the Government of India. The delegations from the People's Republic of Bangladesh, the Kingdom of Bhutan, the Republic of India, the Republic of the Union of Myanmar, Nepal, the Democratic Socialist Republic of Sri Lanka and the Kingdom of Thailand attended the workshop. The Concept Paper on establishment of HSC under the BIMSTEC drafted by India was discussed and all member states agreed in principle to establish the HSC.

## 1.7 Scientific Publications

A total number of 426 research papers were published during 2019 by MoES scientists under various programs of the Ministry. The number of research papers published and the total impact factor (1098.4) are comparatively higher as compared to the previous years (Fig. 1.1).

## 1.9 Budget Expenditure

The total outlay for the Ministry for the year 2019-20 was Rs. 1901.76 crores which was reduced to Rs. 1809.74 crores at the RE stage. The expenditure profile for the last 13 years is shown in the table below.

| Year | RE | BE | 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 | 1745.63 |
| 2019-20 | **1901.76** | **1809.74** | **1340.26*** |

*As on 31/12/2019

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

## Introduction

The Ministry of Earth Sciences (MoES) 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 Scheme ACROSS.

During the year, many significant achievements have been made on providing weather and climate services. Major improvements have been made in the observing systems and data assimilation in numerical models. Special atmospheric Observational campaigns also have been conducted to help us to understand model de-ficiencies and to improve the accuracy of models. Details of significant achievements made under the scheme ACROSS are given below:

## 2.1 Observing Systems and Field Campaigns

### 2.1.1 IMD and IITM Efforts

- Agromet Observatories have been installed at Five (5) Agromet Field Units (AMFUs) in Roorkee, Bhubaneswar, Udaigiri, Pusa and Agwanpur.
- Three (3) Nos of transmissometer-RVR (Drishti System) were installed at Kochi, Thiruvananthapuram and Bhubaneswar making it to total of 44 RVR instruments at the airports.
- Thirteen (13) additional GPS based RS/RW stations were installed to increase total number of RS/RW stations to 56. Special emphasis was given to establish a network in North East India. Jabalpur, Bhuj, Sriganganagar, Gopalpur, Shillong, Passighat, Dimapur, Imphal, Aizwal, Kavali, Ramagundam, Gadag and Bankura are now included in the RS/RW observational network.
- A portable X-Band Doppler Weather Radar mounted on mobile platform was installed at Sonmarg under the Integrated Himalayan Meteorology Programme (IHMP) for Western and Central Himalayas (Fig. 2.1)
- 341 new rain-gauge stations were added in the District Rainfall Monitoring Scheme of India Meteorological Department.

In addition, IITM Pune has carried out intense observational campaigns and strengthened observational network as mentioned below:

- A new chemistry lab was established at HACPL, Mahabaleshwar, which houses PTR-TOF–MS (Proton Transfer Reaction Mass Spectrometer), HTDMA (Hygroscopic Tandem Differential Mobility Analyzer) and Particles into Liquid Sampler (PILS)-Ion Chromotograph.
- To understand the raindrop size distribution over different environments, a disdrometer network has been setup by IITM Pune at Mahabaleshwar, Mumbai, Cherrapunji, and Chennai.

**Fig. 2.1 Portable X-Band Doppler Weather Radar at Sonmarg**

- New sensors for Lightning Location Network have been installed at Vellore, Nellore, Bengaluru, Vijayawada, Hyderabad, Ananthapuram, Shrivardhan, Ratnagiri, Vengurla, Ranchi, Raipur, Goa, Puducherry, Nainital and Madhubani.
- The network of automatic rain gauges (ARG) in Mumbai metropolitan region has been augmented with the addition of about 30 ARGs in Navi Mumbai and Thane region.

A web-based data portal (mumbairain.tropmet.res.in) was developed for archiving and disseminating rainfall data over Mumbai Metropolitan region. To disseminate rainfall data to public and stakeholders, a mobile app (Mumbai Weather Live) and a data portal (mumbairain.tropmet.res.in) are also developed.

### 2.1.2 Satellite and Radar products for weather forecasting services

India Meteorological Department (IMD) is at advanced stage for establishing Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS in collaboration with M/S Antrix Corporation Ltd, ISRO for which a MOU was signed on 6th March, 2017. The MMRDPS system is being used to receive & process the INSAT-3D and INSAT-3DR satellites data in parallel with IMDPS system since 1st October, 2019.

Radar reflectivity mosaic has been developed at 1-km resolution for the entire country. These products are being updated at every 15 minutes interval, to closely monitor the development of thunderstorms. These products are available at https://mausam.imd.gov.in/.

Doppler Weather Radar (DWR) rainfall products have been developed for individual stations and all India Mosaic of radar rainfall at 4-km resolution. These products are used for verification of model predictions and DWR rainfall assimilation.

### 2.1.3 Atmospheric Research Testbed (ART) facility in central India

IITM has received ~100 acres of land from the Madhya Pradesh State Government for establishing a Atmospheric Research Test Bed (ART) at Silkheda village in Sehore District of Madhya Pradesh (about 50 km from Bhopal). The land acquisition deed for 100 acres was registered on 20th November 2019. ART programme is a highly focused observational and analytical research effort that will compare observations with model calculations in the interest of accelerating improvements in both observational methodology and monsoon prediction models.

### 2.1.4 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 observational campaign of 2019-20 (CAIPEEX Phase-IV) is a continuation of the observational

campaign conducted during June-November 2018 which successfully collected data on cloud seeding over the rain shadow region. However, in order to have a statistically significant result and to formulate guidelines for cloud seeding for rain enhancement over the region, CAIPEEX IV 2019 was initiated. Intensive Observational Periods (IOPs) as part of CAIPEEX Phase-IV 2019 started on 1st April 2019 with the ground facility established at Solapur and Tuljapur stations documenting the background data of aerosol, clouds, precipitation, cloud condensation nuclei, ice nuclei, and other dynamical and thermodynamical data needed for the aircraft campaign. The airborne experiment at Solapur commenced on 29th July 2019. The experiment was conducted by using an instrumented research (Beechcraft B200) and a seeder (Beechcraft C90) aircraft for cloud seeding and its scientific evaluations. The experiment took 240 hours of aircraft observations while flying and investigated the randomized and physical evaluation of clouds after seeding. CAIPEEX Phase-IV aircraft observational campaign successfully ended on 17th October 2019.

## 2.2 Global and Regional Data Assimilation

### 2.2.1 GFS Data Assimilation-Forecast System

Retrospective analysis and re-forecasting runs for GFS system (T1534L64; V14) have been carried out for the period 1999-2018 for generation of model climatology required for bias correction of GFS model forecasts.

Regional GSI for WRF-3 km model with assimilation of Indian Doppler Weather Radar (DWR) observations has been developed and operationalized. Quality Control procedure for DWR observations has been developed in which, radial velocity is quality controlled using the region based approach and radar reflectivity is corrected for the speckle echoes. A HYCOM-based HWRF assimilation -forecasting system for tropical oceans over North Indian Ocean (NIO) region has been also operationalized.

### 2.2.2 NCMRWF Unified Modelling and Assimilation System (NCUM)

Various new types of observations viz., wind vectors from satellites GOES-16, GOES-17 and NOAA-20; surface & sonde observations are being assimilated in NCUM data assimilation system. Capabilities have been developed for assimilation of wind data from GK-2A, FY-2G, FY-2H; scatterometer winds from HY-2A and NOAA-20 radiance (ATMS & CrIS).

An advanced observation pre-processing and monitoring system has been developed for NCUM which has the capability to process more meteorological observations reliably and efficiently for its assimilation. An observation monitoring system also has been developed for operational monitoring of all satellite radiance observations received and assimilated in NCUM system.

A regional Land Data Assimilation system has been developed for providing high resolution regional analyses of soil moisture and temperature for regional NCUM. Various studies (OSE, OSSE and FSO) have been carried out to understand the impact of observations on forecast. Operational FSO (Forecast Sensitivity to Observations) system is being used for continuous monitoring and assessment of observation impact on global forecast.

A high resolution regional reanalysis using forty years of data has been generated under the Indian Monsoon Data Assimilation and Analysis (IMDAA) project in collaboration with Met Office, UK. This is the highest resolution reanalysis

available over the Indian monsoon region. Various studies are being undertaken using this data set and results of few initial studies are submitted for publication. Figure 2.2 depicts June to September (JJAS) average IMDAA rainfall (1979-2016) along with the observed rainfall for the same period.

Hindcast runs of the NCUM global model for the period 2016-2018 have been made to generate high resolution model forecast climatology. The mean daily climatology is generated using the moving pentad days methodology centered on each day. This climatology is used for generating the indices of extreme weather events as 90$^{th}$, 95$^{th}$ and 99$^{th}$ percentile probability. The severe weather indices with anomalies of wind, rainfall, temperature and humidity etc. have been generated over India in real time and are being utlized by the operational forecasters.

Verification of the NCMRWF model forecasts has been carried out as per the WMO specified and internationally followed best practices. The standard verification scores/ metrics were exchanged with the WMO Lead centre for Deterministic Model Forecasts (i.e., ECMWF). Figure 2.3 shows the Root Mean Square Error (RMSE) in the 850 hPa wind forecast over India is shown for each of the months from Jan. 1999 to Sept. 2019. The RMSE shows decreasing which is significant from 2016 suggesting improvements in forecasts.

### 2.2.3 NCMRWF Ensemble Prediction Systems (NEPS)

Apart from NCUM based 22-members global ensemble prediction system (NEPS-G) at 12 km resolution, a regional version of ensemble

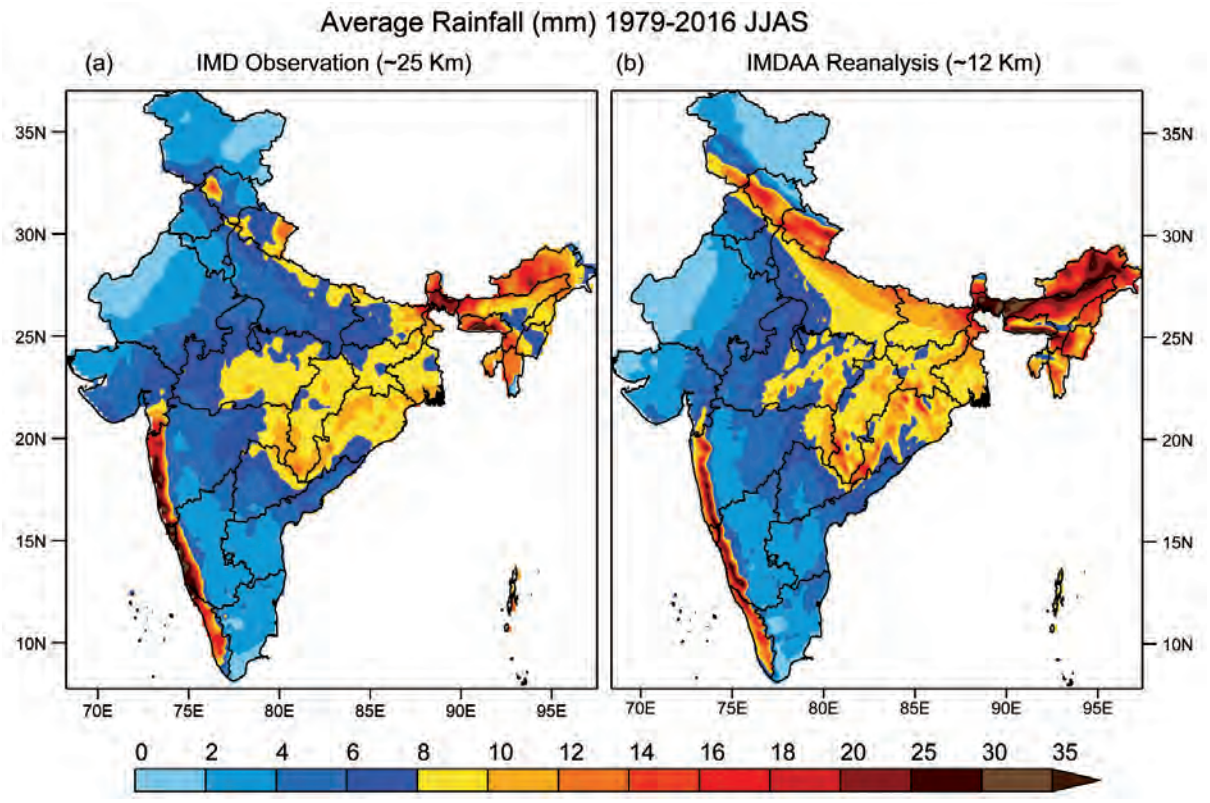



**Fig. 2.2 June to September (JJAS) average IMDAA rainfall (1979-2016) and observed rainfall for the same period**

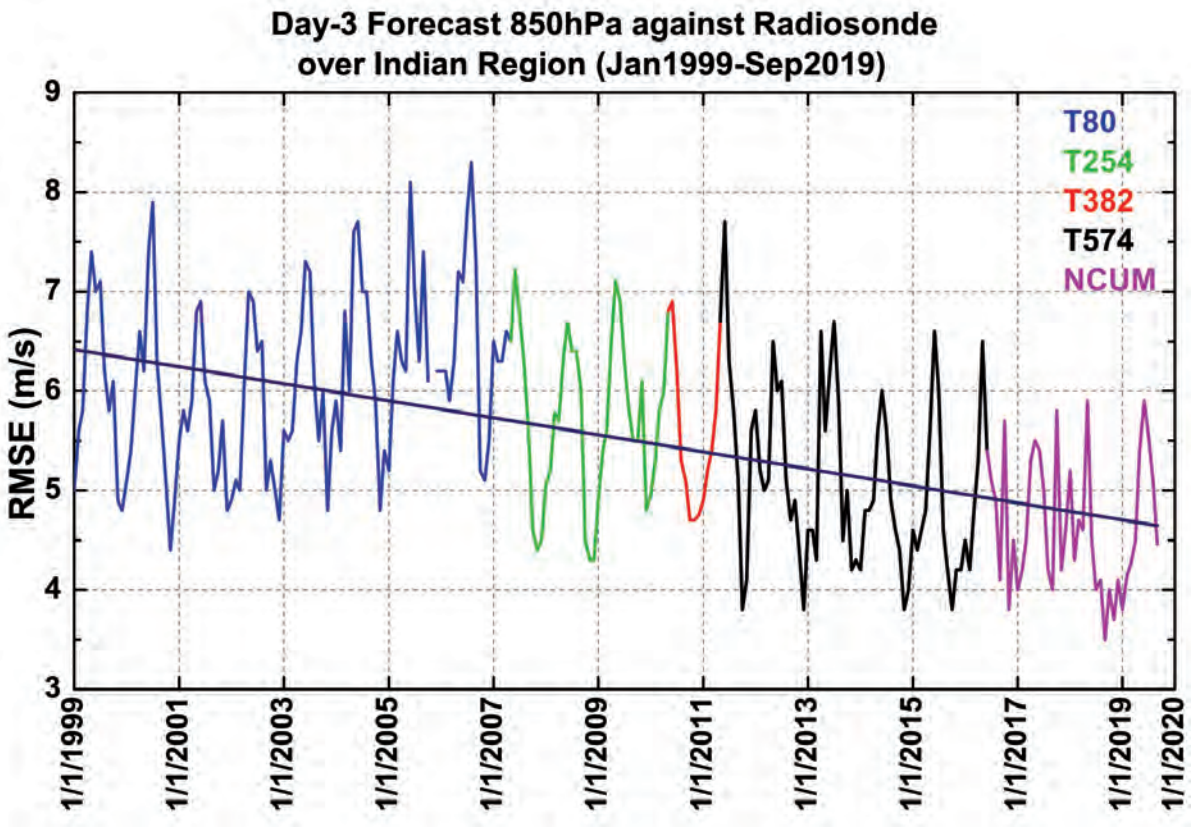



**Fig. 2.3 RMSE of Day-3 wind predictions over Indian Region at 850 hPa level by NCMRWF models from 1999 to September 2019**

prediction system (NEPS-R) with 12 members (1 control+11 perturbed) has been implemented for accurate and reliable probabilistic prediction of extreme weather events over India in July 2019. This system has 4 km horizontal resolution with horizontal domain covering entire India and 80 vertical levels extending up to a height 38.5 km. Initial and boundary conditions of NEPS-R are being provided by the global NEPS. Figure 2.4. shows the probabilistic predictions from NEPS-R for the heavy rainfall event over Mumbai during 4th August 2019.

In addition to the above, the tropical cyclone (TC) track forecasts from global ensemble system NEPS-G have also been implemented. The tropical cyclone tracker provides prediction of cyclone tracks from every member of NEPS-G, the ensemble mean track, the strike probability and the probabilistic forecasting of cyclone intensity along its track. A similar TC tracker has also been implemented for NEPS-R.

### 2.2.4 NCMRWF Coupled Model (C-NCUM):

A state-of-art global coupled Ocean-Atmosphere-Land-Sea ice model (C-NCUM) is being run at NCMRWF along with the ocean data assimilation (ODA) system based on NEMO ocean model. This is the first seamless modelling system implemented at MoES, using same dynamical cores across scales from hours to season. The model is run daily up to 15 days to monitor tropical cyclone heat potential (TCHP) and other ocean features. The same model with six ensemble members is run once a week up to

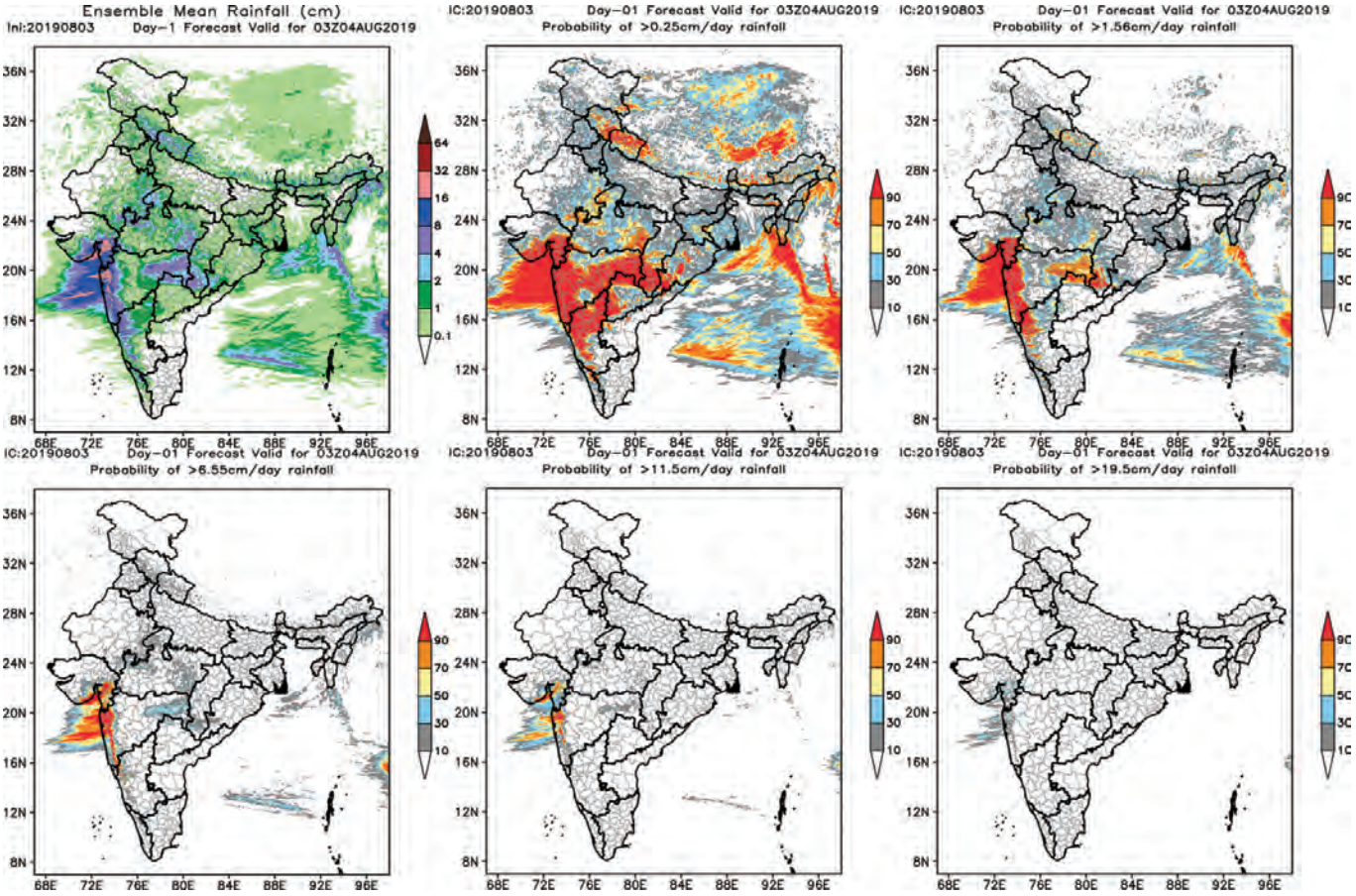



**Fig. 2.4 Probabilistic prediction of heavy rainfall over Mumbai for various rainfall categories along with ensemble means rainfall valid for 4th August 2019**

four weeks to produce real-time extended range (multi-week) predictions. The model also produces real-time Sea-Ice predictions at medium (15 days) and Extended Range (4 week) and is used for Indian operations at Polar Regions and other R&D activities. Upper Ocean plays important role in formation, intensification and maintenance of tropical cyclones by providing heat source.

### 2.2.5 Global Forecasting System (GFS)

The Global Forecasting System (GFS T1534L64) model was run operationally at IMD four times in a day (00, 06, 12 & 18 UTC) to give deterministic forecast in the short to medium range up to 10 days. The forecast model has a resolution of approximately 12 km in horizontal and has 64 levels in the vertical. The initial conditions for this GFS model is generated from the four-dimensional (4D) ensemble–variational data assimilation (DA) system (4DEnsVar) building upon the grid point statistical interpolation (GSI)-based hybrid Global Data Assimilation System (GDAS) run on High Performance Computing Systems (HPCS) at the National Center for Medium Range Weather Forecasting (NCMRWF). The real-time GFS T1534L64 model outputs are generated daily at India Meteorological Department. This 4DEnsVar data assimilation system has capabilities to assimilate various conventional as well as

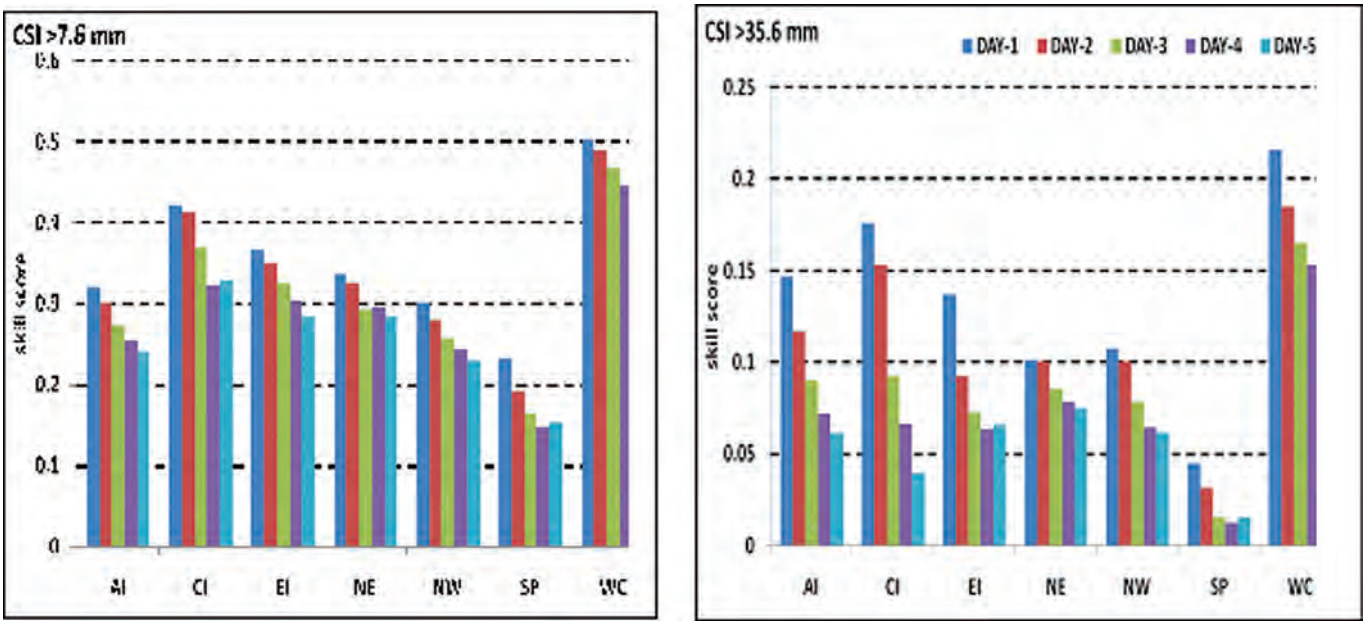



**Fig. 2.5 Domain mean values of Critical Success Index (CSI or threat score) for rainfall category greater than 7.6 mm (left panel) and for > 35.6 mm (right panel) during monsoon 2019.**

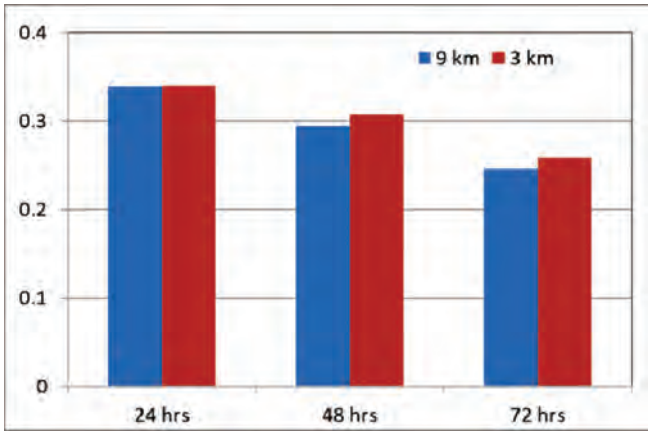
satellite observations including radiances from different polar orbiting and geostationary satellites. The real-time outputs are made available to operational weather forecasters and various users through the national web site of IMD.

### 2.2.6 WRF modeling System

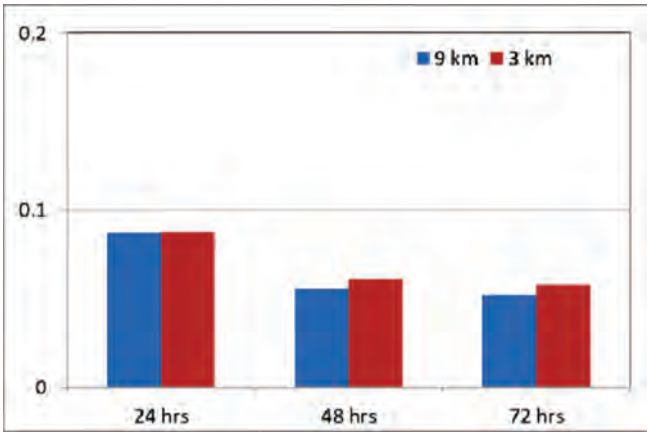
During southwest monsoon season 2019, the double nested WRF model (ARW) delivered three days forecasts twice daily at 00 UTC and 12 UTC. The data assimilation component, WRF Data Assimilation (WRFDA) takes global GFS analysis and all other conventional quality-controlled observations as its input and generates mesoscale analysis with 9 km resolution. The model mother domain (09 km) covered the area of responsibility for Regional Specialized Meteorological Center (RSMC), New Delhi ($23^0$ S to $46^0$ N; $40^0$ E to $120^0$ E). The nested domain with 3 km resolution is centred at 22.5°N and 81.2°E spans nearly 4000 km in both east-west and north-south directions to cover whole Indian region. Fig. 2.6 represents the mean categorical skill scores averaged over whole Indian region during the monsoon season 2019.

### 2.2.7 HWRF-Ocean (POM/HYCOM) coupled model

During the pre-monsoon and post-monsoon cyclone seasons of 2019, the movable triple nested HWRF-Ocean (POM/HWRF) coupled model with horizontal resolutions of 18 km, 6 km and 2 km generated five days forecasts four times a day at 00 UTC, 06 UTC, 12 UTC and 18 UTC for tropical cyclones formed over north Indian Ocean (NIO). The data assimilation component, regional GSI Data Assimilation, takes global GFS analysis and all other conventional quality-controlled observations as its input and generates mesoscale analysis for intermediate and innermost nests which are then merged to generate analysis for all three domains. The INSAT radiance was also assimilated operationally starting from post monsoon cyclone season of 2019. The model parent




(a)




(b)

**Fig. 2.6 The categorical skill scores averaged over whole Indian region for the monsoon season 2019. (a) and (b) are Critical Success Index (CSI) for two rainfall categories with WRF forecasts exceeding 6.5 mm and 64.5 mm rainfall, respectively**

domain (18 km) covered the area of 800 x 800 centred at the storm centre. The movable intermediate domain with 6 km resolution covered area of 240 x 240 and the movable inner most domains covered an area of 70 X 70 centred at storm centre.

## 2.3 Monsoon Mission

### 2.3.1 Seasonal Prediction

The operational Seasonal Forecast of south west monsoon 2019 was prepared by using Monsoon Mission Climate Forecast System (MMCFS) developed at IITM, Pune. For generating this forecast, global atmospheric and oceanic initial conditions up to March 2019 were used, involving 47 ensemble members. The forecast based on the MMCFS model suggested that the monsoon rainfall during the 2019 monsoon season (June to September) averaged over the country as a whole was likely to be 94% ± 5% of the Long Period Average (LPA).

Model development for climatic application in hydrology and agriculture by integrating river runoff in CFSv2 is in progress. To meet the requirements of high resolution model outputs for applications such as agriculture and hydrology, dynamical down-scaling of seasonal forecast models has been attempted at a resolution of ~38 km.

### 2.3.2 Extended Range Prediction

Major achievements on model development activities include: a) development of strategy for the real-time extended range prediction of heat waves, b) development of a methodology to predict the Madden-Julian Oscillation in real-time on extended range, c) development of an improved genesis potential parameter to predict cyclogenesis in real-time. The extended range forecasts are widely used in generating the advisories in agricultural and health sectors.

The extended range prediction products for research/scientific use based on different initial conditions have been made available at http://www.tropmet.res.in/erpas/. Rainfall, Maximum & Minimum temperatures, Heat wave, MJO forecast, soil moisture (0-10 cm), Relative

humidity, and Cyclogenesis predictions are also made available at the same link.

### 2.3.3 Thunderstorm/Lightning Prediction System:

Under Monsoon Mission Phase-II, a modelling framework for thunderstorm/lightning prediction using 'dynamical lightning parameterization' (DLP) in WRF model has been set-up. The system is presently generating real time forecast every day and the same is made available on a dedicated website. These forecasts and related information are available at: http://srf.tropmet.res.in/srf/ts_prediction_system/index.php.

### 2.3.4 Short Range High Resolution Ensemble Forecasting

- Percentile based (90$^{th}$ and 95$^{th}$) extreme forecast of rainfall based on GFS (12 km) model has been developed and operationalized.
- Probabilistic forecast for all the river basins of India has been developed based on GEFS ensemble forecast and operationalized since September 2019. It is being utilized by IMD's Flood Monitoring Offices (FMOs) for different river basins.
- GEFS based indices namely supercell composite parameter (SCP), wind gust index, and hail index have been developed for prediction of thunderstorm occurrence, wind gust, and hail. These products are operationalized since 1$^{st}$ April 2019. A new website "System for Thunderstorm Observation, Prediction and Monitoring (STORM)" (http://srf.tropmet.res.in/srf/ts_prediction_system/index.php) has been made operational since June 2019.
- Bias corrected solar and wind forecasts have been shared on experimental basis with National Institute of Wind Energy. GFS forecasts of rainfall and other weather parameters have been shared with Mahalanobis National Crop Forecast Centre, Ministry of Agriculture & Farmers' Welfare, Government of India.

## 2.4 Centre for Climate Change Research IITM Earth System Model (IITM-ESM)

IITM is contributing to Coupled Model Inter-comparison Project (CMIP6) experiments and IPCC AR6 Assessment Report, for the first time from India, using IITM-ESM. Multi-century simulations corresponding to pre-industrial and present-day conditions performed using IITM-EM showed major improvements in capturing key aspects of time-mean atmosphere and ocean large-scale circulation. The DECK simulations of CMIP6 are successfully completed using IITM-ESM. These include a 300 year spin-up and 500 year preindustrial control (PI Control) simulation, historical simulations of recent past (~150 years), AMIP simulations, transient $CO_2$ and abrupt $CO_2$ increase simulations. The historical simulations performed using time-varying aerosols, land-use land-cover changes and GHG concentrations for the period 1850-2014, realistically simulate the present day climate. Indian Ocean mean state and variability, fundamental characteristics of Indian Ocean dipole (IOD) and IOD-Monsoon teleconnection are better simulated in IITM-ESM. The scenario runs for the end of the 21$^{st}$ century are being performed with IITM-ESM and all the data are being disseminated publically using the ESGF node located at IITM (http://cccr.tropmet.res.in/home/esgf_data.jsp). The IITM-ESM CMIP6 data can be downloaded through https://esgf-data.dkrz.de/search/cmip6-dkrz/.

Preliminary analysis of the selected global climate indicators including global mean surface temperature (GMST), global mean precipitation, and global mean thermosteric sea level (GMSL) for the period 1900 to 2099 from IITM-ESM CMIP6 historical simulations and other available CMIP6 models are shown in Figure 2.7. These include historical simulations for the period 1900-2014 and projections from 2015 onwards. The time-series of GMST show an increase of more than 0.6°C during 1951-2014 (with reference to a base period of 1961-1990). The CMIP6 models simulate the observed warming trend, however, exhibit a wide range of warming levels especially at the end of the 21st century (Fig. 2.7a). The GMST from the IITM-ESM for the historical period closely follow the observed warming, and the global mean temperature rise is within the range of warming shown by other CMIP6 models during the historical period (Fig. 2.7a). Global mean precipitation shows an increase with an increase in temperature in IITM-ESM and other CMIP6 models, higher rates of increase are seen in those models with higher levels of warming (Fig. 2.7b). The global mean thermosteric sea level (TSL) from IITM-ESM and other CMIP6 models show an increase, especially in the recent decades and projected to increase with increase in GMST (Fig. 2.7c).

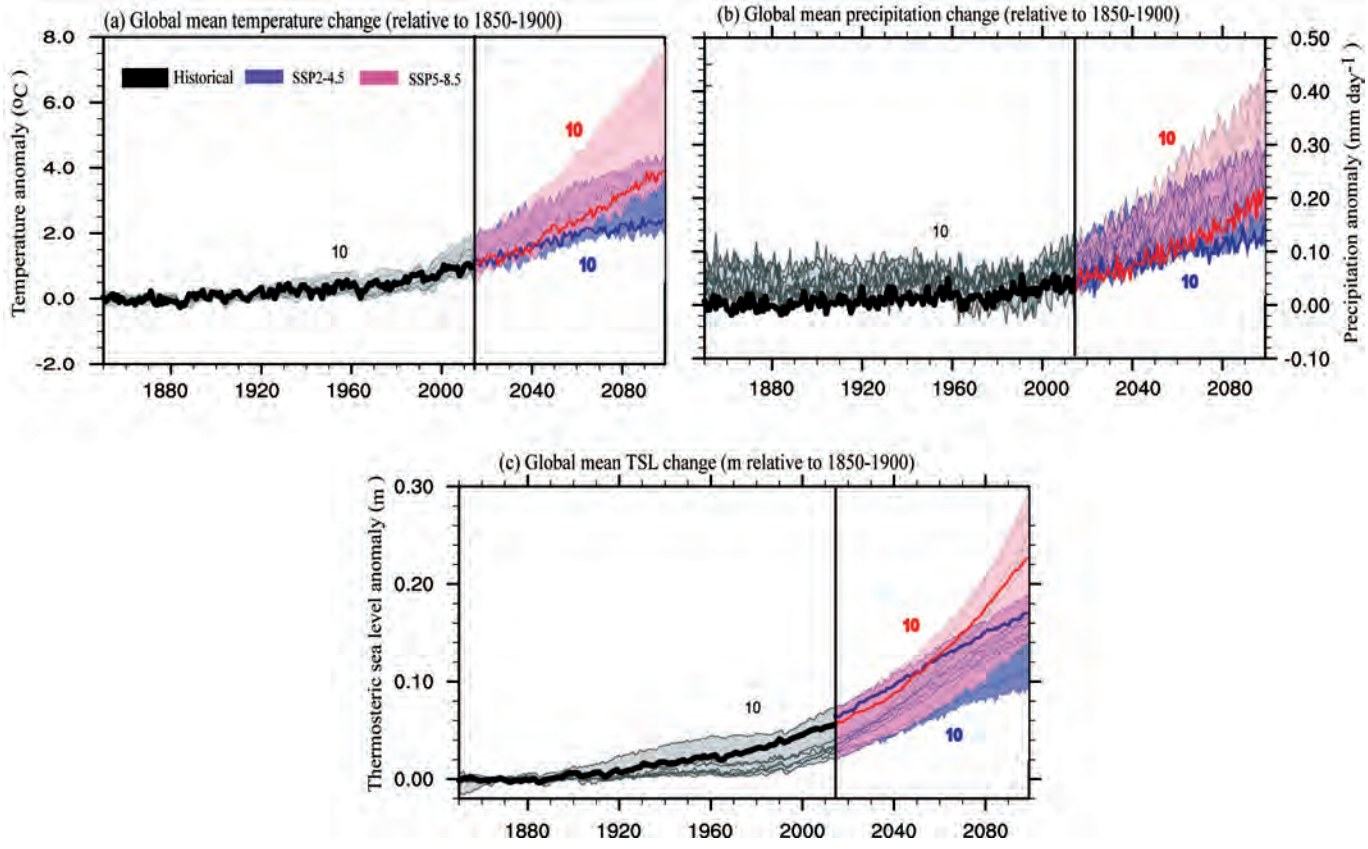



**Fig. 2.7 Time-series of global mean annual mean climate indicators from CMIP6 historical simulations and projections. Blue curve represents RCP 4.5 scenario and red curve represents RCP 8.5 scenario. Solid line represents IITM-ESM simulation. Number of models selected for each variable is shown in numbers.**

## 2.5 Monsoon 2019

### Southwest Monsoon during June to September

### Onset

Based on an indigenously developed statistical model, IMD predicted on 15th May, 2019 that monsoon will set in over Kerala on 6th June with a model error of ±4 days. The actual monsoon onset over Kerala was on 8th June.

### Long Range Forecast of Monsoon Rainfall

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 96% of LPA with a model error of ± 5% of LPA. The update issued in May for this forecast was (96% of LPA) with a model error of ± 4% of LPA. The actual season rainfall for the country as a whole was 110% of LPA, which is 6% of LPA more than upper forecast limits of the April and May forecasts. Out of the total 36 meteorological subdivisions, the season (June-September) rainfall was normal in 19 subdivisions (54% of the total area of the country) and excess in 10 subdivisions measuring 22% of the total area of the country and large excess in 2 subdivisions measuring 8% of the total area of the country. However, the season rainfall was deficient in 5 subdivisions constituting 15% of the total area of the country.

The Table 2.1 below gives the summary of the verification of the long range forecasts issued for the 2019 Southwest monsoon. Fig. 2.8 shows the per cent departure rainfall for 36 meteorological sub divisions during the 2019 southwest monsoon season.

### Northeast Monsoon 2019

The 2019 northeast monsoon season (October-December) rainfall over the country as a whole was above normal (129% of LPA). The seasonal rainfall during the northeast monsoon season over the core region of the south peninsula (comprising of 5 subdivisions viz. Coastal Andhra Pradesh, Rayalaseema, Tamil Nadu & Puducherry, South Interior Karnataka and Kerala), was normal (109% of LPA). All the five subdivisions of the core region received excess/normal rainfall.

**Table 2.1**

**Verification of long-range forecast southwest monsoon 2019**

| Region | Period | Forecast (% of LPA) | | | Actual Rainfall (% of LPA) |
|---|---|---|---|---|---|
| | | 15th April | 31st May | 1st August | |
| All India | June to September | 96± 5 | 96± 4 | 96 | 110 |
| Northwest India | June to September | | 94± 8 | | 98 |
| Central India | June to September | | 100± 8 | | 129 |
| Northeast India | June to September | | 91± 8 | | 88 |
| South Peninsula | June to September | | 97± 8 | | 116 |
| All India | July | | 95± 9 | | 105 |
| All India | August | | 99± 9 | | 115 |
| All India | August to September | | | 100± 8 | 130 |

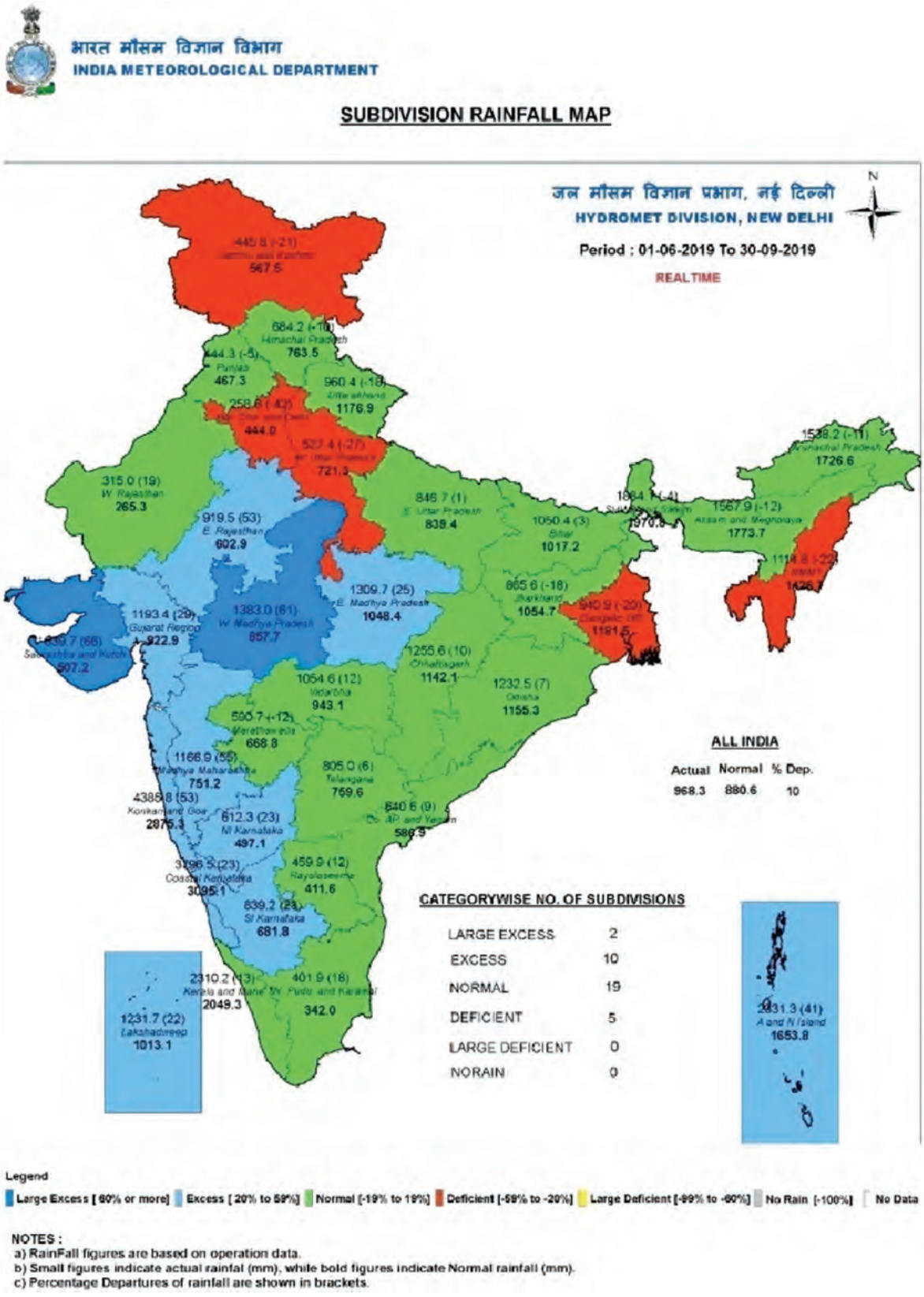



**Fig. 2.8 Subdivision-wise southwest monsoon rainfall during June to September, 2019**

## 2.6 Tropical Cyclone Monitoring and Prediction 2019

The year, 2019 was an exceptional year with respect to cyclonic activity over the North Indian Ocean (NIO) with development of more frequent and more intense cyclones over the NIO. The Arabian Sea (AS) was more active as compared to the Bay of Bengal (BoB). The salient features of the cyclonic activity over the NIO are mentioned below:

Twelve (12) cyclonic disturbances (CDs) developed over the north Indian Ocean (NIO) including 4 over the Bay of Bengal (BoB) and 8 over the Arabian Sea (AS) during the year 2019 against the normal of 12 CDs per year over the NIO. The year 2019 witnessed 8 cyclones (3 over BoB and 5 over AS) and 4 depressions/deep depressions (1 over BoB and 3 over AS). Out of 5 cyclones over the AS, 4 were severe & above intensity cyclones and out of 3 cyclones over BoB, 2 were severe & above intensity cyclones.

The maximum number of 5 cyclones with 4 severe cyclones developed over AS during 1902. Thus, the frequency of cyclones over north Indian Ocean during 2019 is still less than the maximum of 10 cyclones observed in past. The frequency of cyclones and severe cyclones over the AS during the year 2019 as a whole matches the frequency during 1902.

Details of these CDs over the north Indian Ocean in 2019 are listed below:

i. Cyclonic Storm (CS) PABUK over Andaman Sea during 04-08 January

ii. Extremely severe cyclonic storm (ESCS) FANI over the BoB during 26 April-04 May

iii. Very severe cyclonic storm (VSCS) VAYU over the AS during 10-17 June

iv. Deep depression (DD) over the BoB during 06-12 August

v. VSCS HIKAA over the AS during 22-25 September

vi. Depression (D) over the AS during 29 September-01 October

vii. Super Cyclonic Storm (SuCS) KYARR over eastcentral AS during 24 Oct.-02 Nov.

viii. ESCS MAHA over the AS during 30 Oct.-07 Nov.

ix. VSCS BULBUL over the BoB during 05-11 November

x. CS PAWAN over the southwest AS during 02-07 December

xi. DD over East Central AS during 03-05 December

xii. Depression over southwest AS during 08 - 10 December

Arabian Sea was more active during 2019 with the formation of 8 CDs against the normal of 1.7 CDs per year. Similarly, 5 cyclones developed over Arabian Sea during 2019 against the normal of 1 per year. Considering the past data (1891-2018), the maximum of 6 CDs developed over the Arabian Sea in the year 1998 & 5 cyclones in 1902.

The year 2019 witnessed development of more intense cyclones over the Arabian Sea, as out of 5 cyclones, one was a super cyclonic storm (Kyarr), 1 extremely severe cyclonic storm (Maha), 2 very severe cyclonic storms (Vayu, Hikaa), and 1 cyclonic storm (Pawan). The activity over the Bay of Bengal was subdued this year as compared to Arabian Sea with the formation of only 3 cyclones (Pabuk, Fani, Bulbul) against the normal of 4 per year. Out of these, two were severe cyclones (Fani & Bulbul) against the normal of 2 per year.

The year 2019 also witnessed development of **super cyclonic storm (SuCS),**

**Kyarr** which was the 7th super cyclonic storm over NIO during the period 1965-2019. It was the second SuCS over Arabian Sea during this period after cyclone Gonu in June, 2007. However, Gonu crossed Oman coast as a very severe cyclonic storm while Kyarr weakened over the Arabian Sea. The year 2019, also witnessed an **unprecedented 19 days of cyclogenesis** with development of three consecutive cyclones during 24th October-11th November namely Kyarr (24 October-02 November), Maha (30 October-07 November) and Bulbul (5-11 November) over AS and BoB.

Based on preliminary analysis, the enhanced cyclonic activity may be attributed to the following factors:

(i) The above normal sea surface temperatures (SST) and favourable vertical wind shear between upper and lower tropospheric levels during post monsoon season.

(ii) The positive Indian Ocean Dipole (IOD) over Equatorial Indian Ocean (EIO) (i.e. warmer SST over the west EIO near Somalia coast and relatively colder SST over east EIO near Indonesia). The positive IOD is favourable for enhancing the convective activity and the lower level convergence of winds over the Arabian Sea.

(iii) Favourable Madden Julian Oscillation (MJO) prevailed with the enhanced phase of convection lying over the west EIO and adjoining Arabian Sea.

(iv) The active northeast monsoon conditions prevailed during the season leading to seasonally excess rainfall activity over India as on date. The active northeast monsoon conditions help in increasing the moisture up to middle troposphere over the Arabian Sea. Also, the atmosphere becomes more unstable over the Arabian Sea, during such situation.

**Forecast Performance during 2019**

The annual average track forecast errors in 2019 have been 69 km, 104 km and 149 km, respectively for 24, 48 and 72hrs against the past five year average error of 86, 132 and 177 km based on data of 2014-2018. The errors have been significantly lower during this year as compared to long period average (2014-18) for all lead periods upto 96 hours. The track forecast skills compared to climatology and persistence forecast are 68%, 79% and 77% respectively for the 24, 48 and 72 hrs lead period which is comparatively higher than long period average of 2014-2018 (58%, 70% & 74% respectively). It can be seen from Fig. 2.9 that there has been continuous improvement in forecast accuracy with decrease in track forecast errors and increase in skill over the years. The five-year moving average track forecast errors during 2015-19 have been 81 km, 126 km and 171 km, respectively for 24, 48 and 72 hrs against 107, 165 & 230 km respectively for 24, 48 and 72 hrs during the period, 2010-14. The five-year moving average track forecast skill during 2015-19 have been 61, 73 and 74 %, respectively for 24, 48 and 72 hrs against 46, 62 & 68 % respectively for 24, 48 and 72 hrs during the period, 2010-14. The track forecast errors and skill during 2019 are presented in Table 2.2 and Fig. 2.9 and five year moving average track forecast errors and skill since 2013 are presented in Fig. 2.10.

**Table 2.2**

**Track forecast error (km) and Track Forecast skill (%)**

| Lead Period | No.of observations verified | Track forecast error (km) | | | Track Forecast skill (%) | | |
|---|---|---|---|---|---|---|---|
| | | 2019 | 2014-18 | Improvement (%) | 2019 | 2014-18 | Improvement (%) |
| 12 | 168 | 41.0 | 54.7 | 25 | 62.4 | 54.8 | 8 |
| 24 | 150 | 68.6 | 86.1 | 20 | 67.6 | 58.2 | 9 |
| 36 | 136 | 87.8 | 102.7 | 14 | 72.4 | 67.9 | 5 |
| 48 | 123 | 103.7 | 132.3 | 22 | 78.5 | 70.3 | 8 |
| 60 | 109 | 120.4 | 156.8 | 23 | 77.1 | 72.6 | 4 |
| 72 | 89 | 148.6 | 177.7 | 16 | 77.3 | 74.1 | 3 |
| 84 | 66 | 177.7 | 219.2 | 19 | 77.6 | 74.1 | 3 |
| 96 | 55 | 217.8 | 243.4 | 11 | 78.1 | 76.0 | 2 |
| 108 | 46 | 261.3 | 238.0 | -10 | 78.7 | 73.6 | 5 |
| 120 | 33 | 337.5 | 284.6 | -19 | 78.8 | 71.1 | 8 |

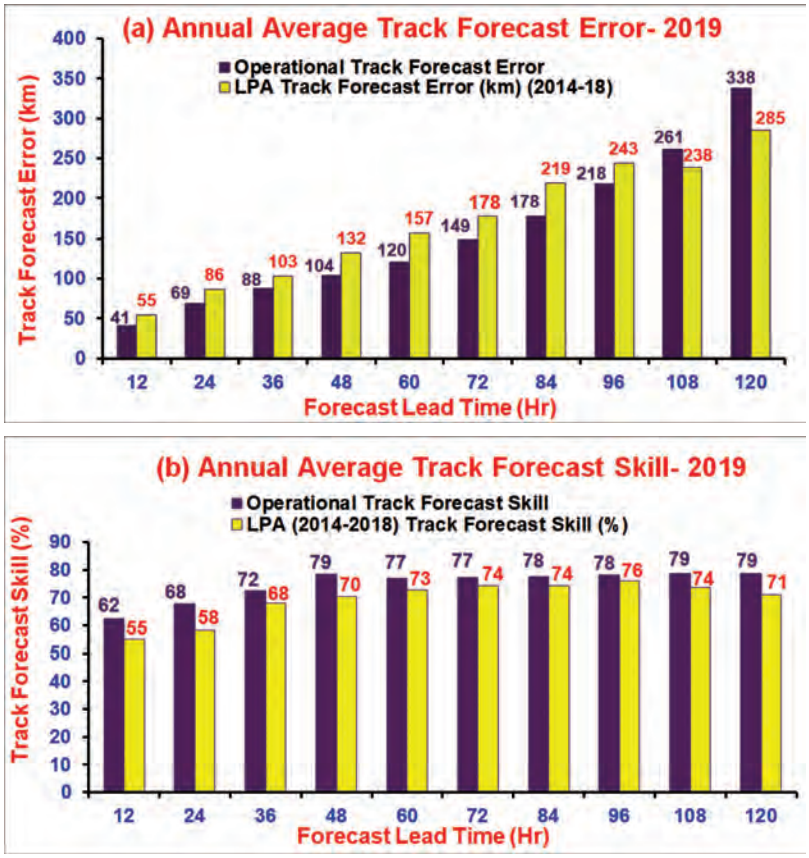



**Fig. 2.9 Annual Average track forecast (a) error (km) and (b) skill (%) during 2019, compared to long period average of 2014-18.**

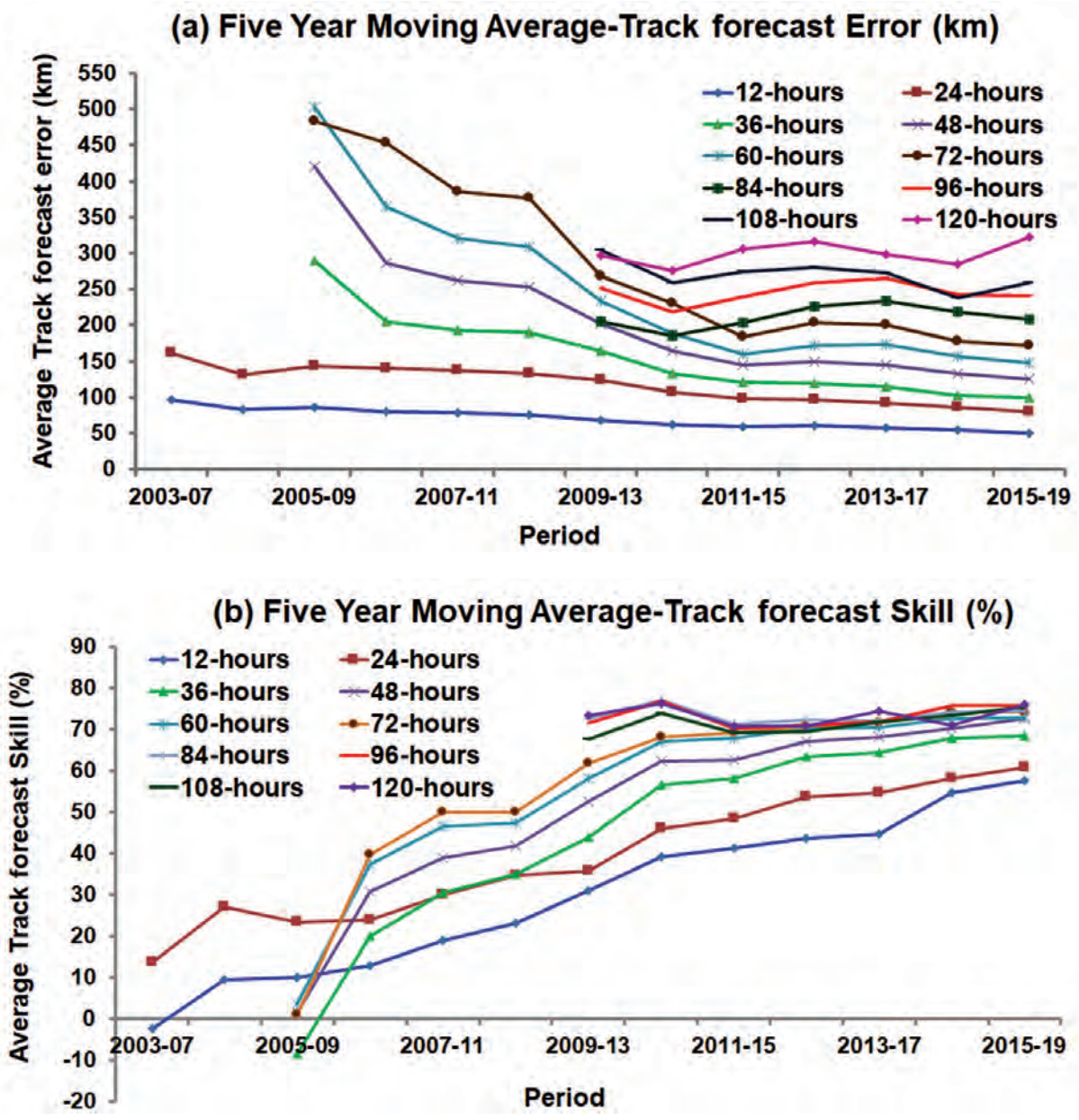



**Fig. 2.10 Five year moving average track forecast (a) error (km) and (b) skill (%)**

## 2.7 Meteorological Services

### 2.7.1 Metropolitan Air Quality and Weather Services

- An advance version Fine Dust Model with different Dust Schemes for large-scale dust storm and transport pathways to predict extreme events in North-West Indian region including Delhi has been developed and augmented in the SAFAR-framework.
- A dynamic gridded emission inventory of Kharif agriculture residue burning of North Indian states of Punjab & Haryana has been developed by synergizing three satellite datasets (INSAT-3D, INSAT-3DR and MODIS data) and ground reality. Based on the new framework, the percentage share

of Delhi's PM2.5 attributed to stubble burning is provided on day to day basis since October 2019.

- **Orientation Programme of Emission Inventory, Pune:** The emission inventory campaign involving 150 students was conducted in Pune by IITM-Environmental Information System (ENVIS) in association with researchers/experts from Environmental Science Department of Savitribai Phule Pune University, Utkal University, and from various colleges on 24th September 2019.
- **Campaign of emission inventory of Stubble burning in Punjab and Haryana:**

  A dynamic emission inventory of PM2.5 due to biomass burning has been developed. The SAFAR Mobile van was deployed at various stubble burning locations in Punjab and Haryana from October 2019 to December 2019 to continuously measure pollutants before, during and after stubble burning to improve the understanding and variability of various pollutants.

### 2.7.2 Air Quality Early Warning System for Delhi

A first of its kind high-resolution Air Quality Early Warning System for Delhi has been developed to predict extreme air pollution events in Delhi and give warnings as per Graded Response Action Plan (GRAP). A very high-resolution (400 meters) operational air quality forecast using both satellite (3 km resolution) and surface (at city scale with 43 monitoring stations) chemical data assimilation integrated with dynamical downscaling has been developed which gives IITM an edge over the leading operational agencies ECMWF, NCAR, US-EPA, NOAA, NASA, UK-MET office, CMA-China The warning system consists of following components:

1. Near real-time observations of air quality (and visibility) over Delhi region and details about natural aerosols like dust (from dust storms), fire information, satellite aerosol optical depth (AOD) and PBL height,
2. Predictions of air pollutants based on state-of-the-art atmospheric chemistry transport models,
3. Warning messages, alerts and bulletins, and
4. Forecast of the contribution of non-local fire emissions to the air quality in Delhi. The warning system also provides an air quality forecast for a few more cities in the northern region of India at 10 km resolution.

The air quality forecast can be accessed at the dedicated website: ews.tropmet.res.in. The website also shows forecast verification for Delhi on daily basis. The high-resolution forecast is able to capture day to day air quality conditions quite near to observations and current air quality emergency situations in Delhi.

In an effort to improve the dissemination of Air Quality forecast in Delhi, the MoES has launched a new website of Air Quality Early Warning which is now open to the public also (https://ews.tropmet.res.in). The warning system consists of (1) near real-time observations of air quality (and visibility) over Delhi region and details about natural aerosols like dust (from dust storms), biomass fire information, satellite aerosol optical depth (AOD) and PBL height, (2) Predictions of air pollutants based on state-of-the-science atmospheric chemistry transport models, (3) Warning Messages and Alerts and

Bulletins issued by IMD and (4) forecast of the contribution of non-local fire emissions to the air quality in Delhi. The warning system also provides an air quality forecast for a few more cities in the northern region of India at 10 km resolution. The website also shows forecast verification for Delhi on a daily basis.

### 2.7.3 Project with Finnish Meteorological Institute

Under project mode cooperation agreement with Finnish Meteorological Institute, two air quality forecast models (1) System for Integrated modelLing of Atmospheric coMposition (SILAM) for India (2) ENvironmental information FUsion SERvice (ENFUSER) a very high-resolution City Scale air quality model for Delhi are being implemented. The operational modelling system provides both real-time and forecasted, high resolution information on the urban air quality.

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

AAS bulletins have been prepared and issued at district, state level on every Tuesday & Friday and national level on every Friday to cater to the needs of users at various levels. The district level AAS bulletins are prepared and issued by 130 Agromet Field Units (AMFUs) located in State Agricultural Universities, ICAR institutes, IITs etc. IMD in collaboration with CRIDA, Hyderabad issued Operational AAS bulletin based on Extended Range Weather Forecast on every Friday to help farmers to cope with climate risks and uncertainties and effectively use seasonal to inter-annual climate forecasts. IMD in coordination with AMFUs and DAMUs started preparation of Experimental Block Level Agromet Advisories for selected 1389 blocks (577 blocks by 83 DAMUs and 812 blocks in 151 districts by 77 AMFUs).

Dissemination of agromet advisories to the farmers through different multi-channels like All India Radio (AIR) and Doordarshan, private TV and radio channels, newspaper and internet, SMS and IVR (Interactive Voice Response Technology) etc. is being carried out on wider scale. Under Public Private Partnership (PPP) mode, Reliance Foundation, IFFCO Kisan Sanchar Limited (IKSL), Mahindra Samriddhi, Kisan Sanchar etc. are disseminating agromet advisories in SMS and IVR format to the farming community. Agromet Advisories are being disseminated in both Regional and English languages through "Kisan SMS", a portal (http://farmer.gov.in/advs/login.aspx) launched by the Ministry of Agriculture, Government of India. In addition to that, a number of AMFUs have been sending agromet advisories through SMS in collaboration with Agricultural Technology Management Agency (ATMA) / KVKs. At present 40.2 million farmers are receiving SMS and benefitted by this service directly. Weather forecast and advisories under alerts and warnings during extreme weather events are also issued through SMS which enable the farmers in planning appropriate farming operations to minimize damage of crops under adverse weather conditions.

District Level Value added forecast for agro advisory is verified for monsoon season is given below (Fig. 2.11).

## 2.9 Hydro-meteorological Services

Flood Meteorological Offices (FMOs, 14 in all over India) of IMD provide Meteorological support in the form Quantitative Precipitation Forecast for 153 river sub-basins to Flood Forecasting Divisions (FFDs) of the Central Water

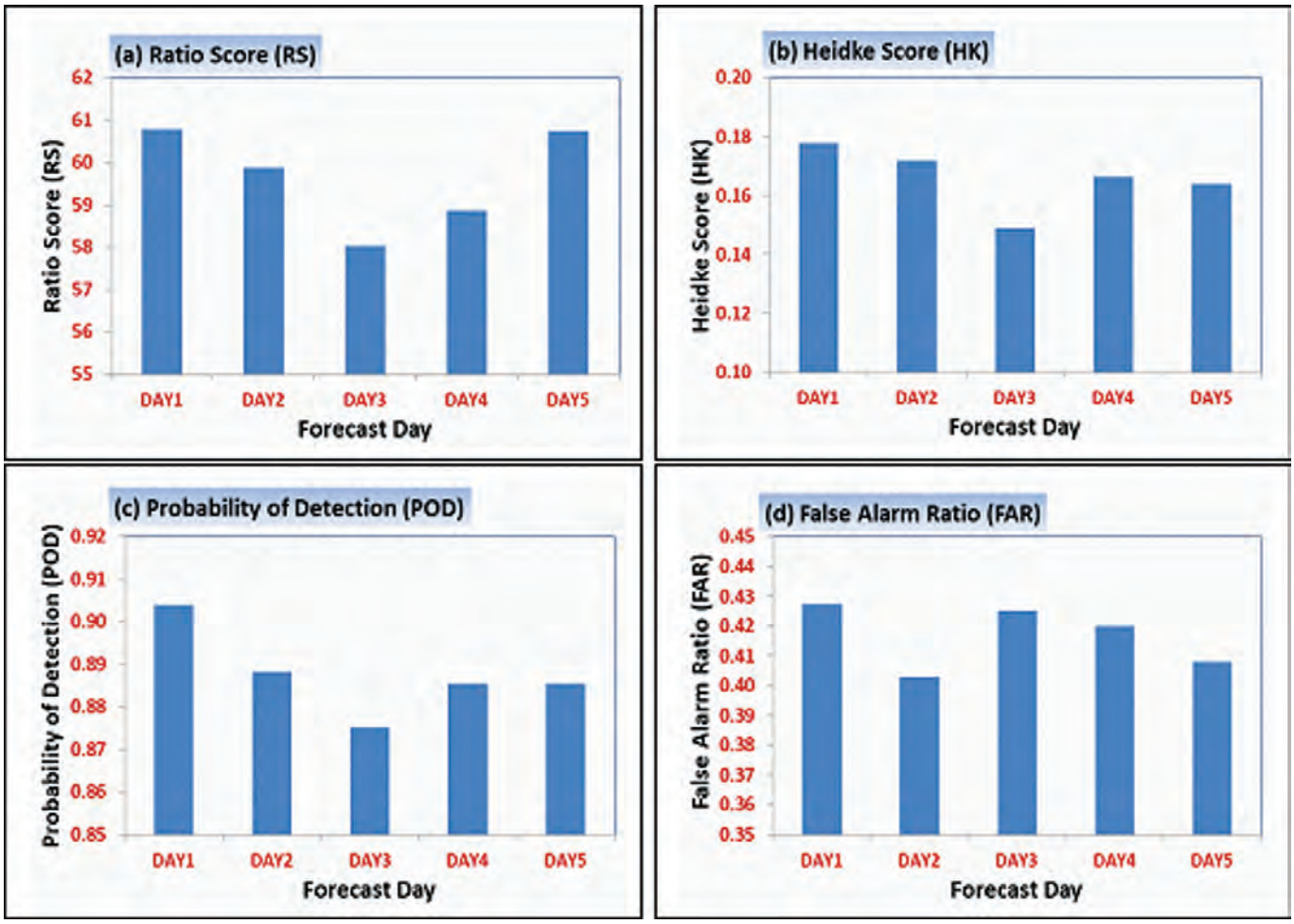



**Fig. 2.11 Verification of District Level Value added agromet weather forecasts a) RS b) HK c) POD and d) FAR**

Commission (CWC) to help them issue "Flood warnings/Flood alerts". The meteorological support is provided in terms of 'Quantitative Precipitation Forecast (QPF)' through Hydromet Bulletins. Forecast for a lead time of 7-days (forecast for 3 days and outlook for subsequent 4 days) are issued daily during the flood seasons.

Sub basin-wise Quantitative Precipitation Estimates (QPE) based on WRF, MME and GFS models are made operational and uploaded in the IMD website. Sub-basin wise probabilistic QPF based on dynamical model GEFS and NEPS was also made operational in the IMD website on experimental mode.

## 2.10 Aviation Meteorological Services

### Performance of Airport Fog Monitoring and Forecasting system in 2018-2019

Fog is one of the major aviation weather hazards. In each winter, Airports of north India are highly vulnerable due to dense fog. On an average a total of 20-25 days of Dense Fog<200m occurred in a season with 6-7 hours per day in December, 2018-January, 2019. Delhi being more polluted, it records more smog days compared to other airports. Timely early warnings and forecast of Fog events help advance fog preparation for cooperative decision making (CDM) by various stake holders to reduce the

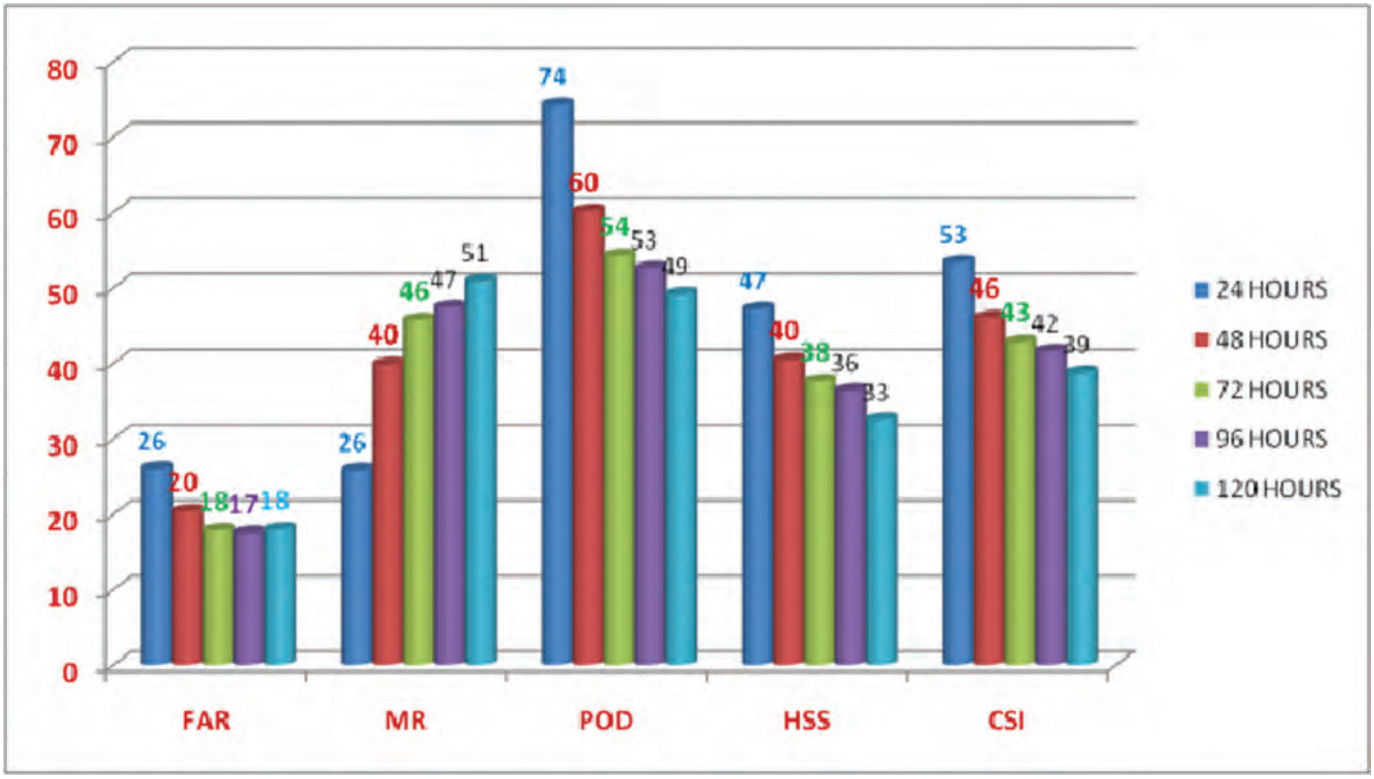



**Fig. 2.12 Verification of Heavy Rainfall Forecasts during the 2019 monsoon season, scores (FAR, MR, POD, HSS and CSI) from Day-1 to Day-5**

impact. In 2018-19, IMD provided Aviation weather services to around 90 civil airfields of India with 17 AMO/AMS alone in north India. One of the major achievements was the successful completion of IMD-IITM WIFEX 2015-19 by which it has collected world class data of four seasons by deploying around 31 types of equipments at IGIA along with 20 m flux tower. All such new rapid developments in the field have helped in reducing the flight disruption and helped for better safety practice for winter 2018-2019 and the present season 2019-20.

The period, November-December, 2018, January-February, 2019 had reported highly subdued fog formation across the entire Indo-Gangetic region. IGIA had CAT-III ILS dense fog events as total of 0/0, 3/9, 5/24 and 4/17 of days/ hours respectively with all total of 12 days and 50 hours of dense fog against the normal of 25 days and 145 hours.

## 2.11 Other Forecast Verifications

**Verification of Heavy Rainfall (>65mm/ day) during the Monsoon Season 2019:** Verification of heavy rainfall forecasts for monsoon season 2019 has revealed significant improvements in the verification scores. The heavy rainfall skill scores for Day 1 to Day 5 forecast for the year 2019 is given in Fig. 2.12. The skill of heavy rainfall forecasts in 2019 was much better than the previous years. This was mainly due to better model products, observations and improvement in forecasting tools.

**Table 2.3 Skill Scores Related to Heat Wave Warning**

| All India | FAR | | | MR | | | CSI | | | POD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D1 | D2 | D3 | D1 | D2 | D3 | D1 | D2 | D3 | D1 | D2 | D3 |
| 2017 | .07 | .06 | .02 | .33 | .51 | .77 | .40 | .32 | .19 | .67 | .49 | .23 |
| 2018 | .03 | .04 | .02 | .09 | .28 | .52 | .54 | .40 | .32 | .91 | .72 | .48 |
| 2019 | .11 | .10 | .08 | .08 | .15 | .38 | .49 | .47 | .38 | .92 | .85 | .62 |

D1- Day-1, D2- Day-2, D3- Day-3.

FAR- False Alarm Rate, MR- Missing Rate, CSI- Critical Success Index, POD- Probability of Detection

**Heat wave warning**

All major heat wave epochs during the summer season 2019 were well predicted and warning for the same was given about 3 to 5 days in advance. The skill scores related to heat wave warnings for the year 2017, 2018 and 2019 are given in Table 2.3, showing significant improvement in forecast skill of heat waves over India in 2019.

**Nowcasts of Thunderstorms**

During the year 2019 about 259 stations were added to the thunderstorm Nowcast list.

**Table 2.4**
**Skill Scores for Thunderstorm Verification for STORM Period - 2019**

| 24-hour TS Verification FDP-2019 | | | | | |
|---|---|---|---|---|---|
| Month | Ratio Score | POD | FAR | CSI | ETS |
| March | 0.84 | 0.63 | 0.47 | 0.41 | 0.31 |
| April | 0.74 | 0.75 | 0.35 | 0.53 | 0.31 |
| May | 0.78 | 0.74 | 0.29 | 0.57 | 0.37 |
| June | 0.61 | 0.53 | 0.30 | 0.43 | 0.14 |
| Average | 0.74 | 0.65 | 0.33 | 0.49 | 0.29 |

Nowcasts (next 6 hours) are prepared using Doppler Weather Radar images. Thus, the total number of stations for the nowcast has gone up to 694 in 2019.

The skill scores pertaining to thunderstorm predictions are given in the table below. On an average 65% of thunderstorms are detected in 24-hour forecasts. In general, the nowcasts have shown some positive forecast skill.

## 2.12 Outreach and Dissemination of forecasts

Agro Met Field Unit (AFMU) Hissar and Rahuri have developed mobile app to disseminate Agromet Advisories, *viz.*, Phule Jal (AMFU, Rahuri), eMausam HAU (AMFU, Hisar). For better outreach many AMFUs also started using mobile apps like WhatsApp for dissemination of Agromet advisory to the farmers.

National Geographic Channel aired a story on "The Mega Cyclone FANI" on 7th October. The story highlighted the role IMD in monitoring of cyclone FANI and the role of Odisha State Government in mitigating the disaster associated with FANI cyclone.

■

# Chapter 3 OCEAN SERVICES, MODELLING APPLICATION, RESOURCES AND TECHNOLOGY (O-SMART)

The scheme on O-SMART aims at providing ocean information services, exploration and survey of oceans and resources, developing technologies for sustainable utilization of ocean resources (both living and non-living), and promoting front ranking research on Ocean sciences. The programme is implemented by five different institutes under the Ministry.

The major achievements under O-SMART during the year are enumerated below:

## 3.1 Ocean Sciences and Services

### 3.1.1 Tsunami Services

The Indian Tsunami Early Warning Centre (ITEWC) at the Indian National Centre for Ocean Information Services (INCOIS) monitored 24 earthquakes (Ocean and near coast) of magnitude ≥ 6.5 during the period 01 January to 25th November 2019 and disseminated the bulletins to all its regional and national stake holders. Three earthquakes with potential to trigger tsunami occurred in the Indian Ocean in 2019. Based on pre-run model scenarios and analysis, ITWEC issued a NO THREAT bulletin for the coastline of India and Indian Ocean Region for these earthquakes. The Decision Support System to issue tsunami warnings has been upgraded as per the latest TSP (Tsunami Service Provider) Service Definition Document. With this, the Indian Tsunami Warning Centre has become the first Tsunami Service Provider to provide operational Tsunami warnings as per the Service Level II guidelines of Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG-IOTWMS) towards improving the Tsunami Service.

INCOIS has developed a web based application to support the Intergovernmental Co-ordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) which evaluates the performances of the Tsunami Service Providers (TSP) of Indian Ocean against the Key Performance Indicators (KPI) in a common format.

### 3.1.2 Ocean State Forecast Services

Ocean State Forecasts were issued during the passage of all cyclones andlow pressure systems occurred during 2019, including for the extremely severe cyclonic storm “Fani”. Forecasts include information on the associated ocean state parameters waves, current speeds and other oceanic parameters offshore and nearshore. Sixty five INCOIS-IMD Joint Bulletins were issued during the passage of cyclone ‘Fani’, and the warning SMS were sent to 378773 registered users in the east coast of India and at the Andaman & Nicobar Islands. Joint bulletins were also disseminated through NAVIC, a satellite-based direct to ocean communication system developed in collaboration with ISRO. INCOIS also provided storm surge advisories to India Meteorological Department (IMD) during the passage of cyclones ‘Fani’, ‘Kyarr’, ‘Bulbul’ and ‘Vayu’.

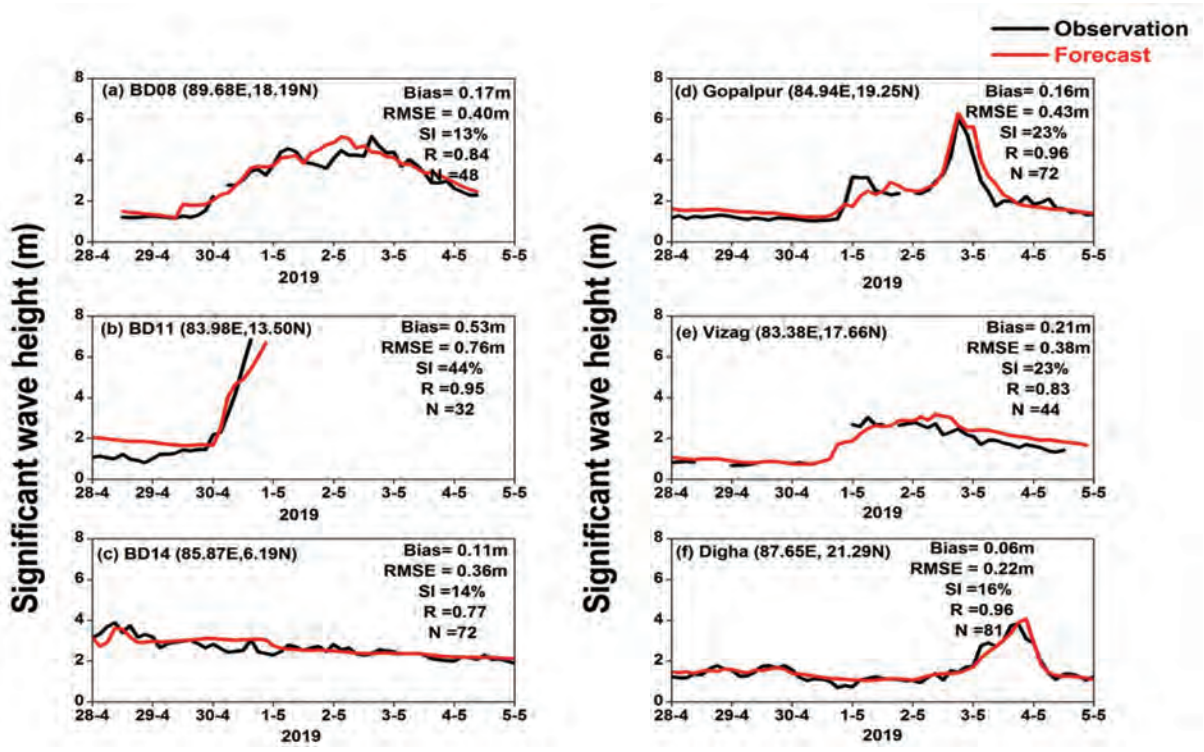



**Fig. 3.1 Significant Wave Height forecasts issued by INCOIS are compared with buoy data at various locations during the passage of Fani.**

**GAGAN Enabled Mariner's Instrument for Navigation & Information (GEMINI)**

INCOIS, in collaboration with Airport Authority of India, has developed a dissemination system based on GPS-aided GEO augmented navigation (GAGAN) to provide daily Ocean State Forecast/High Wave Alerts/Potential Fishing Zone Advisories and Tsunami/cyclone alerts for the fishermen at sea. GAGAN Enabled Mariner's Instrument for Navigation & Information (GEMINI) was inaugurated by Dr. Harsh Vardhan, Hon'ble minister for Science & Technology, Earth Sciences & Health and Family Welfare on 9th Oct 2019 at New Delhi.

### 3.1.3 Potential Fishing Zones (PFZ) and Tuna PFZ Advisories

The Potential Fishing Zone (PFZ) advisories, which convey information on the fish aggregation regions at sea using the satellite data of various parameters such as Sea Surface Temperature (SST), chlorophyll concentration, water clarity and sea level were disseminated in smart map and text form on daily basis, depending on satellite data availability, except

**Fig. 3.2 Inauguration of GEMINI by Dr. Harsh Vardhan, Hon'ble Minister for Science & Technology, Earth Sciences & Health and Family Welfare on 9th Oct 2019 at New Delhi.**

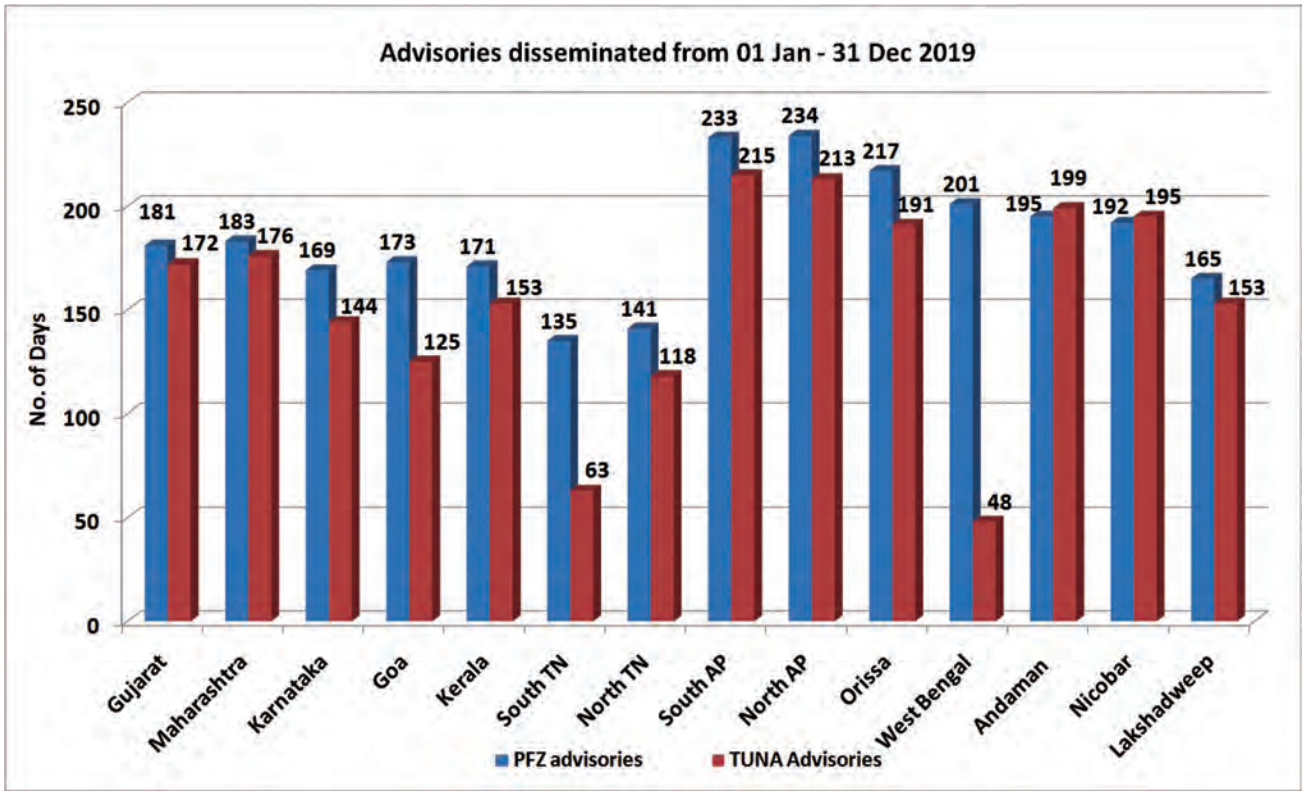



**Fig. 3.3 Number of PFZ and Tuna PFZ advisories issued during 1st January – 24th November 2019.**

fishing-ban period and during adverse sea-state. During the period 1st January - 24th November 2019, multilingual Potential Fishing Zones (PFZ) advisories were provided on 265 days to one or more sectors. During the same period, specific advisories on the potential zones for Yellowfin Tuna, also were issued on 239 days, which include the maximum fishing depth information.

### 3.1.4 Data Services

INCOIS being the National Oceanographic Data Centre (NODC) as designated by the International Oceanographic Data Exchange (IODE) Programme of the Intergovernmental Oceanographic Commission, continued serving as the central repository for the oceanographic data in the country. The INCOIS data centre sustained and strengthened the real-time data reception, processing, and quality control of surface meteorological and oceanographic data from a wide variety of ocean observing system such as Argo floats, moored buoys, drifting buoys, wave rider buoys, tide gauges, wave height meter, ship mounted autonomous weather stations and HF radars.

### 3.1.5 Ocean Observation Network and Process specific observations.

During 2019, INCOIS maintained many ocean observing platforms in collaboration with many national and international agencies, as well as on its own. These observation platforms are designed to collect high quality data from the Indian Ocean. Data from these platforms and research cruises helps to advance basic research as well as improvements in ocean modelling.

**The Argo program**

During 2019, INCOIS deployed 20 core Argo floats (temperature and salinity sensors only) and 08 bio-floats (temperature, salinity,

dissolved oxygen, chlorophyll and backscatter sensors). Indian contribution to the international Argo program stands at 482 floats as of November 2019, of which 149 are presently active. Including the deployments by other countries, there are 834 floats active in the Indian Ocean.

**Coastal ADCP and Equatorial current meter network**

During 2019, 17 coastal ADCP moorings were maintained along Indian coastal regions. The number of slope moorings along the Indian west coast has gone upto seven with the deployment of a new mooring off Okha during the reporting period. There are six moorings on the slope and four moorings on the shelf off the Indian east coast. At present, there is at least one slope mooring off every coastal state, keeping an inter-mooring spacing of around 2.5-3 degrees.

**XBT Program**

During the reporting period, 3 transects were conducted along Chennai-Port Blair, Port Blair-Kolkata and Kochi-Lakshadweep, and collected 42 XBT data, 33 XCTD data and 82 sea water samples were taken. Additionally, utilizing opportunities in research cruises, 119 XBT data, 38 XCTD data and 386 water samples were collected from 7 cruises.Utilizing the collection of XBT data over 27 years, a climatology of geostrophic currents along the Chennai-Port Blair section was estimated which matches well with observations.

**The drifter program**

With the funding from INCOIS, CSIR-National Institute of Oceanography (NIO) continued deploying drifters in the Indian Ocean during 2019. A total of 06 drifters were deployed in 2019.

**Tsunami Buoys**

INCOIS continued to maintain a network of 4 tsunami buoys deployed close to the tsunamigenic source regions in Bay of Bengal and Arabian Sea. In addition to that, INCOIS received real-time data from three Indian Tsunami Buoys (ITBs) deployed and maintained by National Institute of Ocean Technology (NIOT, Chennai). These high precision buoys are capable of detecting very minor water level changes of 1 cm at water depths up to 6 km.

**Tide gauges**

INCOIS continued to maintain a network of 35 tide gauges installed at strategic locations along the coasts of the Indian mainland and islands to monitor the progress of tsunami waves. In the year 2019, INCOIS set up a new Radar-based tide gauges at Dhamra, Odisha. The data from tide gauges were also used to validate the model results. In addition, INCOIS also received data from around 350 international tide gauges in near-real time.

Owing to the growing storage and processing requirements and to enhance the data reception and dissemination, upgradation and augmentation of shore station was accomplished and the facility **CORNEA – Centre for Ocean Real-time iNformationviEw and Archives** has been established at NIOT. It serves as the nerve centre for dissemination of critical data like cyclone and Tsunami to INCOIS for early alerts and warnings.

INCOIS has taken up a project to install co-located strong motion sensors, GNSS receivers and meteorological sensors with real-time VSAT connectivity at 35 locations in the Andaman & Nicobar (A & N) Islands. Installation of GNSS receivers and Strong Motion Accelerometers has been completed at 30 locations. VSAT

connectivity has been provided to all these stations.

**Current Status of various observations systems deployed in the Indian Ocean**

| Type of Platform | Commissioned during April 2017- December 2020 |
|---|---|
| Argo Floats | 73 |
| Drifters | 5 |
| Moored Buoys | 19 |
| Tide Gauges | 36 |
| High Frequency(HF) Radars | 10 |
| Current Meter Array | 2 |
| Acoustic Doppler Current Profiler(ADCP) | 20 |
| Tsunami Buoys | 7 |
| Wave Rider Buoy | 16 |

**Deployment of INCOIS flux mooring in the Bay of Bengal**

To better understand and document the air-sea interaction, upper ocean processes and dynamics of freshwater in the Bay of Bengal (BoB), INCOIS deployed a mooring (INCOIS-Flux), which includes a Direct Covariance Flux System (DCFS) on 23rd May, 2019 onboard ORV Sagar Nidhi (SN-141) at 17.804°N, 89.504°E with the support from Woods Hole Oceanographic Institution (WHOI), USA. This system with DCFS is first of its kind deployed in the Indian Ocean. Scientists from INCOIS and NIOT received hands on training in design, assembly and testing at WHOI, USA as well as during deployment of the INCOIS-Flux Mooring onboard ORV Sagar Nidhi.

### 3.1.6 Ocean Modeling and Data Assimilation

**INCOIS-HYCOM-HWRF coupled simulation of Tropical Cyclone Fani**

HWRF-HYCOM coupled system with moving nest was implemented with Ocean Initial and boundary conditions obtained from high resolution (1/16°) Operational Indian Ocean HYCOM nested to a 1/4th degree Global HYCOM. The NCEP Global Forecast System (GFS) analysis is used to generate the initial conditions (ICs) for the HWRF parent domain. The operational ocean analysis generated by HYCOM model at INCOIS is

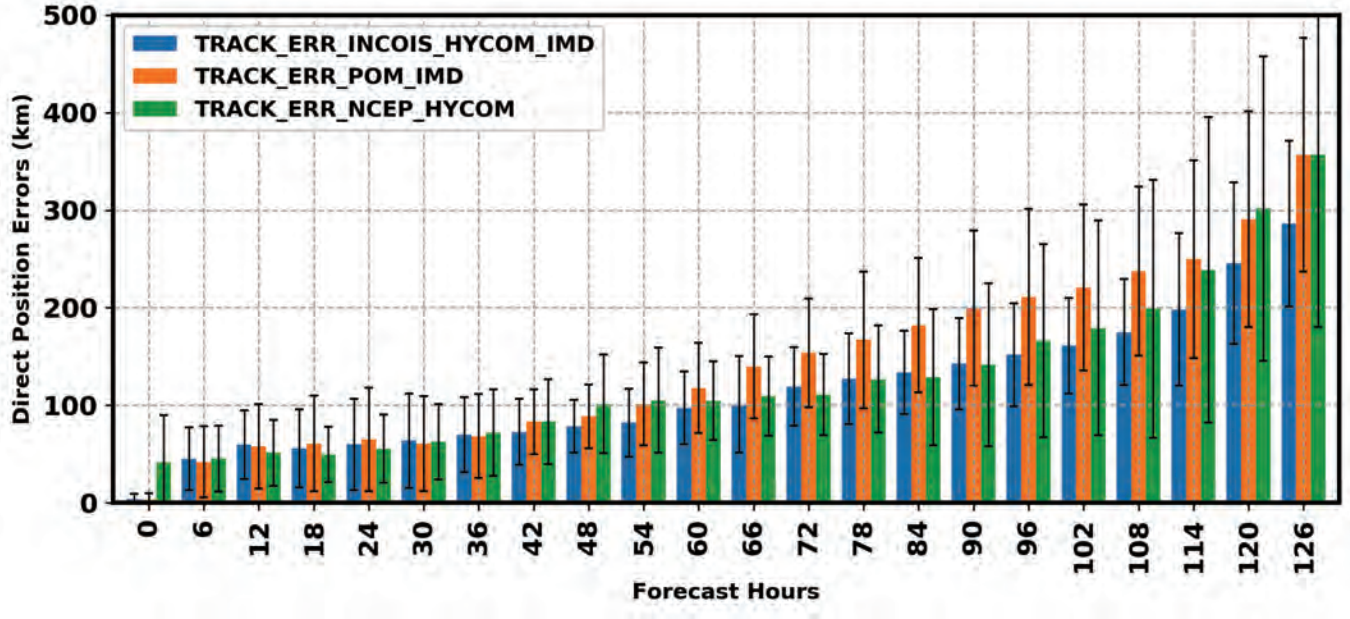



**Fig. 3.4 Comparison of mean direct position errors at different forecast lead times from HWRF coupled to HYCOM, POM and of NCEP run.**

converted to the required format to provide the ocean initial for the coupled system. Subsequently, IMD made the first operational forecast during Cyclone Fani using HWRF-HYCOM coupled system together with other models during April 2019 using the initial and boundary conditions from HYCOM.

**Potential Fishing Zone Forecast System**

The operational Potential Fishing Zone (PFZ) advisories generated and disseminated by INCOIS rely on remotely sensed sea surface temperature (SST) and chlorophyll-a (Chl-a) data from NOAA-AVHRR and MODIS-AQUA and/or Oceansat-2 satellites, respectively. During the situations of cloud cover, it becomes difficult to retrieve SST/Chl-a data from satellite images. Further, the present PFZ advisories are valid only for the next 24 hours. As the resources are depleting in near shore regions, it is essential to encourage the fishermen to carry out the pelagic fishing activities in deep seas, which involves multi-day fishing. Therefore, accurate forecasting on the regions of fish availability for next 3 to 5 days has become more desirable. To overcome the operational difficulties in generating PFZ advisories due to non-availability of data and to transform the PFZ advisories into PFZ forecasts, a coupled physical-biogeochemical model in the regional scale has been developed. This system was dedicated to the nation by Dr. Harsh Vardhan, Hon. Minister for Earth Sciences, Science and Technology and Health and Family Welfare on 9th October, 2019.

**Regional Analysis of Indian OceaN.**

Regional Analysis of Indian OceaN (RAIN), developed by INCOIS is a regional ocean analysis system which assimilates in-situ temperature and salinity profiles and satellite track data of sea surface temperature (SST) into a 9 km resolution


**Address of Dr. Harsh Vardhan, Hon. Minister for Earth Sciences during the inauguration of the PFZ forecast System at Ministry of Earth Sciences (MoES) on 9th October, 2019.**

basin-wide model Regional Ocean Modeling System (ROMS) using Local Ensemble Transform Kalman Filter (LETKF). This system provides analysis of the Indian Ocean from Aug 2016 onwards till date and the analyses are regularly updated in https://incois.gov.in/portal/rain/rain_about.jsp. This initial and boundary conditions for integrating the model for issuing operational forecasts of ocean general circulation forecasts are being provided by RAIN now.

### 3.1.7 International Training Centre for Operational Oceanography (ITCOocean)

The ITCOocean continued its operations using the state-of-the art facilities of INCOIS, Hyderabad. During January - till date, 159 persons were trained of which 121 are from India and 38 from 19 other countries. The newly constructed ITCOocean building along with facilities for faculty, students was handed over to INCOIS and classes will commence in this building starting from 2020. In total, 12 short term courses were conducted during the period, which covered various topics like remote sensing of marine phytoplankton, discovery and use of

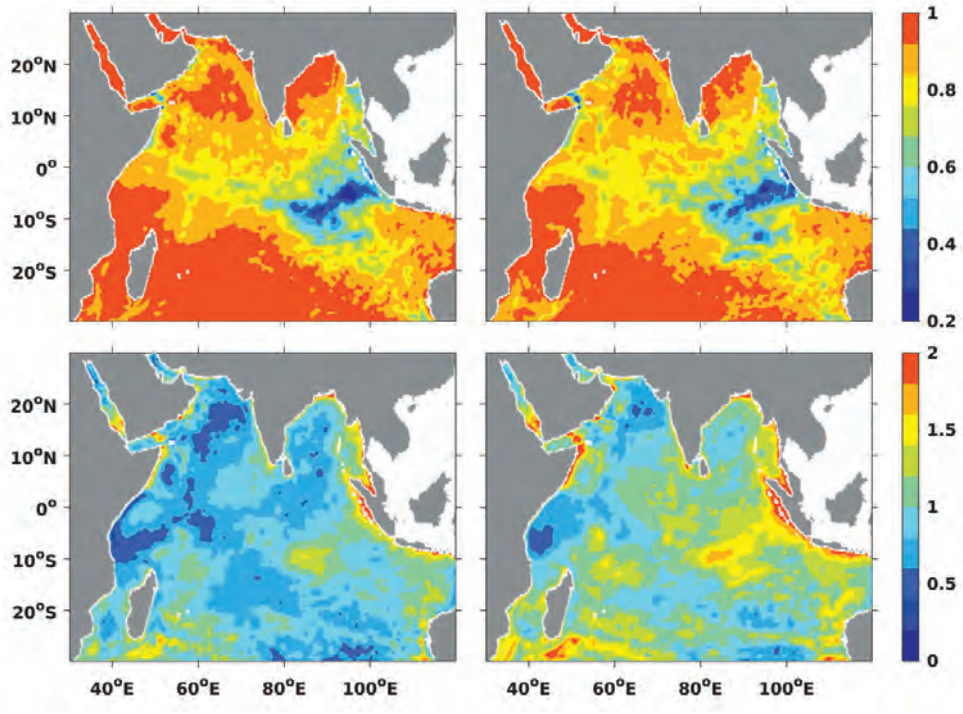



**Fig. 3.5 Maps of correlation (top) and root mean squared error (bottom) between AVHRR SST and SST of RAIN (left) and free model (right)**

operational ocean data products and services, coastal vulnerability studies using QGIS, ocean color remote sensing, IOCINDIO workshop etc. This included training sessions for officers from Indian Coast Guards and National Hydrography Office. The Governing Body of Category 2 Center is formed with the approval of MoES and the first meeting of the Governing Body is planned during January 2020.

A MOU was signed with Swami Ramanand Theerth Marathwada (SRTM) University, Nanded, Maharashtra for academic collaborations between INCOIS and SRTM University. As part of this MoU, SRTM and ITCOocean have agreed to start a certificate course in "Operational Oceanography". The first certificate program will be announced early next year for a span of 6 months.

## 3.2 Studies on Marine Living Resources (MLR)

### 3.2.1 Marine Ecosystem Dynamics of Eastern Arabian Sea (MEDAS)

Meridional distribution of vertical stability during summer period in coastal and offshore waters for the Eastern Arabian sea was studied from time-series observations at a frequency of 30-40 days along seven coast-offshore transects and 10 transects for seasonal observations (December'17 to January 2018). Surface water column near to the coast is found to be stable during southwest monsoon period in the SEAS except Cape and Northern Arabian Sea. Mixing of different water mass altered the water column stability, this is clearly observed in the Northeast Arabian Sea during monsoon where influence of Persian Gulf waters in the subsurface depth. In offshore region, there is neutral stability (0-5 cycl/hr) along the surface waters of Eastern Arabian Sea during the summer in the offshore region and the stability value is around 5-10 cycl /hr along subsurface waters.

### 3.2.2 Seasonality of Microzooplankton community off Goa

Seasonality in the microzooplankton community of the surface waters from seasonal observations along off Goa from January to December, 2018 showed that Goa behaves as a transitional zone in the hydrographical characteristics of Eastern Arabian Sea and thereby influences the community structure of microzooplankton. The relative contribution of ciliates to the microzooplankton community varied among the seasons (spring-inter monsoon: 65%; summer monsoon: 47%; fall-inter monsoon: 55%; winter monsoon: 54%) which indicated the importance of ciliates in the microbial food web.

### 3.2.3 Subsurface chlorophyll Maxima in the North Eastern Arabian Sea: Simulation on impact of warming

Stratified tropical oceanic systems are in general observed with Subsurface Chlorophyll Maxima (SCM), which was identified as light adaptation of shade-loving picophytoplankton groups. The study recently published shows that


Kasagia Sudhakari 2019


Gordonpsisrobusta 2019

Homolomiarajeevani 2019

**Fig. 3.6.a New Species of Deep Sea Crabs**

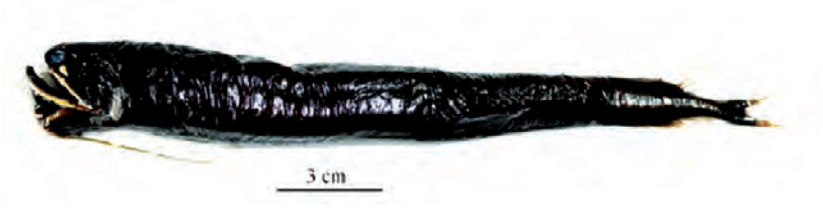



**Fig. 3.6.b New Species of Deep Sea Fish**

apart from the light adaptation strategies of phytoplankton, the physical properties of water masses have significant role to hold the phyto-plankton in particular layers. The study provides theoretical explanation on the influence of fluid properties of water on the settling velocities of micro-nano phytoplankton groups, which contribute the SCM.

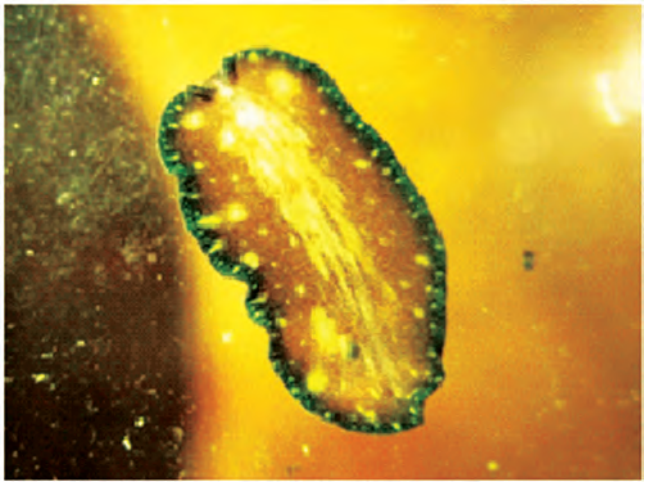
### 3.2.4 Resources Exploration and Inventorisation System (REIS)

A total of 7 cruises were undertaken onboard FORV Sagar Sampada in the Eastern Arabian Sea and the Andaman Sea during the year 2019-20 so as to explore and inventorise the marine biodiversity of Indian seas. The surveys have yielded numerous new records and new species to the inventory of Indian Ocean fauna. A total of 6 new species have been described during the period 2019-20 from *Sagar Sampada* surveys in the Arabian Sea, Andaman Sea and Central Indian Ocean. These include 1 deepsea fish, 2 polyclads and 3 deep seacrabs. Several new species from other groups are in the process of description.

New records reported for Indian waters were represented as 21 for deepsea crustaceans, 2 deepsea fishes, 2 echinoderms, 4 heterobranchs and 3 polyclads, A total of 2,326 voucher specimens under different phyla have been recorded, maintained and disseminated through IndOBIS data portal.

During the year 2019, a total of 4 surveys of Marine Mammal were conducted onboard FORV Sagar Sampada. 398 hours of efforts were put in 56 days for the observation of marine mammals in Arabian Sea and Bay of Bengal, covering about 4946 nm. The most commonly observed mammals were spinner dolphin, spotted dolphin, bottlenose dolphin, common dolphin and Risso's dolphin.

***Pseudoceros agattiensis***



***Pseudoceros stellans***

**Fig. 3.6.c New Species of Polyclads from Lakshadweep**

### 3.2.5 The New CMLRE Building

The Permanent Campus of CMLRE, Puthuvypu, Kochi has been dedicated to the Nation on 23rd Feb. 2019 by the Union Minister Dr. Harsh Vardhan. This includes various facilities such as Instrumentation Lab, Dry Chemical Lab, Wet Lab, Plankton Analytical Lab, Fishery Lab, COML Lab, Plankton Wet Lab, Microscopic Lab, Referral Centre, Processing And Computation Lab, Conference Hall, Library, Administration And Account Division, Sitting Place for Scientists /


**INAUGURATION OF CMLRE PERMANENT CAMPUS**

Technical Staff. The transit hostel with 10 rooms and canteen facilities has been dedicated to the Nation on 1st Nov. 2019 by Dr. M. Rajeevan, Secretary, MoES.


**NEW BUILDING OF CMLRE AT PUTHUVYPE, KOCHI**

### 3.2.6 MoES-NOAA Bilateral Workshop (WS-8) on 16th - 20th September 2019

The 8th workshop has been conducted at CMLRE Kochi as part of the MoES-NOAA (USA) technical collaboration on development of Predictive Capabilities on Fishery, with special emphasis on Oil Sardine of the South Eastern Arabian Sea. A statistical prediction model based on landing data and environmental covariates have been developed as a collaborative effort. As an extension of the statistical modelling, analysis addressing the role of ecosystem processes and ecological concepts in fishery oceanography which regulate the inter-annual variability in Sardine landing, based on long term data sets from climatological/reanalysis products, satellite measurements, in-situ sources and secondary information on fish biology etc. is in progress.

Two CMLRE Scientists participated in Acoustic Trawl Biomass estimation cruise on-board *FRV Reuben Lasker* in the California waters from New Port to San Diego during 7th July to 19th August 2019 as part of the technical collaboration.

## 3.3 Coastal Research

### 3.3.1 Sea Water Quality Monitoring (SWQM) along Indian Coast

Selected locations along the Indian coast are monitored seasonally for the various physico-chemical, biological and microbiological characteristics of seawater and sediment to detect the periodical changes in the seawater quality. To assess the health of the coastal waters, a Coastal Water Quality Index (CWQI), has been developed based on the data generated under SWQM

program. The data sets generated under SWQM program supports the National Indicator Framework for United Nations Sustainable Development Goal – 14 (SDG 14 - Life Below Water). A spatial CWQI map was developed for the Tamil Nadu coast. The CWQI map indicates that 11% of the monitored Tamil Nadu coast is under Good condition followed by 79% with Moderate and 18% with Poor condition.

### 3.3.2 Prediction of seawater quality in Coastal Waters

Long term coastal water quality data for many locations along the Indian coast indicate serious pollution threat. The prediction of seawater quality (PWQ) program was initiated to understand the dispersion, transport of pollutants from the rivers and water bodies to the marine environment and forecast the water quality. The program is implemented for Chennai coastal water that is exposed to uncontrolled disposal of sewage, agricultural runoff and industrial waste water and later extended to Puducherry and Puri-Konark coasts.

### 3.3.3 Marine litter and Micro plastics

A coastal cleanup campaign was organised as part of International Coastal Cleanup day on 21st September 2019 at 34 locations along the Indian coastal states and UTs with the assistance of 26 coordinators involving 6,984 volunteers with the objective to create awareness among the public about the importance of a clean ocean environment and how to manage the coast

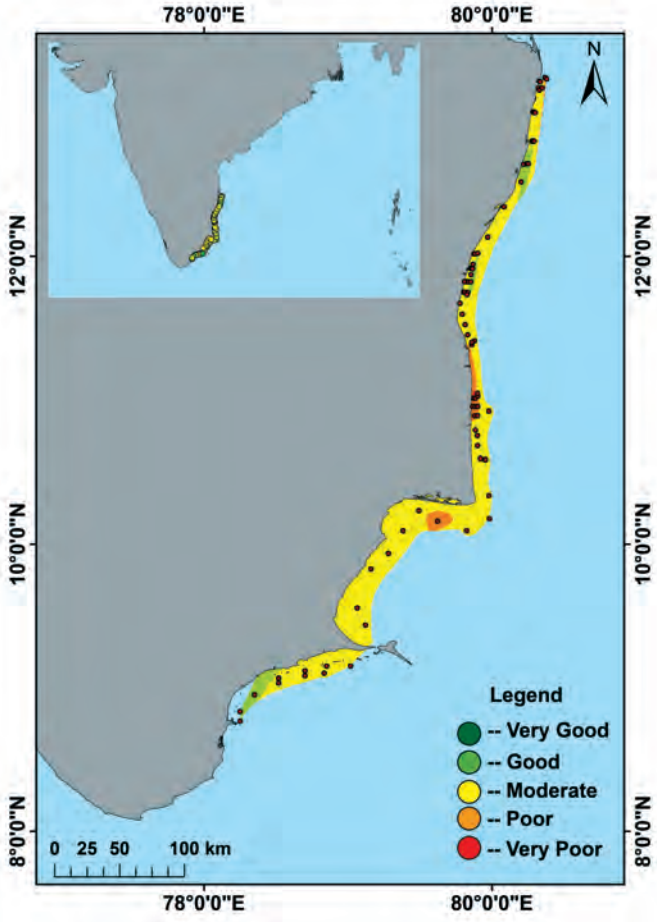



**Fig. 3.7 Coastal Water Quality Index (CWQI) for Tamil Nadu coast – 2019**

sustainably. A total of 35 tons of waste and 2, 39,095 individual pieces of litter were collected within 2 hours of activities.

Sampling for sediment and water was carried out from Chennai to Puducherry during March and July 2019 along the east coast of India to quality the micro plastics in the marine environment. Micro plastics particles in the sediment ranged from 12- 290 particles $kg^{-1}$ dry wet (DW). Marine plastics were studied in seven commercially important fish species collected from the fish landing centre near the Marina beach.

### 3.3.4 Shoreline Management: Mapping of the Shoreline changes and Sediment Transport along Indian Coast for Coastal Protection

Long-term (1990-2018), short-term (2012-2018) and annual (2017-2018) shoreline change rate for entire Indian main land is analyzed using satellite images. 526 shoreline change maps were generated using standard protocol (1:25000 scale) for entire Indian coast. Land loss/ land gain was estimated for 1990-2018 period (Table 3.1).

**Table 3.1 State-wise erosion and accretion pattern of entire Indian coast (1990-2018)**

| Coastal States | Length (km) | Erosion | | Stable | | Accretion | |
|---|---|---|---|---|---|---|---|
| | | Km | % | Km | % | Km | % |
| **Gujarat, Daman & Diu** | **1701.78** | 447.98 | 26 | 920.64 | 54 | 333.16 | 20 |
| **Maharashtra** | **739.57** | 162.02 | 22 | 503.49 | 68 | 74.06 | 10 |
| **Goa** | **139.64** | 26.82 | 19 | 93.72 | 67 | 19.1 | 14 |
| **Karnataka** | **313.02** | 74.34 | 24 | 156.78 | 50 | 81.9 | 26 |
| **Kerala** | **592.96** | 245.26 | 41 | 220.3 | 37 | 127.4 | 21 |
| **Tamil Nadu** | **991.47** | 402.94 | 41 | 370.39 | 37 | 218.14 | 22 |
| **Puducherry** | **41.66** | 23.14 | 56 | 15.12 | 36 | 3.4 | 8 |
| **Andhra Pradesh** | **1027.58** | 289.36 | 28 | 250.22 | 24 | 488 | 48 |
| **Odisha** | **549.5** | 140.72 | 26 | 128.77 | 23 | 280.02 | 51 |
| **West Bengal** | **534.35** | 323.07 | 60 | 76.4 | 14 | 134.88 | 25 |
| **Total** | **6631.53** | **2135.65** | **32** | **2735.83** | **41** | **1760.06** | **27** |

### 3.3.5 Ecosystem Based Services for the Management of Coastal Areas

As a part of the Marine Ecosystem Dynamics of Eastern Arabian Sea (MEDAS) project activities**,** the monthly field data collected at different transects since Nov 2017 have been analysed to study the Green House Gases (GHG), benthic species diversity and impact of micro plastics on marine organisms along west coast (Okha to Kanyakumari). During the NE monsoon (January), low surface DIC (Dissolved Inorganic Carbon) along the south-eastern Arabian Sea (Cape) was observed which was due to the intrusion of low saline Bay of Bengal water mass in the Arabian Sea. The reason for this anomaly is due to the influx of

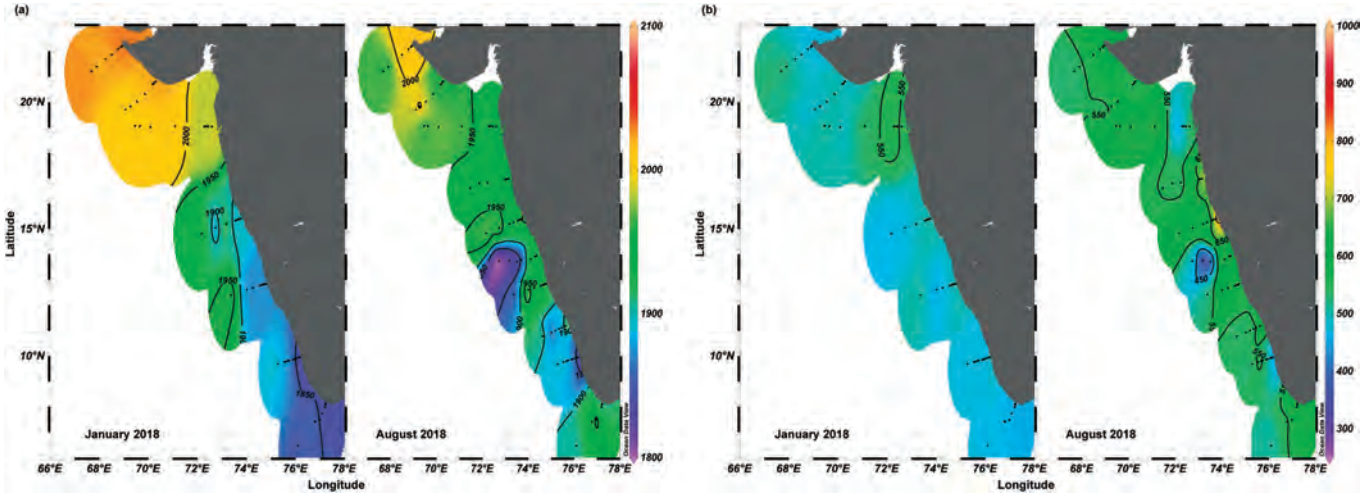



**Fig. 3.8 Spatial distribution of a) Surface DIC (µmol $L^{-1}$) and b) Surface $pCO_2$ (µatm) during Jan 2018 (NE Monsoon) and Aug 2018 (SW Monsoon).**

freshwater as a result of intense precipitation from the adjoining Indian monsoonal rivers resulting in suppression of upwelling.

### 3.3.6 Coral Reef Monitoring and Restoration in Gulf of Mannar

Coral reef monitoring in Gulf of Mannar and Palk Bay was undertaken to assess the diversity of corals, estimate the present live coral coverage in the reef area. and to identify the major threats to coral reefs of Gulf of Mannar. During August 2018 to October 2019, a total of 606 locations were surveyed to assess the health of coral reefs and 475 transects were laid in coral reef areas to estimate the percentage of live and dead coral cover. Average live coral cover was found to be higher in Mandapam group. Coral Reef restoration mainly aims to restore the reef ecosystem. A total of 72 frames were installed in Hare Island and Manoli&Manoliputti Island to assess the growth and survival of corals in restoration sites.

### 3.3.7 Coastal hazards

The Coastal Flood Warning System for Chennai (CFLOWS-Chennai) was developed as a multi institutional project initiated by the office of the Principal Scientific Advisor (PSA) and was

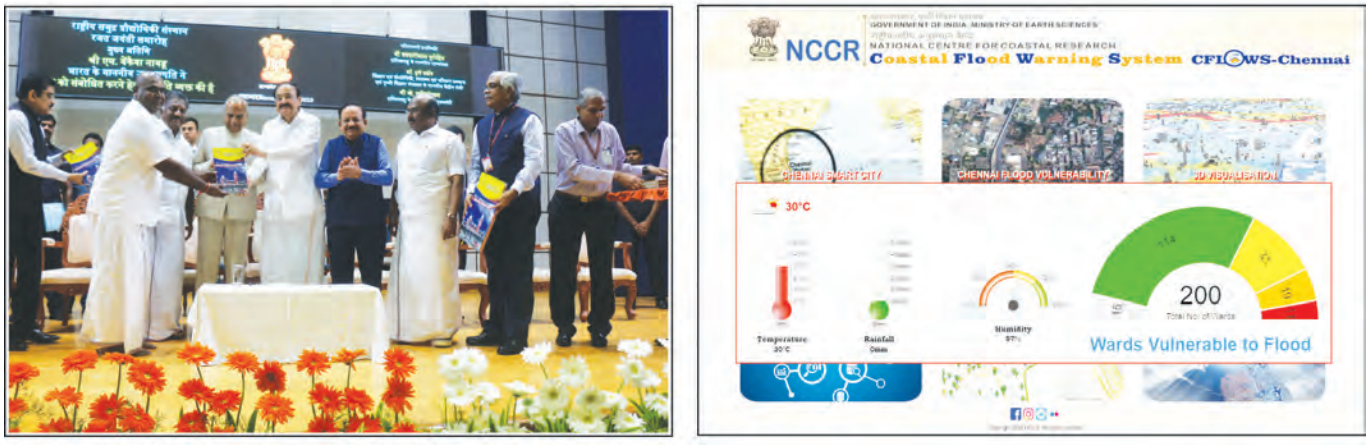



**Fig. 3.9 Coastal Flood Warning system for Chennai (CFLOWS-Chennai)**

handed over to the State Government in November 2019.

A mobile app and dashboard have been developed for the safety and security of the Coastal fishermen and implemented by the Department of Fisheries in the state of Tamil Nadu (Thoondil).

## 3.4 Ocean Technology

### 3.4.1 Development of Manned & Unmanned Underwater Vehicles

**Manned Submersible**

The design and development of 6000 m depth rated scientific research manned submersible was taken up. The system concept and preliminary system design were reviewed and specifications with a capability to carry 3 persons with operation duration of 12 hours at 6000 m depth and emergency endurance of 72 hours were finalised for the development of personnel sphere/human capsule, life support systems, ballast systems, propulsion systems, underwater battery, power distribution system, sensors, control hardware and navigation. A MoU was signed with VSSC-ISRO for the indigenous development of deep water personnel sphere. A 2.1 m diameter shallow water spherical hull of 25mm shell thickness capable of operating in shallow waters was designed and developed using mild steel material with Indian industry (Fig. 3.10).

**Unmanned underwater vehicle**

A shallow water ROV is developed for the Centre for Marine Living Resources for Ecology (CMLRE), Cochin for carrying out bio-diversity studies up to a depth of 300m. Data telemetry and Control, power and mechanical systems were developed in-house. Subsystems were assembled and tested at Laboratory and Acoustic Test Facility (ATF). Hands on training for ROV operations with deck power, control, launching and retrieval system was imparted to CMLRE scientists/engineers at In-house water tank during June 2019.

An underwater imaging skid comprising high definition cameras, LED lights and 100m long underwater cable was developed and deployed for carrying out underwater inspection up to 52m depth in the Kalpakkam Madras Atomic Power Station (MAPS) sea water intake sump. Results brought out occurrence of green mussels in greater extent which needs further remidial measures to be addressed by MAPS.

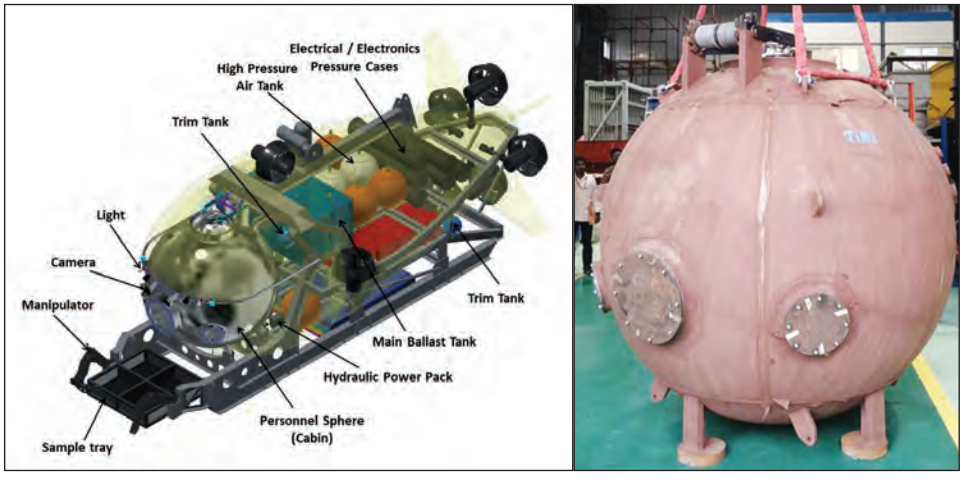



**Fig. 3.10 Schematic of manned submersible and Shallow water spherical hull**

**Fig. 3.11 Winch and Umbilical cable test on-board ORV Sagar Nidhi**

### 3.4.2 Deep Sea Technologies/Deep Sea Mining

**Integrated mining system :** Experiments were performed on a reduced model undercarriage with various mechanisms to prevent sinkage in low bearing strength seabed and aid effective locomotion. A new deep sea winch with 7000 m electro-optic umbilical cable (6000 m depth rated) was installed on-board Sagar Nidhi and tested successfully. Trials were undertaken to prove the system.

Locomotion trials of the mining machine fitted with pick-up/collector systems was planned in the Test Mining Site at the CIOB. The mining machine with buoyancy packs weighed 14.5 t in air and 2.5 t underwater. The depth in the trial area was 5100-5400 m. Two deployments were attempted on 26$^{th}$ April and 4$^{th}$ May 2019. The deployments had to be aborted midway due to heavy swells and unfavourable weather conditions as a result of concurrent cyclones in the mid and northern Indian Ocean.

**In situ Soil Tester deployment at Polymetallic Nodule Mining site :** The In-situ soil tester was deployed for seabed soil assessment in the PMN mining area in the CIOB at a depth of 5418 m during April 2019. The newly procured deep sea winch and 7000 m hybrid aramid umbilical cable was used. The seabed soil was assessed to be non-clayey and fairly strong to support the underwater weight (2.2 ton) of the soil tester.

### 3.4.3 Coastal Engineering

**Establishment of desalination plants in UT Lakshadweep Islands**

Ministry of Earth Sciences through National Institute of Ocean Technology is constructing6 desalination plants based on Low Temperature Thermal Desalination (LTTD) Technology with capacity of 1.5 lakhs per day at Amini, Androth, Chetlat, Kalpeni, Kiltan and Kadamat Islands of UT Lakshadweep. All the desalination plants are scheduled to be completed by end of 2020.

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

NIOT has assessed the status of existing protection measures, studied long term shoreline changes using satellite data, carried out process based measurements in various seasons and numerical model studies. Based on these studies, a detailed hybrid solution with submerged north reef, offshore south reef and beach nourishment was suggested to GOP for restoration of lost beach in Pondicherry. North

**Fig. 3.12 Present status of Beach formed at Puducherry**

reef was successfully implemented and resulted in formation of wide beach. (Fig. 3.13) The project was dedicated to public by Hon'ble Minister for Earth Sciences, Dr. Harsh Vardhan, on 24th January, 2019 in the presence of Dr. Kiran Bedi, Hon'ble Lt. Governor of Pondicherry and Shri. V. Narayanasamy, Hon'ble Chief Minister, Pondicherry.

**Performance Evaluation of Kadalur Submerged Dyke Project**

Demonstration of an environmentally friendly shore protection measure was carried out at Kadalur villages near Kalpakkam in Tamil Nadu. The field and satellite observations have shown that the Beach width has increased in front of the villages. Bathymetry surveys indicated sediment deposition behind the dyke segments.

### 3.4.4 Energy & Fresh Water

**OTEC Powered Desalination Plant at Kavaratti:**

Dispersion and other studies were carried out and the Environmental Impact Assessment (EIA) report of the OTEC (Ocean Thermal Energy Conversion) Powered Desalination Plant at Kavaratti was presented to the committee of Lakshadweep Coastal Zone Management

**Fig. 3.13 Dedication of Restored beach at Kadalur villages by HMoES**

Authority (LCZMA). The Technical Committee accepted the studies carried out and recommended LCZMA to approve and provide consent for the project. No Objection Certificate (NOC) was issued on 22nd June 2019. Several experiments were carried out in the OTEC Desalination Laboratory at NIOT for the performance assessment of various components of Open cycle OTEC and LTTD system for understanding the system and component level design of various process equipment.

**Wave powered navigational buoy demonstration**

The wave powered navigational buoy is in continuous operation in the navigational channel of Kamrajar Port Ltd. (KPL) and measured oceanographic parameters are being transmitted hourly to port authorities through GSM communication. As part of efforts for transfer of technology to industry, Technology Licensing Agreement (TLA) was signed with industrial partners for commercialization.

### 3.4.5 Ocean Science and Technology for Islands

The major focus of Ocean Science and Technology for Islands (OSTI) is on four activities viz. Marine Algal Biotechnology, Marine Microbial Biotechnology, Open Sea Cage Culture, Establishment of Ballast Water Treatment Technologies – Test Facility.

**Marine Algal Biotechnology**

Mass culture of marine Chlorella strain (*Chlorella vulgaris*- strain code-NIOT-74) was done in raceway ponds at seafront facility, Nellore for demonstration of nutraceutical production from marine *Chlorella*. Marine *Spirulina* isolated from the Andaman Sea was optimized for mass culture using different culture media like F/2, commercial fertilizers with superphosphate, NPK and modified organic medium with sodium bicarbonate and a maximum biomass (2.3g) was achieved on the 30th day.

**Microbial Biotechnology**

The polyphasic characterization study showed that *Streptomyces olivaceus* NIOT-Ch-40 isolated from 2000 m sediment sample as a new taxa producing an active compound piericidin. This compound is a member of the class of monohydroxypyridines that acts as an irreversible mitochondrial Complex I inhibitor that strongly associates with ubiquinone binding sites in both mitochondrial and bacterial forms of NADH:ubiquinoneoxido reductase at nanomolar

The deep sea bacterial isolates (502 nos.) isolated from deep sea samples collected from 3000m–4500m (SN134, Lat: 1°S to 4°S; Long; 80°E to 87°E) were grouped into 88 morphological colonies and screened for antagonizing quorum sensing genes from *C. violaceum* CV017 using a biosensor strain, *C. violaceum* CV026 (mini-Tn5 mutant of wild type strain), deficient in autoinducer synthase.

**Open Sea Cage Culture**

NIOT team made a survey on availability of milkfish seed in Sangumal, Dhanuskodi, Kundhukkal, Mandapam and Vethalai. Collection of milkfish seed was carried out using a specially designed net. Meetings were conducted with fishermen Self Help Groups of Olaikuda fishing village near Rameshwaram to start cage culture. As a part of brood stock development, *Caranxignobilis* of average body weight 3.5 and seabass, *Latescalcarifer* of average body weigh 205 kg were stocked in 9 m wide open sea cages at North Bay, Port Blair. The growth performances of these brood stocks are being continuously monitored. A MoU was signed

between NIOT and ICAR-CIBA, at Chennai for technical partnership in the promotion of aquaculture in the country.

**Establishment of Ballast Water Treatment Technologies – Test Facility**

A mesocosm study on the stratification of living organisms in ballast water tanks was done under light and dark conditions in the laboratory using a mesocosm facility. Phytoplankton viability was assessed using SYTOX® green showed gradual decrease in viability in the dark mesocosm tanks compared to the tanks incubated in the light conditions. A steep decrease in the zooplankton density and viability (Neutral red uptake method) was observed. To meet the inlet water requirement as per the IMO G8 guideline for testing and validation of ballast water treatment system in land-based BWTT-TF, the physico-chemical parameters of the coastal water was continuously monitored and open sea was found to be suitable as a source of intake water with the addition of suitable surrogates.

### 3.4.6 Marine Sensors, Electronics & Acoustics

**Marine Sensors**

NIOT is also involved in indigenous development of underwater acoustic imaging systems, sensors and acoustic transducers. Experimental studies with the proposed Mills Cross array transducer configuration are carried out in Acoustic Test Facility (ATF) of NIOT to develop Acoustic Imaging SONAR for 2D/3D imaging of sub seabed objects such as pipelines, submerged objects with fine resolution. The state-of-art Calibration Test Facility (CTF) was successfully established to calibrate the sensors which measures the parameters such as Air temperature, Air humidity, Air pressure, precipitation with reference instruments which is recommended by the World Meteorological Organization (WMO) for the Regional Marine Instrumentation Centre (RMIC) laboratories. The reference equipments are having traceability with National standard, i.e. National Physical Laboratory New Delhi.

**Ocean Electronics**

The main objective is to design, develop and demonstrate new autonomous ocean observation technologies and systems for oceanographic applications.The first proto type unit, 500m workable Deep Sea Autonomous Underwater Profiling Drifter -1 (DAUPD) was developed in-house using 1000CC variable buoyancy engine. Short duration deployment was carried out at underwater acoustic research facility (UARF) in Idukki, Kerala and performance observed for few cycles. The system was operated up to a depth of 110m and performance was satisfactory. DAUPD-2 was built subsequently and necessary functionality test has already been carried out including mission cycle test and field testing in Bay of Bengal to study the system performance in variable salinity conditions.

**Ocean Acoustics**

Development, deployment and operation of passive acoustic system for polar region and deep ocean regions for continuous noise measurements was undertaken by NIOT. Deep Ocean Ambient Noise Measurement System (DANMS) was successfully incorporated in the OMNI buoy mooring and deployed at AD09 location (Lat 8.14° N Lon 73.18°E) in the Arabian Sea. Data is acquired at a sampling of 32 kHz for a duration of 12 minutes, in every half an hour. The system is operational in Arabian Sea. An autonomous ambient noise measurement system (ANMS) deployed as part of IndArc mooring in the Kongsfjorden Arctic in July 2017 was successfully retrieved after two years in July 2019.

**Coordinated Arctic Acoustic Thermometry Experiment (CAATEX) 2019**

NIOT participated in CAATEX (Coordinated Arctic Acoustic Thermometry Experiment - 2019) experiment in the Central Arctic Ocean, jointly carried out by Norway, USA and Canada. The main aim of CAATEX experiment is to deploy acoustic sources and receivers in the Central Arctic Ocean through basin scale acoustic thermometry to measure the heat content of Arctic Ocean and to benchmark climate models.

## 3.5 Ocean Survey and Mineral Resources

### 3.5.1 Geoscientific surveys of the Exclusive Economic Zone (EEZ)

During 2019-20, Five survey cruises were undertaken in eastern offshore region onboard ORV-Sagar Kanya (One cruise) and RV-MGS Sagar (Four cruises). A total area of approx. 92,300 km$^2$ were surveyed using Multi Beam Echo Sounder (MBES) and underway geophysical data including Sub Bottom Profile(SBP), gravity and magnetic data of about 34,300 line kms along track were also acquired. 48 CTD/SVP station data and 7 successful Gravity cores were also acquired. Data processing, integration and mosaicking were done using the standardized data processing procedures. Analysis and integrated interpretation of geoscientific datasets were undertakento identify various seabed geomorphological features and address various scientific issues including sedimentary processes, origin, evolution and tectonics etc. As a part ofidentification of submarine hazard potential, a major submarine landslide has been identified in Kerala offshore

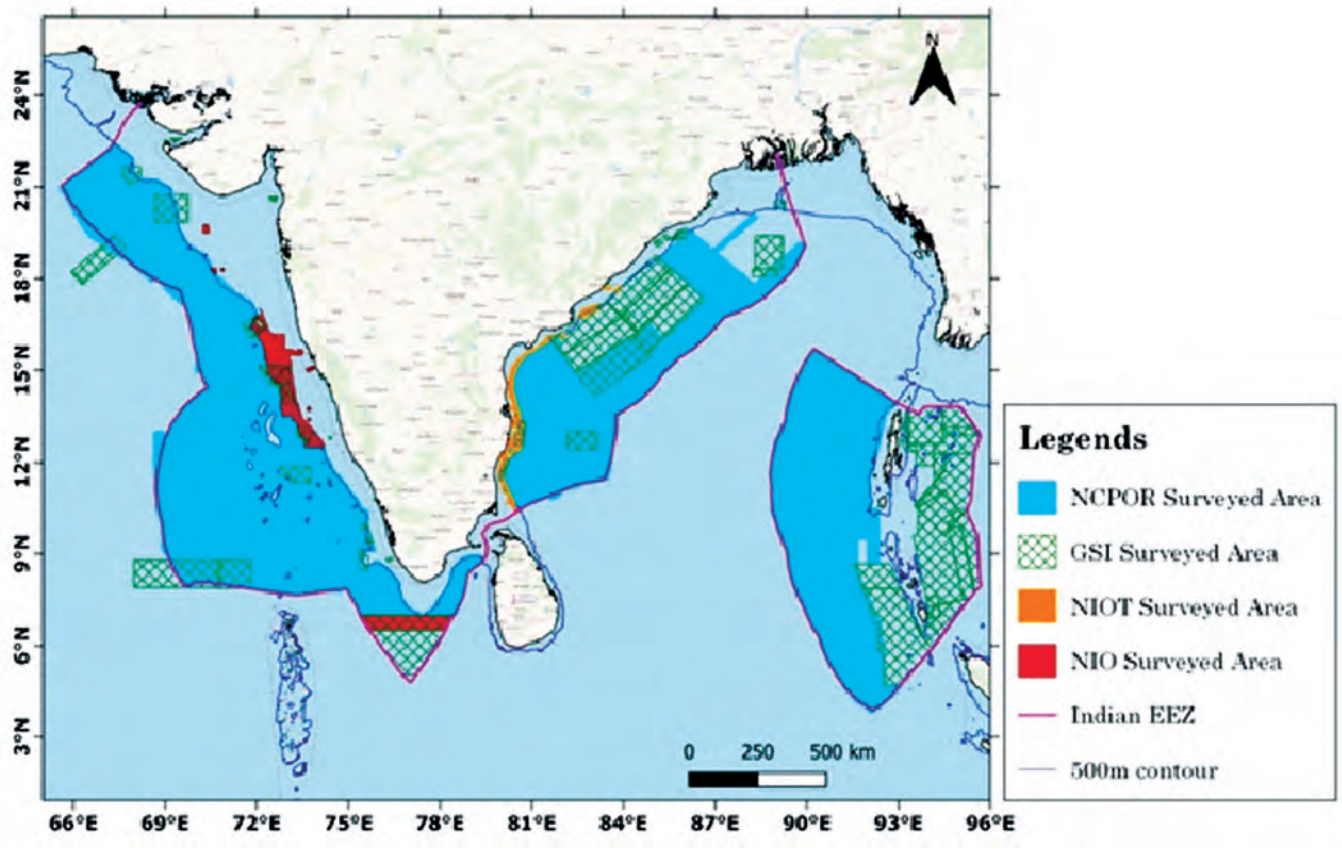



**Fig. 3.14 Map showing total coverage in Indian EEZ**

region apart from various associated features such as crown cracks, collapsed canyon walls and debris flow etc. in the western continental margin of India. A similar submarine hazard area has also been identified in the Palar region along the eastern continental margin of India.

NCPOR has thus far completed 65 cruises exclusively for Multibeam Swath Bathymetry survey to achieve the assigned targets and covered a total area of approx. 16,56,000 $km^2$ of EEZ area off the mainland and Andaman Island region (Fig. 3.14 ). The coverage comprises ~88% of the deep-water blocks with water depth above 500 m within the Indian EEZ.

### 3.5.2 Continental Shelf Program of India

The Indian continental shelf project seeks to gather, analyse and document the requisite scientific and technical information that would help define the country's extended shelf boundaries beyond 200 M as per the provisions of the United Nations Convention on the Law of the Sea (UNCLOS). India submitted its first partial claim of Continental Shelf in May, 2009 to the United Nations. A Sub-commission was established by the CLCS to consider India's partial Submission for the Western Offshore Region recently. The 1st meeting of the Sub-commission was held from 14-18 October 2019 in which Indian delegation made a presentation and participated in the discussions with the Sub-commission clarifying various technical queries. Further, the Sub-commission sought technical inputs in respect of their observations, by February, 2020 from India.

### 3.5.3 Studies on Hydrothermal Sulfides

In order to narrow down the sources of the identified hydrothermal plume signatures, to locate new hydrothermal plumes and to generate environmental baseline data, survey and exploration cruises were undertaken in two legs from 15th March 2019-24th May 2019 in the contract area.

**Significant Achievements of the studies are:**

- Water samples collected from the identified turbid layers were analysed for confirmation of hydrothermal plumes. Helium, methane and manganese concentrations are very high. The plume layers are enriched in helium-3 isotope ($d^3He$ in %) and varies from 14-88 %. This provides the evidence for high temperature hydrothermal venting in CIR near station CTD-17-P5.
- Integrated bathymetric, petrological and microstructural evidences reveal an inverted oceanic crust-mantle rock sequence and associated shear zone at around 67.30 E of northern flank of the SWIR and based on the evidences, it is inferred that the site 67.30 E of SWIR is a potential site of Oceanic Core Complex (OCC) and associated hydrothermal mineralisation.
- Benthic macrofauna studies in sediments from the CIR shows the presence of various species viz. Pycnogonida (sea-spider) sp., Hydrozoan sp., Nematode (roundworm) sp. and Tanaidacean sp. in them.

### 3.5.4 International Seabed Authority Training Programme

In accordance with the contract for the exploration for polymetallic sulphides with (ISA) and MoES, eight-week training was organised by the NCPOR in association with various National Institutes viz. CMLRE, INCOIS, NCESS, NIOT during 3rd December 2018-25th January 2019. Five participants representing different countries viz. Mauritius, Somalia, Brazil, Sri Lanka and Cameroon attended the training program.

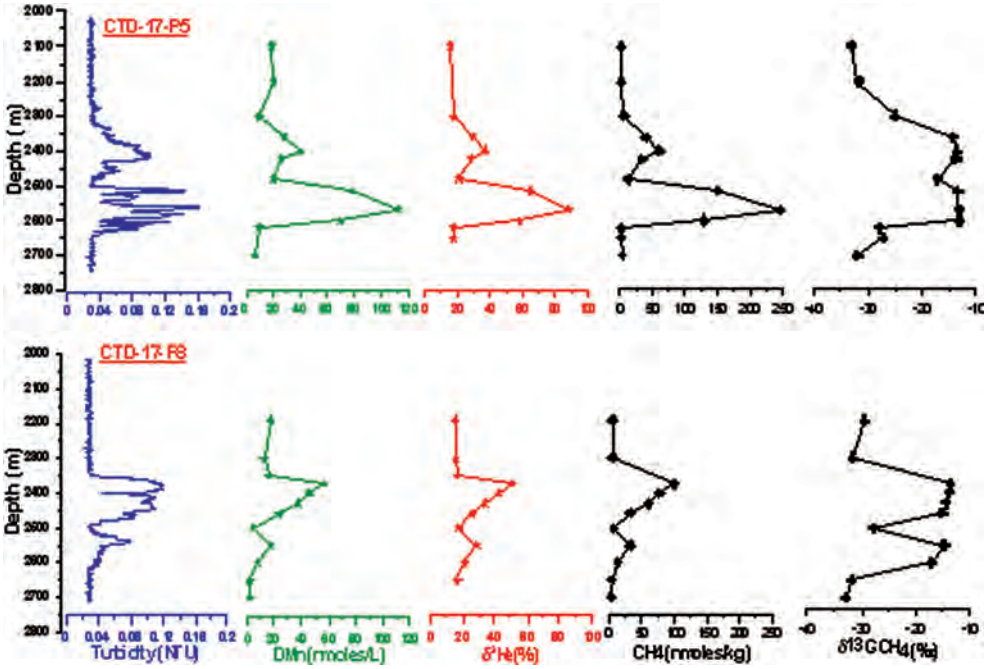



**Fig. 3.15 Turbidity, dissolved manganese, helium (d$^3$He), dissolved methane concentrations and its d$^{13}$C (‰) of two CTD stations CTD-17-P5 & CTD-17-P8.**

### 3.5.5 Studies on Polymetallic Nodules

The Revised First Mining Site (RFMS) was identified within the contract area. The earlier exercise of identification of the FGM was conditioned by contiguity of blocks. This requirement appears to be unnecessary and restrictive. Consequently, the best blocks are selected based on the previous parameters but the FGM may be an aggregate of multiple nodule fields rather than a single contiguous nodule field. The selection of the Revised FGM (RFGM) is based on the updated block wise resource estimates. The total area of the RFGM that was identified in the contract area is around 9929 km$^2$ (13% Contract Area). The RFGM area contains 53 blocks of 0.125° x 0.125° size. There are nearly 6 clusters of blocks scattered in different parts of the contract area (Fig. 3.16). A total of 6 blocks out of the 53 blocks of the RFGM were sampled at 6.25 km x 6.25 km grid spacing, onboard CSIR-NIO vessel *RV Sindhu Sadhana*.

The statement for assessing Environment Impact of mining is being prepared based on the data available in Central Indian Ocean Basin. The research and development endeavours were continued in Institute of Minerals and Materials Technology. (IMMT), Bhubaneshwar on process routes for extraction of metals from nodules. The developments pertaining to technology development in mining have been reported earlier.

## 3.6 Research Vessels

The Ministry implements various programmes with the help of Research Vessels viz. Oceanographic Research Vessel (ORV) Sagar Kanya, Fisheries Oceanographic Research Vessel (FORV) Sagar Sampada, Technology Demonstration Vessel (TCV) Sagar Nidhi, Buoy Tender Vessel (BTV) Sagar Manjusha, and Coastal Research Vessel (CRV) Sagar Poorvi.

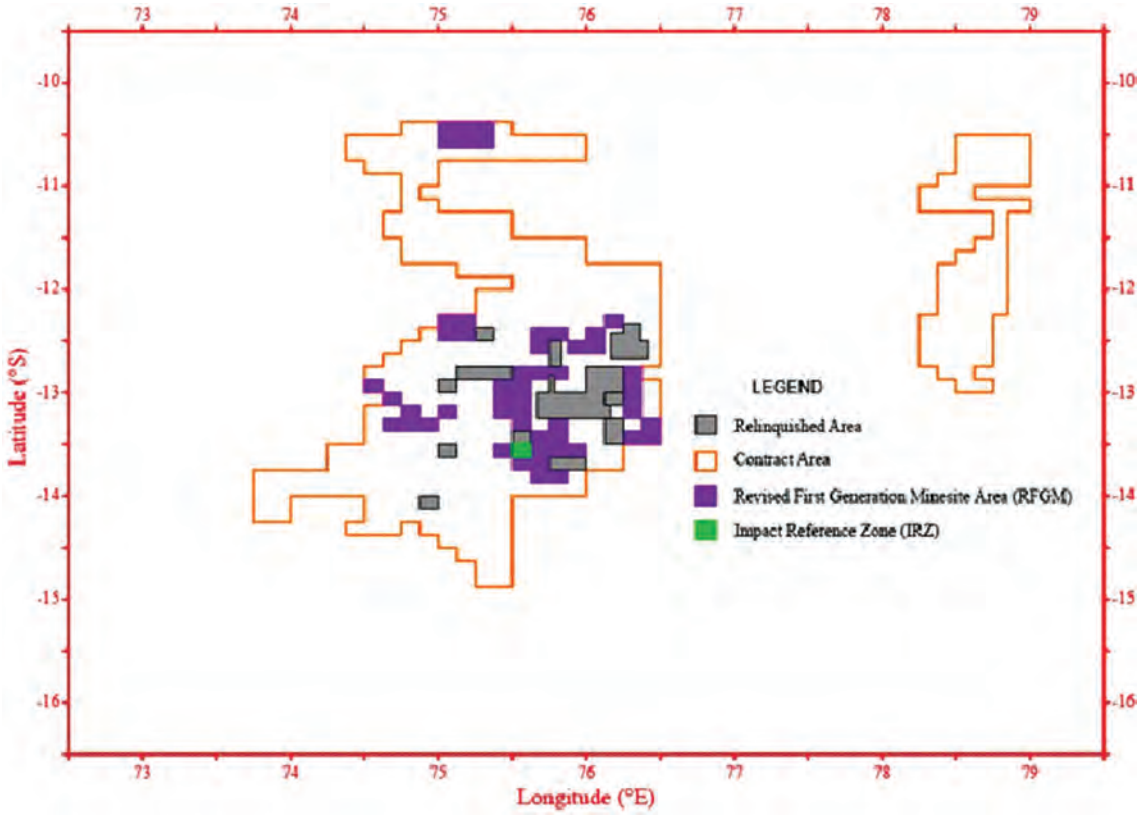



**Fig. 3.16 Revised First Generation Minesite Area (RFGM) and Impact Reference Zone (IRZ) within the Contract Area in the Central Indian Ocean Basin (CIOB).**

Following are some of the highlights of work carried out by the Research Vessels:

- FORV Sagar Sampada undertook studies on Resource Exploration and Inventorisa-tion System (REIS), Marine Ecosystem Dynamics of Eastern Arabian Sea (MEDAS), Bio-Exploration and exhibition at Port Blair & Swatchtha Hi Sewa awareness programme organized at Port Bhander, Okha, Karwar-South Goa & Kochi.
- As part of "Swachhata Hi Seva", the Centre for marine Living Resources and Ecology (CMLRE), Ministry of Earth Sciences (MoES), Kochi has organized a unique campaign to spread awareness on marine plastic pollution, especially to school students and coastal communities from 21st September to 2nd October, 2019. FORV Sagar Sampada, was the backbone of this 'Porbandar to Puthuvype' Campaign, making stops at several ports during her voyage from Okha in Gujarat to Kochi in Kerala. In this event, students from different schools and universities, general public were welcomed on-board Sagar Sampada where they interacted with scientists and learnt about the ongoing research in the field.
- ORV Sagar Kanya was deployed for Ocean Observations in Arabian Sea, buoy operations in Arabian Sea, Indian Ocean Geoid Low Studies in Indian Ocean through Ocean Bottom Seismometers, Geoscientific Studies of EEZ in Bay of Bengal, Marine Geological, Oceanographic Investigations of SW Shelf of India in Arabian Sea and

**Fig. 3.17 Students of SBS Primary School, Porbandar after their visit to FORV Sagar Sampada**

Training/Acclimatization of NCPOR Research Fellows & Goa University Students and Seabed Sediment Sampling-In Arabian Sea.

- Sagar Nidhi participated in a coastal security exercise 'Sagar Kavach' with Indian Navy/Indian Coast Guard/ Marine Police. Multibeam Bathymetry survey, sampling & data processing was completed for selection of suitable locations for construction of desalination plants in Six Islands of Lakshadweep archipelago.
- The retrieval and deployment of RAMA moorings for the collaborative project between NIOT and PMEL-NOAA was carried out successfully. Further, a microbial study was undertaken at Equatorial Indian Region onboard Sagar Nidhi.
- Successful installation and testing/trails of new tow fish winch system was completed onboard Sagar Manjusha.

**Acquisition of New Coastal Research Vessels**

Considering the growing coastal activities and ageing costal Research Vessels, Ministry has acquired two Coastal Research Vessels, Sagar Tara and Sagar Anveshika, which were constructed in TWL Shpipyard, Kolkata.

Sagar Tara joined the MoES fleet after successful and satisfactory harbour & sea trials on 16th August, 2019. Ship's machinery and scientific equipments were tested & tried out at sea satisfactorily. Sagar Tara sailed out from TWL Shipyard for her maiden scientific cruise with NIO-Vizag team & successfully completed sampling & survey off-Paradip. The other Coastal Research Vessel (CRV), Sagar Anveshika was successfully launched on 31st August, 2019 at M/s TWL Shipyard.

■

# Chapter 4 | Polar and Cryosphere Research (PACER)

## 4.1 Scientific Studies in Antarctica

### 4.1.1 Polar Cryosphere and Ice core Studies

Various glaciological and geophysical measurements were carried out along the 2000-km-long coast in coastal Dronning Maud Land (cDML) to understand the response of the Antarctic ice shelves to global warming. Field based photochemical experiments, as well as, snow/cryoconite hole sampling was conducted in Larsemann hills, East Antarctica for a better understanding of biogeochemical process in supraglacial environments (Fig. 4.1).

**Increased influence of ENSO on Antarctic temperature since the Industrial Era**

Multiple oxygen records from the west and east Antarctica have been examined and past temperatures were reconstructed. Temperature records reveal significant increasing trend at El Nino/Southern Oscillation (ENSO) band and decreasing trend at Pacific Decadal Oscillation (PDO) band since the post-industrial era. Further, greenhouse gas (GHG) forced model simulation results show an increasing trend in Pacific South American (PSA) activity since the post-industrial era. These observations are also consistent with the earlier report of increasing ENSO activity,

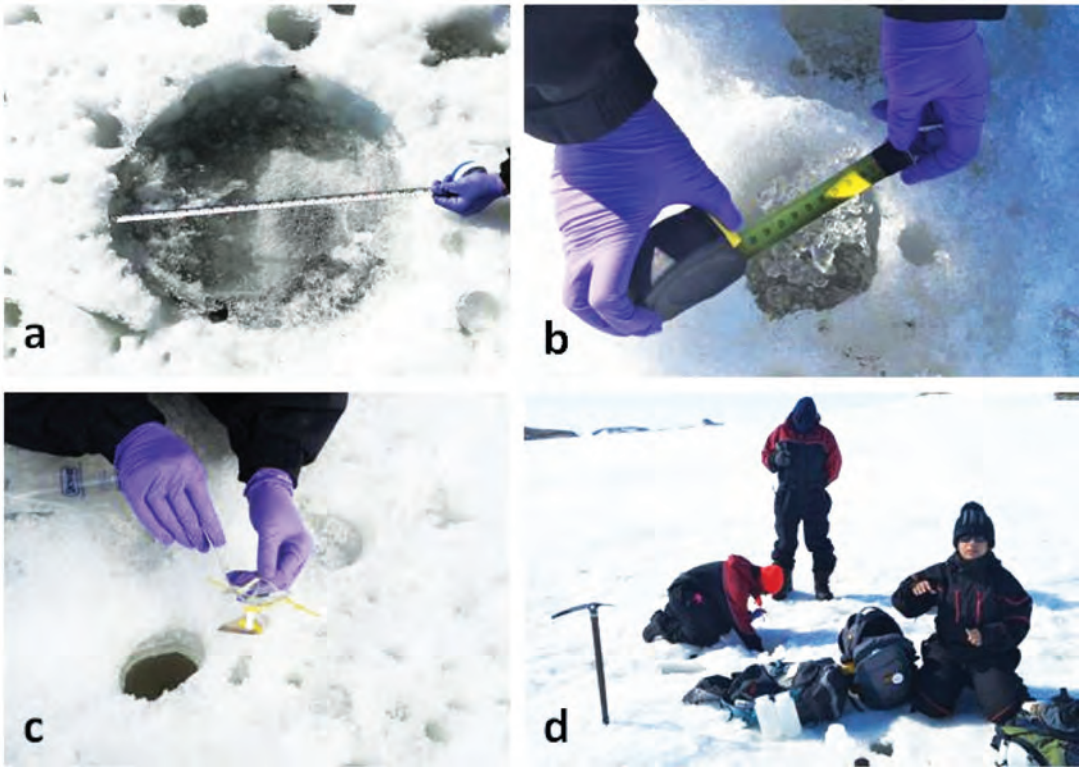



**Fig. 4.1 Cryoconite holes in Larsemann Hills, East Antartica (a and b) and field sampling (c and d).**

reconstructed based on tropical-subtropical tree ring records.

**Photochemical and microbial transformation of dissolved organic matter on surface snow**

Photochemical and microbial (termed photo-biochemical) degradation of dissolved organic matter (DOM) would determine its fate on the glacier surface and in recipient coastal ecosystems. In order to understand the molecular imprints of photo-biochemical alteration of DOM, *in situ* field experiments were conducted over a period of 35 days in a coastal Antarctic site and DOM was molecularly characterized using ultrahigh-resolution mass spectrometry. The biogeochemistry of DOM was found to be highly complex and intimately connected with microbial and photochemical processes operating individually or in combination (Fig. 4.2). Photo-biochemical processes resulted in shifts in the nitrogen, sulfur, and phosphorous content of the DOM.

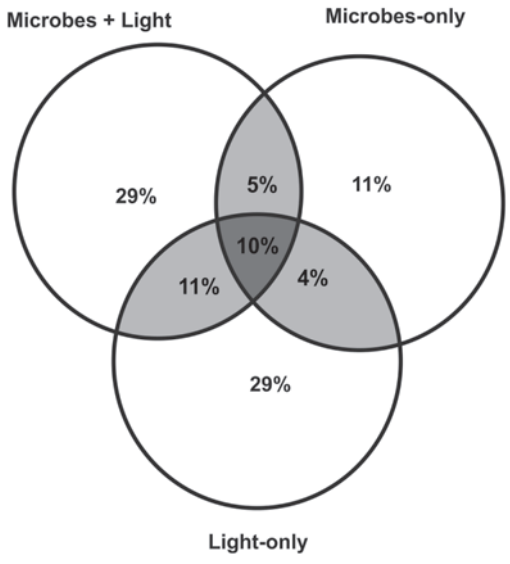



**Fig. 4.2 Venn diagram of light-only, microbe-only, and light+microbe treatments. Areas of overlap are percentages of molecular formulas that are detected at all time points in both or all three of the treatment types. Percentages in areas of no overlap indicate molecular formulas that are unique to that individual treatment.**

### 4.1.2 Paleolimnology and Biogeochemistry of Antarctic Lakes

**Impact of Antarctic climate during the Late Quaternary: records from Zub Lake sedimentary archives from Schirmacher Hills, East Antarctica**

A 79-cm-long radiocarbon dated sediment core retrieved from a peri-glacial lake of Schirmacher Oasis, East Antarctica was analysed for elementary (Corg %, Norg %), isotopic ($\delta$13COM, $\delta$15NOM) and particle size (sand, silt, clay). The sediment core spans the last 43 Kyr. The organic sedimentary data reveals that the OM varies between two end-members i.e., autochthonous (aquatic algae) and allochthonous (lichens and mosses). The C/Natomic ratio and $\delta$13C time-series suggests that the Late Glacial Stage (LGS) is dominated by the former (ice-cover condition) while the Holocene is a mixture of both the end-members (ice-free condition) suggesting the lake experience consistently ice-free (ice-cover) condition during the Holocene (glacial) owing to consistently (colder) warmer conditions during austral summer. The Antarctic Isotope Maximum (AIM) and Antarctic Warming event (A1) is reflected in the multi-proxy records.

### 4.1.3 Operations and management of Indian Antarctic stations

The chartered expedition vessel MV Vasiliy Golovnin sailed from Cape Town on 26 January 2018 with 28 expedition members and after operations at Bharati and Maitri stations the vessel sailed for Cape Town on 27 March 2019 and reached Cape Town on 05 May 2019 along with 26 Indian expedition members (Fig. 4.3).


**Fig. 4.3 Expedition Vessel – MV VasiliyGolovnin: near Bharati station in February 2019 (left) and while approaching Indian Barrier near Maitri about 2 weeks later (right).**

## 4.2 Scientific Studies in Arctic

### 4.2.1 Characterization of Polar Aerosols

**Black carbon aerosols over Arctic**

Gruvebadat aerosol monitoring laboratory at Ny–Ålesund observed higher (>40 ng $m^{-3}$) Black carbon (BC) mass in winter-spring (Jan-Feb-Mar) than that in summer-autumn (Aug-Sep-Oct) (<30 ng $m^{-3}$) (Fig. 4.4). Higher BC during winter-spring may have been transported from mid-latitude regions, while wet scavenging of BC in summer-autumn may have led to lower values.

### 4.2.2 Hydrography of Kongsfjorden

**Role of Greenland Sea gyre circulation on Atlantic Water temperature variability**

Greenland Sea Gyre was identified as a mechanism to determine Atlantic Water (AW) temperature at Fram strait. The gyre's response to atmospheric forcing can change the AW flow in Nordic Seas and modify the heat that reaches the Arctic Ocean through Fram Strait (Fig 4.5). In the presence of a cyclonic atmospheric circulation, the gyre circulation strengthens leading to faster AW flow by narrow and swift

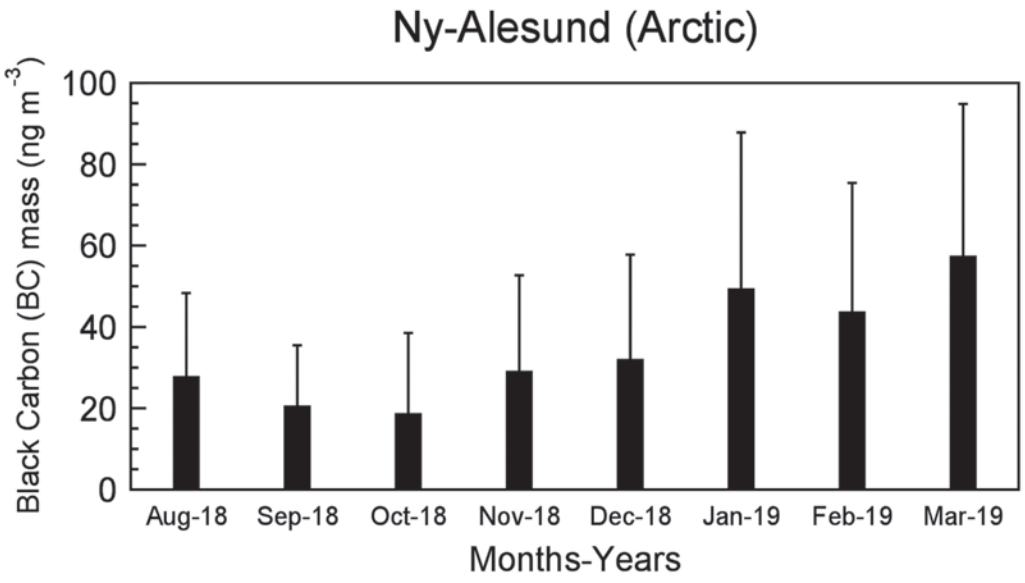



**Fig. 4.4 Monthly mean variations of BC mass over Ny-Ålesund during Aug 2018 to Mar 2019.**

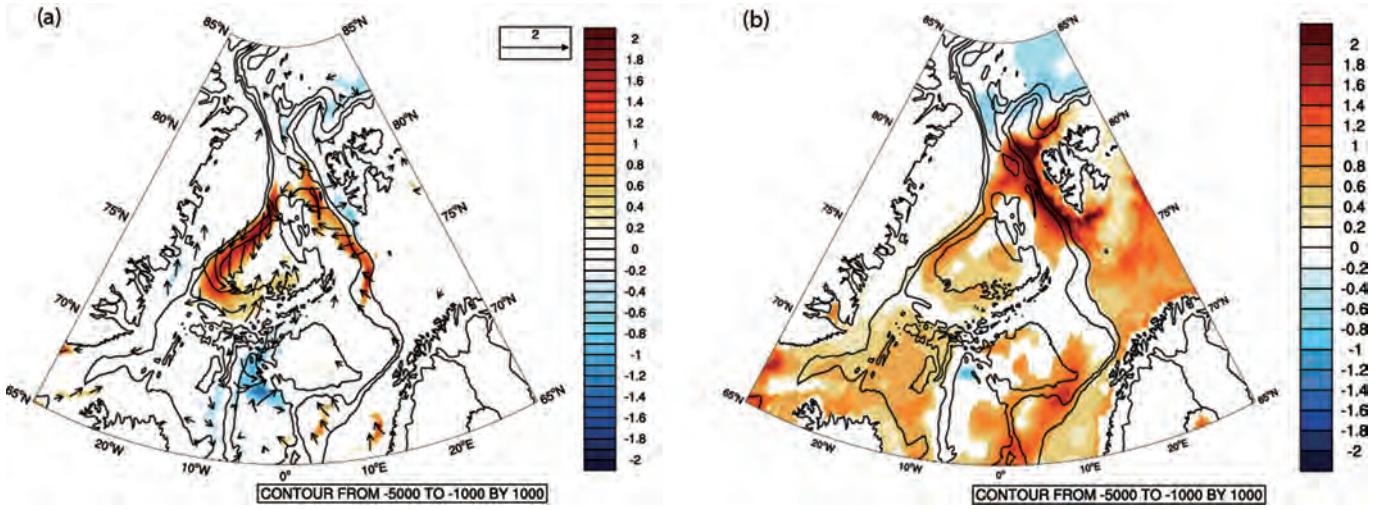



**Fig. 4.5 (a) Regression of 700m depth integrated flow speed anomaly (cm $s^{-1}$) on AW temperature in the Fram Strait. The shading indicates the magnitude of the of the flow speed. (b) Regression of 700m depth averaged ocean heat content (109 J $m^{-2}$) relative to 2 °C on AW temperature in the Fram Strait. Only regression coefficients significant to 99% confidence level are shown.**

West Spitsbergen Current (WSC). As the heat loss is less in a narrow and swift current than a broad and slower flow, the warm and saline AW along the WSC remains warmer as it reaches Fram Strait (Fig 4.5b).

**Role of Atlantic water advection in Kongsfjorden thermodynamics**

The periods and depths of Atlantic Water (AW) in Kongsfjorden observed using underwater

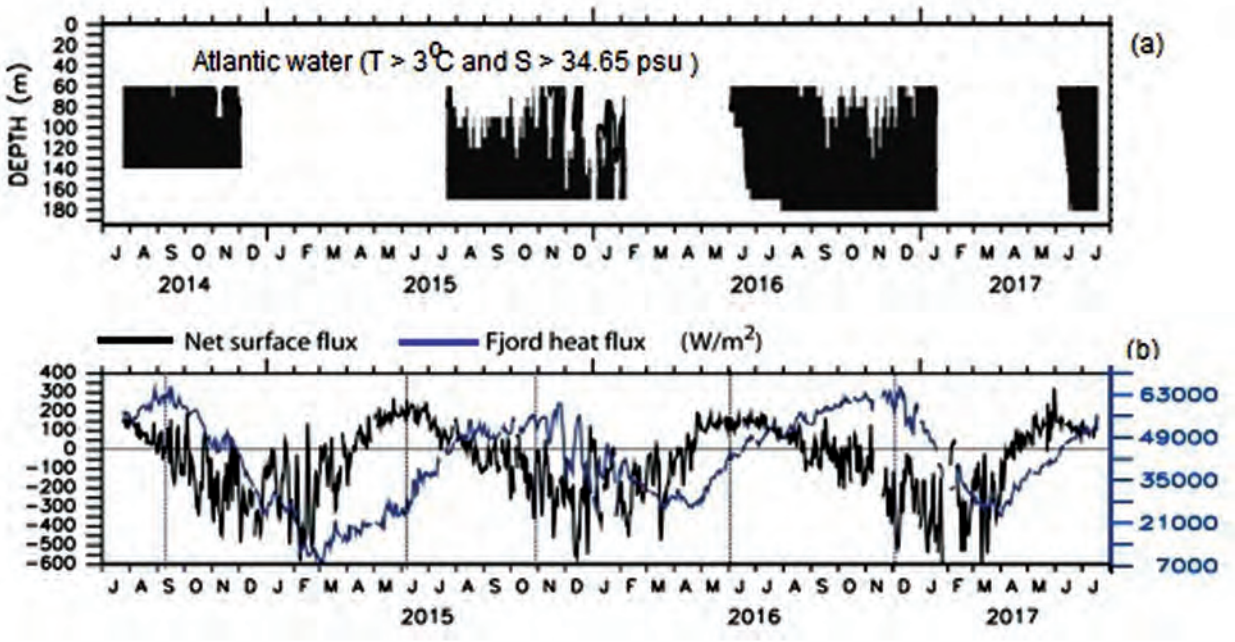



**Fig. 4.6 (a) Atlantic Waters (gray shade) delineated from daily temperature (T)-salinity (S) data using criteria T>3°C and S>34.65psu below 60m depth (b) Daily time series of net surface heat flux estimated and total flux in mooring location.**

observatory (IndARC mooring) mooring data from July 2014 to July 2017 (Fig. 4.6a) indicated total heat flux much higher than net surface heat flux available, indicating an additional internal supply of heat to the fjord (Fig. 4.6b). The residence period of AW inside the fjord corresponds well with peak total heat fluxes showing the role of Atlantic currents in the heat transported into the fjord through exchange mechanisms.

**Numerical modelling of Kongsfjorden**

A high-resolution 3D hydrostatic primitive equation model was set up covering Kongsfjorden, Krossfjorden, adjacent shelf region and WSC. Model bathymetry was obtained from Shuttle Radar Topography Mission (SRTM) 30 plus. Horizontal resolution was set as 1/48° (~2km). Forcing fields are interpolated to model grid and model integration was carried out for 2013-2017. We compared the model simulations with hydrography data from Indian mooring observations (Fig. 4.7). The model reproduces both the seasonal evolution and vertical distribution of the fjord hydrography. In winter, the fjord is well mixed. However, the simulation temperatures from December to January were ~1-2°C warmer than the observations. Model also resolves AW intrusions timings, subsurface temperature maximum, low saline waters in upper column associated with freshwater discharge during summer.

**Phenology of phytoplankton bloom in Kongsfjorden using IndARC mooring**

Bloom phenology refers to the study of cycle of development of the bloom and its evolution under seasonal and inter-annual

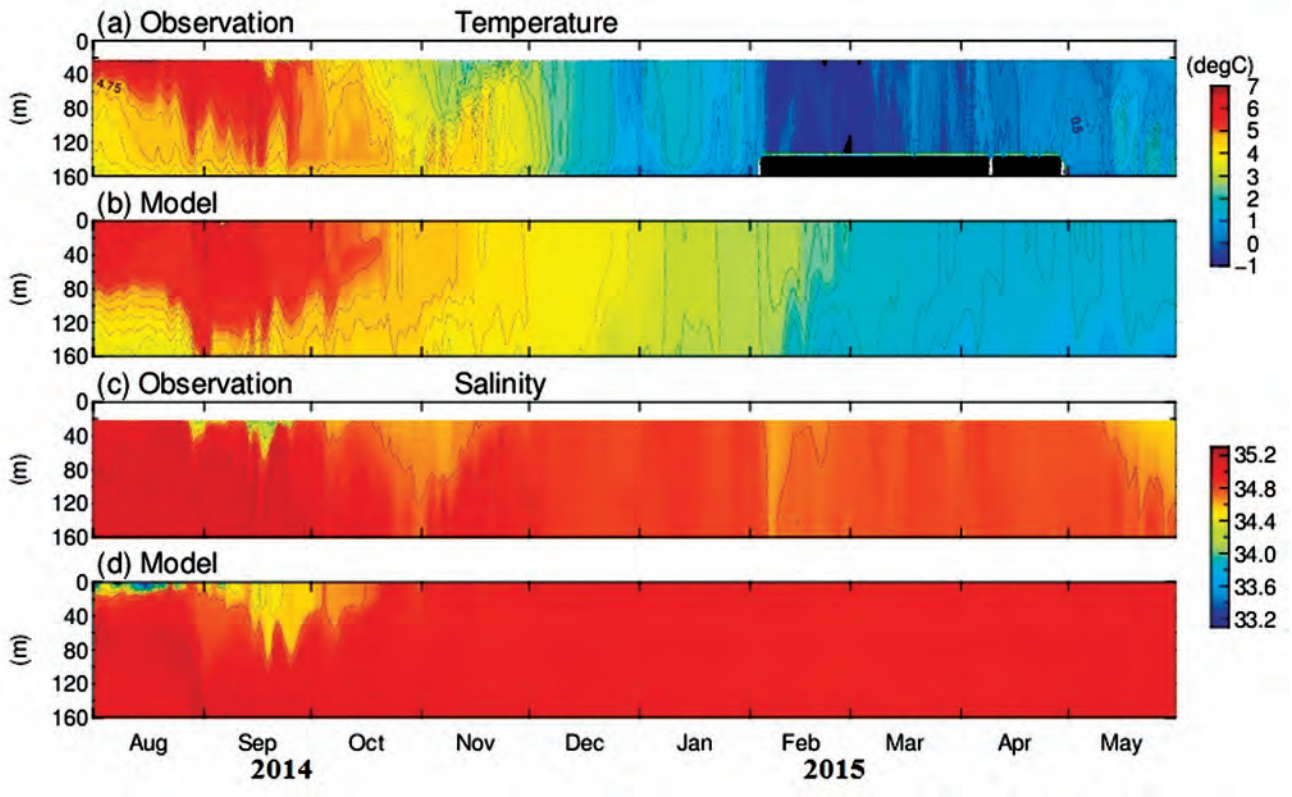



**Fig. 4.7 Evolution of temperature and salinity from observations and simulations during 2014-2015. Upper 25 m data is not available in observations.**

variations in the environmental factors. High temporal resolution data from IndARC mooring were used to study physico-biochemical parameters and bloom phenology in the fjord. High nitrate concentration 13.3µM and near-zero chlorophyll-a was observed in winter (November-April). Increased chlorophyll-a values up to 7.2µg/L at 24m and 4.8µg/L at 34m indicated spring bloom during mid-April to May. During the bloom, chlorophyll-a fluorescence showed negative correlation with nitrate.

**Ocean surface warming in Krossfjorden, Svalbard, during the last 60 years**

The study highlights changes in sea surface conditions of Krossfjorden during the last 60 years (1953-2014). August sea surface temperatures (aSST) and Sea ice extent (SIE) have been reconstructed using diatom microfossil-based reconstructions from a 32 cm Multi-core collected from the fjord. The reconstructed aSST demonstrates a warming trend of 0.1°C decade$^{-1}$, from 1953-2014. Parallel to increasing aSST, the SIE shows a declining trend for the observed period. The factor analysis from the core reveals the dominance of diatoms of Arctic water masses throughout the period and decadal variations in sea ice diatom assemblage, during periods of peak sea ice extent. Dominance of Arctic water diatoms along with increasing aSST suggest open water conditions and increased sea ice melting in the region. Compared with other instrumental and proxy records like surface air temperature, SST and Sea ice anomalies and ice core records the reconstructed record suggest that ocean surface warming in Krossfjorden is in line with the general background warming in the Arctic.

### 4.2.3 Microbiological studies

**Bacterial diversity in the glacio-marine system of Ny-Ålesund, Arctic**

Significant variation in the bacterial community structure among glacier snow, ice, melt waters and fjord waters was observed. In particular, members of β-*Proteobacteria* were dominant in the glacier snow, ice and melt water streams while α-*Proteobacteria* and *Verrucomicrobiae* was predominant in the fjord waters. The meltwater community represent the true signatures of the glacier ecosystem, whereas the fjord community mostly represented by heterotrophic marine taxa, which were influenced by phytoplankton bloom dynamics and warm Atlantic waters intrusion.

**Diversity and distribution of Planctomycetes in Kongsfjorden**

Planctomycetes diversity with 16S rRNA gene in the surface sediments of Kongsfjorden were studied. Major phyla observed were *Planctomycetes* (20%), *Verrucomicrobia* (15%), *Clamadia* (2%) and *Latescibacteria* (7%).

### 4.2.4 Cryospheric studies

Vestre Brogerbreen and Feiringbreen glaciers at Ny-Ålesund, Svalbard are being monitored since 2017-18 for mass-energy balance, terminal monitoring, glacier flow, ice flux, snow and water chemistry. The winter and summer balance of Vestre Broggerbren were 0.31±0.06 m water equivalent (w.e.) and -1.13 ±0.31 m water equivalent (w.e.), respectively. The winter balance was significantly lower than (25%) than previous year (0.51±0.1 m w.e.). Overall net annual surface mass balance of Vestre Broggerbreen glacier was negative (-0.86±0.16 m w.e.) and entire glacier lost 4.03 x $10^6$ tons of glacier ice.

#### 4.2.5 Operations and management in the Arctic

Indian research station 'Himadri' was manned for over 150 days since March 2018 till November 2019. Over 40 researchers visited the station, 7 sailed in *RV Lance* for mooring retrieval-deployment, and 4 sailed in *RV Clione* on Svalbard coastal cruise under 23 different scientific projects. Gruvebadet Atmospheric Laboratory, Ny-Alesund has also been operational for continuous monitoring of precipitation, clouds and aerosols, with instruments like radiometer profiler, micro rain radar, aethalo-meter, nephelometer, net radiometer and sun-photometer. IndARC-4 (2017-18-19) was retriev-ed and IndARC-5 was deployed in July, 2019.

### 4.3 Himalayan Studies

**Glaciological studies in Chandra Basin, Western Himalayas**

A systematic long-term scientific investigation of Himalayan glaciers with objective "to understand the response of Himalayan Cryosphere to the changing climate and its hydrological impacts" have been carried out. Six selected benchmark glaciers (Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Gepang and Kunzam) of Chandra basin, western Himalaya have been monitored. Station 'Himansh' is used as base for all operational activities to carry out Glaciological studies in the Himalaya. Field expedition have been carried out from June–October 2019 for various observations such as discharge, water level, snow/ice accumulation and ablation.

**Mass balance studies**

Mass balance measurements at six studied glaciers covering more than 300 $km^2$ revealed significant temporal and spatial variability. Glaciers of Chandra basin have experienced an overall negative mean annual mass balance ((Sutri Dhaka -1.34±0.26m we, Batal -0.54±0.11m we, Samudra Tapu -1.56±0.31m we, Bara Shigri -0.82±0.16m we, Gepang Gath -1.51±0.30m and Kunzam -0.31±0.06m we) during 2017-18 (Fig. 4.8). Equilibrium Line Altitude (ELA) and Accu-mulation Area Ratio (AAR) of Sutri Dhaka glacier was close to 5375 m and 36% respectively, for year 2017-18.

**Moisture sources for precipitation and hydrograph components of the Sutri Dhaka Glacier basin, western Himalaya**

Three-component hydrograph separation based on stable isotope methods shows a dominant contribution of ice-melt (65% ± 14) to the stream discharge, followed by snowpack (15% ± 9) and fresh snow (20 ± 5%). Further, the moisture source over the study region is domi-nantly (>70%) derived from the Mediterra-nean regions by Western Disturbances (WDs) during winter (October–May) and minor (<20%) contribution from the Indian Summer Monsoon (ISM) during summer season (June–September).

**Glacier response to climate in Arctic and Himalaya during last seventeen years: A case study of Svalbard, Arctic and Chandra basin, Himalaya**

The data show that mean annual mass waste of Svalbard glaciers has increased by 16–26% during twentieth century due to high melting rate of glaciers in this region. Similarly, in Chandra basin of Himalaya the mean annual balance decreased substantially and became more negative. In spite of having significant years (25%) of positive mass balance, these glaciers have lost a huge mass of ice during 2000–2017. The mean annual mass wastage of Chandra basin glaciers was –0.21 m w.e. before 2000 which

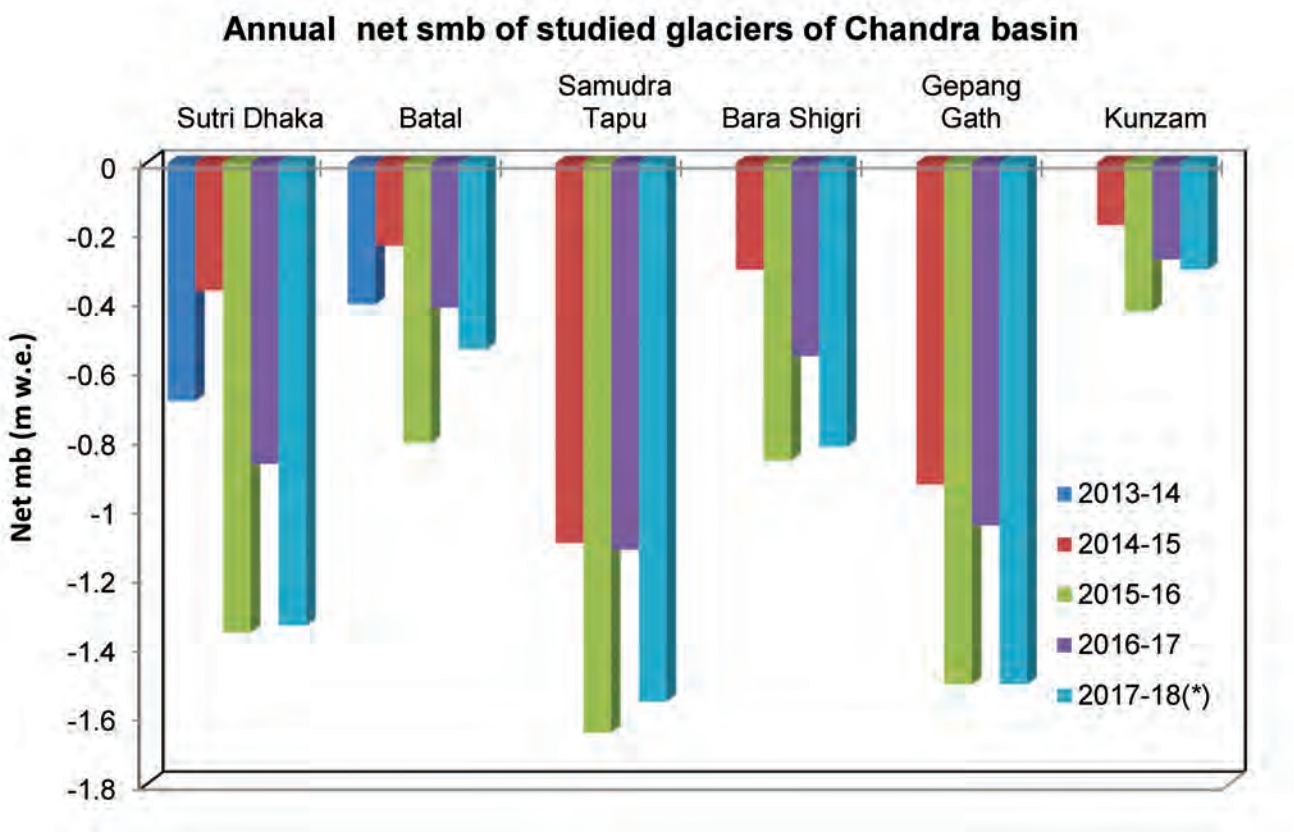



**Fig. 4.8 Annual surface Mass Balance of six representative glaciers of Chandra basin, Western Himalaya during last five years (2013-18)**

increased significantly to –0.56 m w.e. after 2000.

**Physico-chemical and optical properties of aerosols at a background site (~4 km a.s.l.) in the western Himalayas**

Studies on aerosol properties such as mass concentrations and size distributions, their chemical properties and columnar aerosol optical depth (AOD) conducted at Himansh station in Chandra basin, western Himalayas during August - October, 2017 depicted very low values of columnar AOD (mean ~ 0.07) with ~4% contribution of BC (mean BC ~ 168 ng $m^{-3}$) to near surface composite aerosol mass. The total suspended particulate (TSP) matter showed significant variations between 5 micro gram $m^{-3}$ and 40 micro gram $m^{-3}$, having dominance of mineral dust components (~67%) during the entire study period. The ratio of organic carbon (OC) to elemental carbon (EC) varied over a wide range from 7.8 to 18.9, with a mean value of 12.5 ±2.95.

## 4.4 Southern Ocean Studies

**Hydrography and water mass variability in the Prydz Bay**

The watermass variability in the Prydz Bay (PB) during the austral summers of 2017 and 2018 is studied. During 2017, the SST of PB was anomalously warm (> $1^0$%C) whereas in 2018, it was below $0^0$C. A well developed Dicothermal Layer was noticed in the outer regions of the PB with contrasting variability between these years. Large variability in the distribution of water-

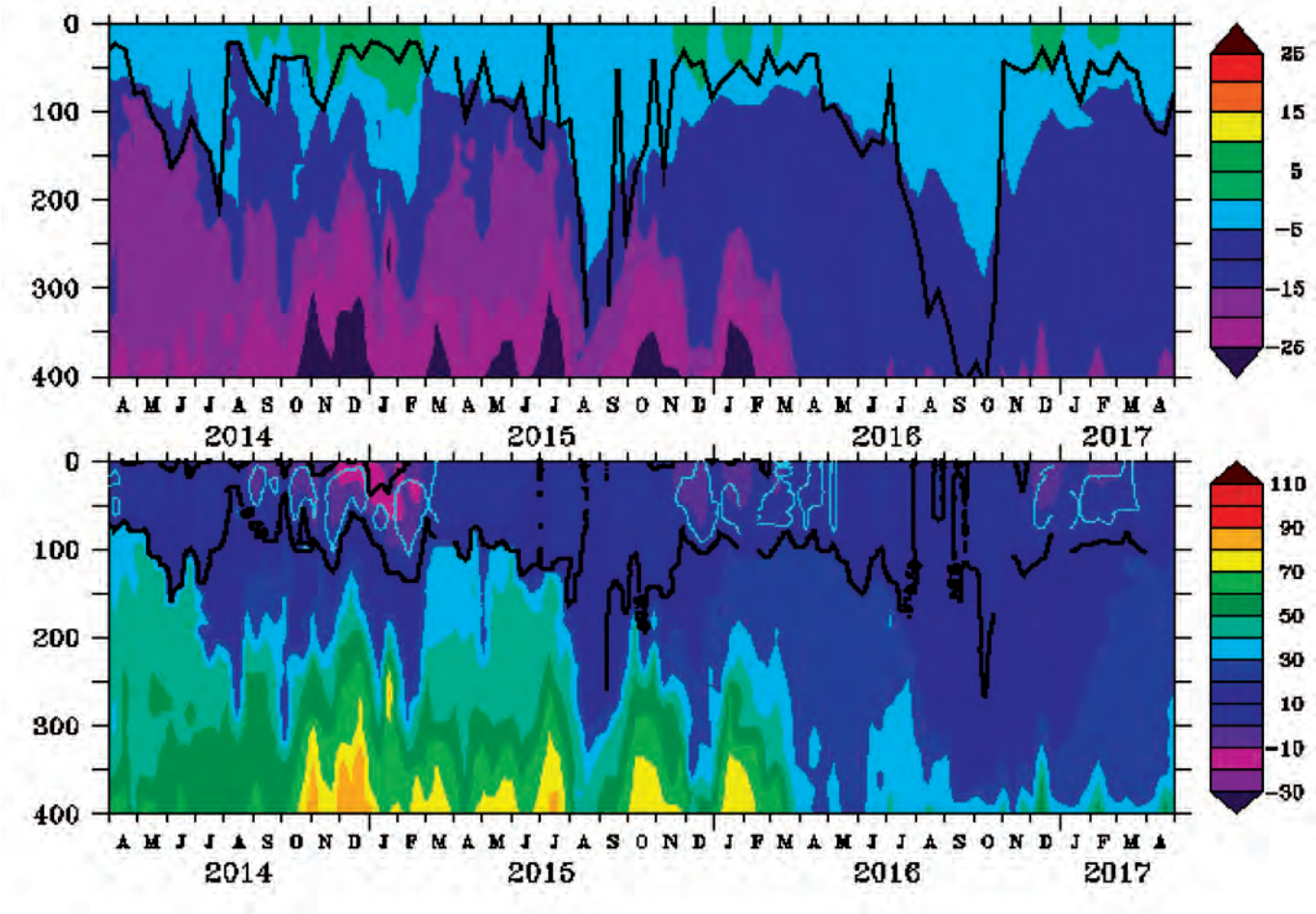



**Fig. 4.9 Seasonal dissolved oxygen saturation (upper window) and apparent oxygen utilization (AOU) (lower window).**

masses was also noticed during these years. The study revealed that atmospheric forcing changes due to Southern Annular Mode play an important role in the dynamics of Prydz Bay (PB).

**A Bio-Argo study: Phytoplankton bloom in the Indian Sector of the Southern Ocean**

The seasonal cycle of dissolved oxygen (DO) and apparent oxygen utilization (AOU) in the ocean, which are important for understanding global biogeochemical cycling was studied based on the data by two Bio-Argo floats deployed in 2014, in the Indian Sector of SO frontal region. Seasonal dissolved oxygen saturation and AOU for one float are shown in Fig. 4.9. A noticeable positive DO saturation anomaly is observed during the summer season. The positive DO saturation anomaly as well as negative AOU resulted from the high chlorophyll during summer season.

**Reoccurrence of a large open-ocean polynya on the Maud Rise, Southern Ocean**

The polynya plays an important role in the Earth's climate system by modulating the albedo, air-sea exchange of heat, fresh water, carbon, and ocean-atmospheric circulation. Satellite observations showed that a large and most prolonged Maud Rise polynya (Lazarev Sea), reappeared on 14$^{th}$ September 2017 for the first

time since its frequent appearance during the 1970s. On 14th September 2017, the areal extent of the polynya was ~9.3 × 103 $km^2$ which expanded maximum on 1st December 2017 up to ~298.1 × 103 $km^2$, lasting for 79 days. The formation of the polynya was due to the combined influence of the (i) existence of the geological features such as seamount (leads to local upliftment of thermocline), (ii) upwelling of warm water into the upper ocean from the thermocline (induced by a large cyclonic ocean eddy and negative wind stress curl), and (iii) the large-scale anomalous atmospheric warming.

**Unprecedented phytoplankton blooms on the Maud Rise, Southern Ocean**

Satellite derived chlorophyll-a concentration showed unprecedented phytoplankton blooms in the Maud Rise polynya, Southern Ocean with chlorophyll-a reached up to 4.67 mg $m^{-3}$. Multi-satellite data indicated that the bloom appeared for the first time in the entire mission records started since 1978. The occurrence of bloom was associated with the supply of nutrients into the upper ocean through the Ekman upwelling, and improved light condition up to 61.9 Einstein $m^{-2}$ $day^{-1}$. The net primary production from satellite observations showed that the Maud Rise polynya was as productive as the Antarctic coastal polynyas with the carbon fixation rates reached up to 415.08 mg C $m^2$ $day^{-1}$.

**The possible linkage between the Southern Ocean sea-ice and Indian summer monsoon rainfall**

Time series analysis of passive microwave satellite data (1979-2017) suggested moderate increase in The Southern Ocean sea-ice (SOSI) at average rate of 14615±5.1 $km^2$ $year^{-1}$. The relationship between the SOSI area and Indian summer monsoon rainfall (ISMR) variability was evaluated using satellite derived south-ocean sea-ice data. Cross-correlation analysis with various lead-lag time scale were computed between the anomalies of the ISMR and SOSI area as a whole and its different sectors for the period 1979 to 2016. Results indicated the austral summer sea-ice anomaly has significant inverse relationship ($r = -0.4$, $p < 0.05$) with ISMR that lagged the SOSI area. The dominant contribution to this relationship was observed from the Ross sea sector. Similarly, moderate inverse relationship was observed during austral autumn with significant contribution ($r = -0.5$, $p < 0.05$) from the Bellingshausen sea sector. Whereas, the sea-ice extend in the Indian Ocean sector follows the ISMR with a significant positive relationship during austral summer ($r = 0.55$, $p < 0.05$) and austral autumn ($r = 0.6$, $p < 0.05$).

**Iron-stimulated phytoplankton blooms in the Southern Ocean: a brief review**

Nine iron fertilization experiments were carried out in the Southern Ocean (SO) comprising of seven artificial fertilization and two naturally enriched events.Satellite-derived chlorophyll-a concentration (2002-2016) are utilized to characterize the monthly evolution of phytoplankton blooms in the SO. Results suggest that the areal extent of the bloom varied from 1.1 to 18.1 million $km^2$ during July (austral winter) and January (austral summer), respectively. In total the SO contributes up to 60% of global ocean phytoplankton blooms during December and January (austral summer), and the dominant region of bloom occurrence is located in the Atlantic sector of the SO, which could be ascribed to iron-rich dust input from Patagonia and regional physical processes.

## 4.5 National Conference on Polar Sciences, (NCPS)

NCPS-2019 was organised at NCPOR from 20th-22nd August, 2019. The three-days event included Young Polar Scientists Meet (YPSM) and conference with about 69 oral and 108 poster presentations, 03 plenary and 07 keynote talk under 07 themes covered studies from Polar Regions to the Southern Ocean. The event was attended by more than 250 scientists and researchers across India.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# Chapter 5 SEISMOLOGY AND GEOSCIENCE RESEARCH (SAGE)

## 5.1 Observational Seismology, Earthquake Monitoring and Services

The National Seismological Network with 115 observatories, spread across the country, has been functioning smoothly. Each observatory is collocated with state-of-the-art broadband seismograph and accelerograph. The ground motion data recorded at the field stations (Figure 5.1) are transmitted in real time through VSAT communication systems to the Central Receiving Station (CRS) located at National Center for Seismology (NCS), New Delhi. A Central Facility (CF) is in operation on 24X7 basis at New Delhi with modern facilities for data collection, processing and dissemination of earthquake information to the various concerned user agencies including, the state and central government.

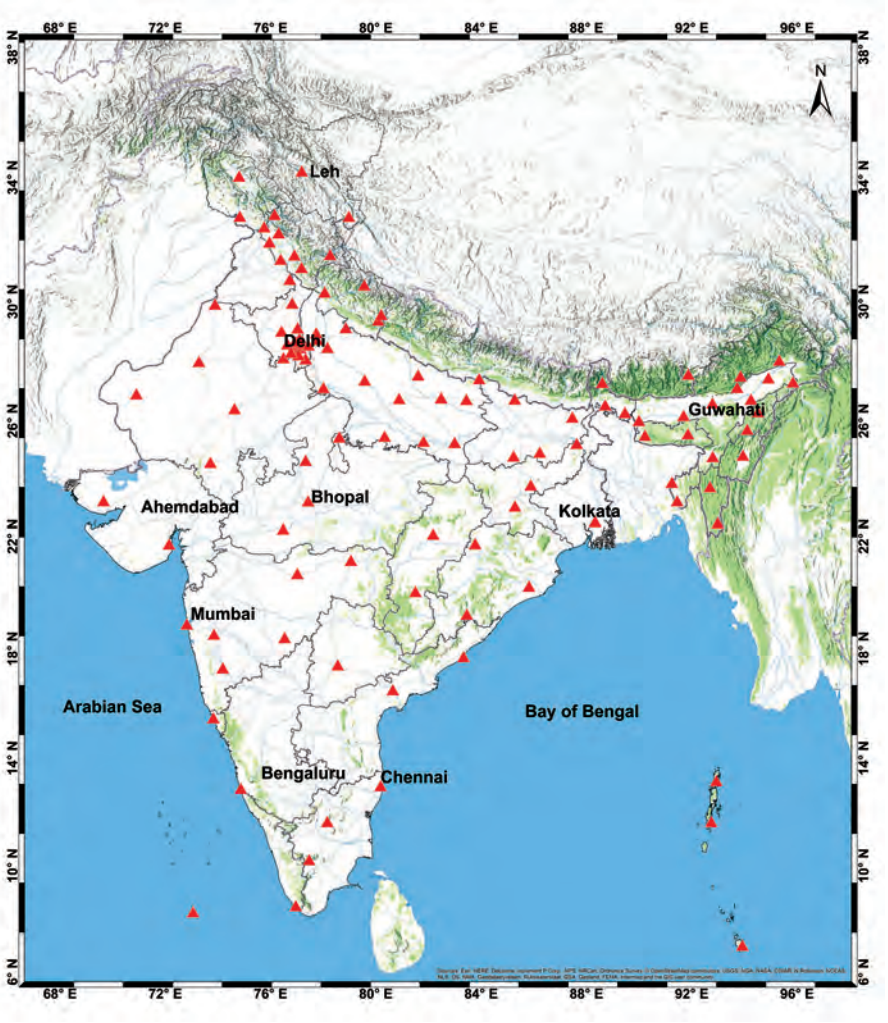


**Fig. 5.1 National Seismological Network (NSN) of 115 stations**

During the last 11 months (January-November 2019) 350 earthquakes were located and reported. While most of the events were of magnitude 5 and below, about 15% i.e. 47 events fall with magnitude range 5.1-6.1 (Fig. 5.2). Information pertaining to significant events were provided to all concerned state and central government agencies, dealing with relief and rescue operations in the region through different modes of communications, and published with value added products on NCS's Website (www.seismo.gov.in).

Recently, the information dissemination system has been upgraded with new website of NCS (Figure 5.3). The website is GIS based with a host of features that provides earthquake information suited to individual's requirement (in the form of list/table, map overlaid with different layers etc). Detailed information about any earthquake, such as, intensity map, Did You Feel It (DYFI) responses, nearby seismicity, Moment tensor solutions of significant earthquakes, are published on dedicated page. In addition to the website an official mobile app

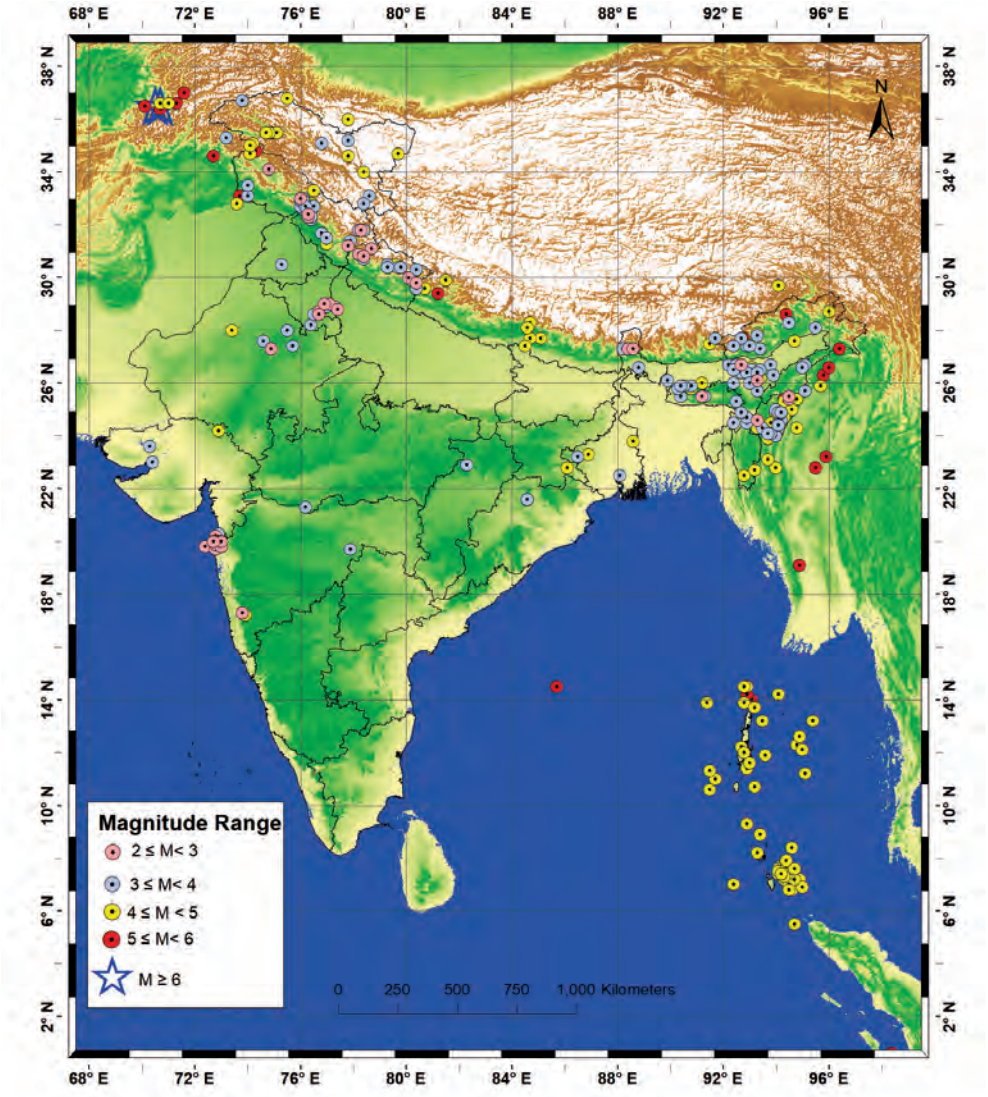


**Fig. 5.2 Epicentral map of earthquakes with magnitude classification, occurred during January to November, 2019.**


**Fig. 5.3 A snapshot of new Website (https://seismo.gov.in) of NCS**

has also been launched for earthquake information "RISEQ" on PLAY Store (Android Users) and APP Store (IOS Users) which provide the latest earthquake information.

### 5.1.1 Earthquake Swarm activity in Palghar District of Maharashtra

The sequence of small magnitude earthquakes (ML ≤3.8) started in Palghar district on 11 November 2018 and is still continuing. The National Network and local network have recorded 22 earthquakes till 31 December 2019. The focal depth for majority of the events is within 6 km. The seismic activity is clustered in a small region of an area of 6 x 12 sq. km around Dhundalwadi village located ~120 km north of Mumbai and 40km NNW of Palghar. At present five temporary field observatories are in operation in the area for close monitoring of earthquake activity. During the field visits, officials from NCS and IMD inter-acted with the local people in the earthquake affected region and advised them about Do's and Don'ts in the event of earthquake occurrence.

Analysis of data shows that earthquake activity exhibits normal sense of motion without any migration with time. Preliminary investigations indicate that shallow sub-surface processes like fluid movement and cavity collapse are main reasons for the activity. However, a detailed analysis is required prior to drawing conclusions.

### 5.1.2 Seismic Microzonation of selected cities

The Seismic Microzonation work related to Geophysical investigations has been taken up for the four cities, namely, Chennai, Bhubaneswar, Coimbatore, and Mangalore. Micro-tremor survey, one of the components of microzonation study, to acquire site specific seismic noise data for estimating the parameters like dominant frequency and peak amplification has been carried out at every 500m x 500m grid. The survey in Mangalore (578 sites) and Coimbatore

(500 sites) have already been completed, while in Chennai (1684 sites) and Bhubaneswar (1910 sites) it is in completion stage. Based on the analysis of Micro-tremor data, the locations for drilling boreholes in these cities have been identified.

## 5.2 Scientific Deep Drilling in the Koyna Intraplate Seismic Zone, Maharashtra

### 5.2.1 Target zones for borehole seismic monitoring

Deep drilling up to ~7 km and setting up of the proposed fault zone observatory to measure co-seismic changes in physical and chemical properties at hypocentral depth requires *apriori* knowledge of the rock properties and fault zone parameters in the Koyna region. To obtain these parameters, a pilot borehole was drilled to 3 km depth in the seismogenic zone for downhole geophysical measurements and possible seismic monitoring.

Analyses of the geophysical logs delineate several anomalous zones between 2100 m and 3000 m depth based on low resistivity, low density, low P- and S-wave velocity, high porosity, low Young's modulus and high Poisson's ratio when compared with the adjacent intact rock mass **(Fig. 5.4)**. Association of these zones with high stress-induced anisotropy, significant rotation of fast polarised shear wave azimuth and borehole breakouts indicate that these zones are either fault damage zone(s) or subsidiaries of nearby fault zone(s).

Gas extraction and analysis during drilling showed the presence of anomalous formation gases $CO_2$ (up to 1200 ppmv), $CH_4$ (up to 186 ppmv), $H_2$ (up to 139 ppmv) and He (up to 12.8 ppmv). Enriched zones are mostly below 2100 m

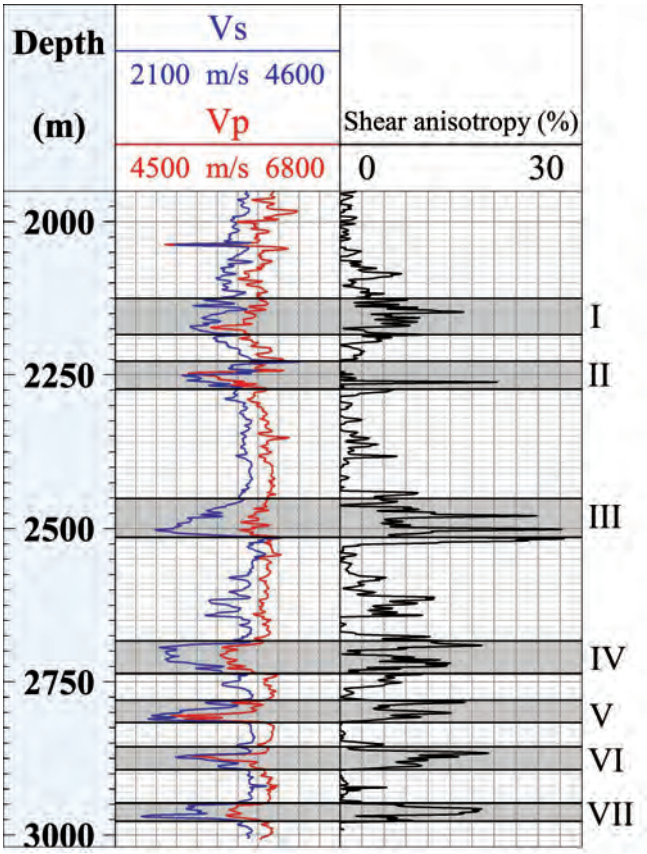


**Fig. 5.4 Depth profile of Vp, Vs, and shear wave anisotropy computed from cross-dipole sonic logs in the basement section 2,000–3,000 m in the Koyna Pilot Borehole. Zones of anomalous physical and mechanical properties are numbered I through VII (grey shading).**

depth, with significant (4.6-7.6 ppmv) helium enhancement above the atmospheric value of 5.24 ppmv. Isotope studies confirm that He gas is primarily of crustal origin. He-rich zones correlate well with the fault damage zones delineated at multiple depths from geophysical logs. These fault damage zones delineated below 2100 m depth are potential targets for borehole seismic monitoring to determine the fault parameters in the region.

An important offshoot of the scientific drilling experiment is the discovery of microbial life within the deep, hot (~80$^0$C), igneous

biosphere and their role in carbon and another element cycling. The study provides new insights on evolution of life and their function on this planet and beyond.

## 5.3 Geological and Geophysical studies

### 5.3.1 Indian scientific endeavors in the International Ocean Discovery Program (IODP)

The International Ocean Discovery Program (IODP) is an international marine research consortium of 26 nations. India is associate member of IODP. By virtue of its membership, more than 45 young Indian scientists have taken part so far in various IODP expeditions, the world over. This year, 4 Indian scientists participated in different IODP expeditions i.e. IODP 379 (Eastern Amundsen Sea continental shelf), IODP 382 (Iceberg Alley and Sub-Antarctic Ice), IODP 383 (Dynamics of the Pacific Antarctic Circumpolar Current) and IODP 385 (Guaymas Basin Tectonics and Biosphere) and gained unique hands-on experience in scientific ocean drilling.

#### 5.3.1.1 Scientific drilling in the Arabian Sea to unravel the links between the tectono-climatic changes and the Himalayan orogeny

A major project aimed at understanding the possible tectono-climatic links between Himalayan orogeny and Indian monsoon as well as nature of crust was implemented by NCPOR through Arabian sea drilling at IODP-355 in 2015. During the expedition two boreholes were drilled in in the Laxmi basin, eastern Arabian sea, Indian ocean with the help of vessel JOIDES Resolution. In total ~1700m of sediment and sedimentary rock, as well as 17m of igneous basement was drilled.

Two-dimensional flexural back stripping and thermal modelling applied along regional depth-converted seismic profiles from the Laxmi basin in the Arabian sea revealed considerable basin-wide subsidence in response to the crustal geodynamics during and after the last extensional phase.

#### 5.3.1.2 Discovery of fossil subduction event in the Arabian Sea

IODP-355 expedition in the Arabian sea has also enabled scientists to discover how a short-lived subduction event around 70 million years ago played a key role in shaping up the modern western Indian continental margin. The new findings are based on an intensive post-cruise study. A distinctive geochemical imprint of igneous rock has been found when the Indian plate changed direction and older crust began to sink under the younger oceanic crust about 70 million years ago in the Laxmi basin. The result provides the first ever conclusive glimpse of a convergent plate motion amidst an overall divergent tectonics of Gondwanaland breakup which separated Madagascar and Seychelles from India.

#### 5.3.1.3 Workshop on ocean drilling in Andamans and surrounding Indian Margins

IODP-India hosted an International Workshop at NCPOR, Goa, during Sep 17-18, 2018 for scientific drilling in Andaman and surrounding regions to identify and improve the understanding of several geological paradoxes in the region. As a follow up, scientists from India, U.S., and ECORD met at Delhi during Jan 15-17, 2019 to analyse existing seismic data and to enable frame paleoclimate/ paleo-oceanographic drilling proposals. 25 potential targets appropriate for scientific drilling along the Indian

margins were identified to address the scientific objectives. Based on the discussions, a collaborative site survey proposal "Evolution of the Indian Monsoon along the Western Indian Margin and Tip of India" (WInTip) has been developed and submitted for requesting German R/V Sonne - capable of high-resolution imaging of the upper 1 second of sediment cover, multibeam mapping, and piston coring.

### 5.3.2 Exploring the largest geoid low on the earth Indian Ocean Geoid Low (IOGL)

The geoid is typically considered as a hypothetical equipotential surface that explains the geometrical irregularities of the earth. It approximates to the mean sea level and deviations of the geoid from an idealized hydrostatic ellipsoid are known as geoid anomalies. The uneven mass distribution in earth's interior is predominantly attributed to the geoid variations from place to place in terms of highs (positive) and lows (negative). The IOGL, centered near to south of Sri-Lanka, is the largest geoid low on the globe and investigations of IOGL are expected to help in understanding the dynamics of earth's interior. The main objective of the program is to find out a con-clusive point in understanding unusual structures and related mechanisms responsible for this largest geoid low, IOGL.

Due to inherent methodological limitations and almost no offshore seismological observations in this region, secrets of this perplexing anomaly remain unresolved. This program has been planned to achieve a comprehensive understanding about the nature, source and causes of the geoid anomalies in the region. In a recently concluded ocean expedition in July-August 2019 onboard ***ORV Sagar Kanya***,

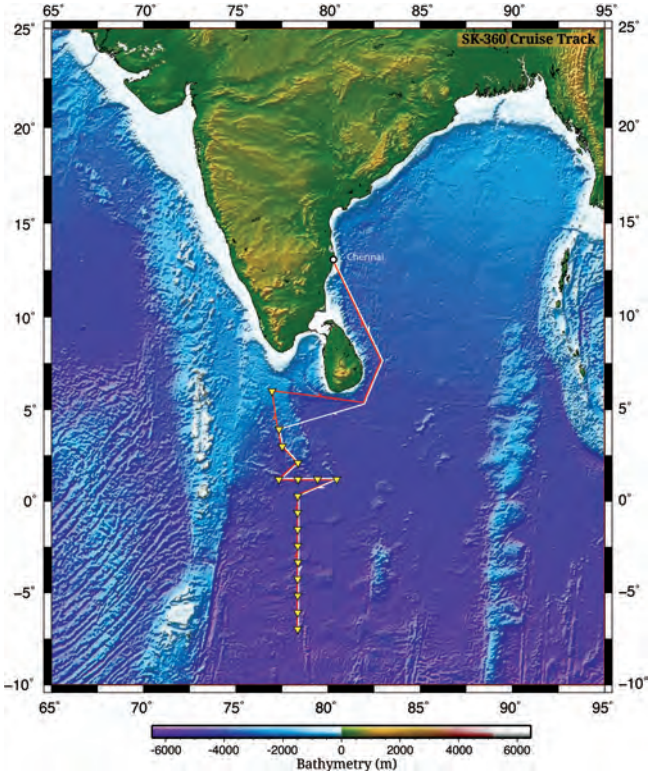


**Fig. 5.5 Cruise track of SK-360: OBS recovery and redeployment in the Indian Ocean. Solid inverted yellow triangles indicate the OBS locations.**

17 Ocean Bottom Seismometers (OBS) have been retrieved successfully which were deployed in 2018 in Indian Ocean (Fig. 5.5). The array recorded continuous marine seismological data for a period of more than 14 months. The data would be used to image the earth's mantle structure, understand and reduce the gap between the dynamics of materials beneath the surface and its surface manifestation as the Indian Ocean geoid anomaly.

To improve the resolution of the subsurface image for understanding the anomalies in a better manner, NCPOR has re-deployed all the 17 OBSs at the current location in July-August 2019 to trace events for the succeeding year.

### 5.3.3 Granulite Studies: metamorphism, melting and crustal evolution

A study on Granulite, aimed to understand the evolution of continental crust (Archean to present) and to characterize lower crustal melting in the realm of high temperature (HT)/ ultra-high temperature (UHT) metamorphism with focus on Archean cratons, Southern Granulite Terrain (SGT), Eastern Ghat Belt (EGB) and Himalaya was initiated by NCESS, Thiruvananthapuram. The study taken up around Kerala Khondalite Belt (KKB) characteri-zes partial melting process in the lower crust using phase equilibria modelling in conjunction with geochronological analysis from zircon and monazite. It suggests that a maximum of 35% granitic melt can be produced during the metamorphism of the studied gneiss at ~ 900$^0$C. The chemical ages from monazites as well as in-situ U-Pb zircon isotopic studies reveal a complex tectono-metamorphic evolution of the terrain with a dominance of Neoproterozoic ages.

The mineralogical and compositional attributes of studied amphiboles from Bundelkhand granitoids suggests similar protolith for tonalite trondhjemite granodiorites (TTGs) and high-K granodiorite granitoids (KGGs). During Paleo-Archaean, TTGs with low-K content was formed by partial melting of hydrous basalt in overthickened mafic crust. Subsequent melt-

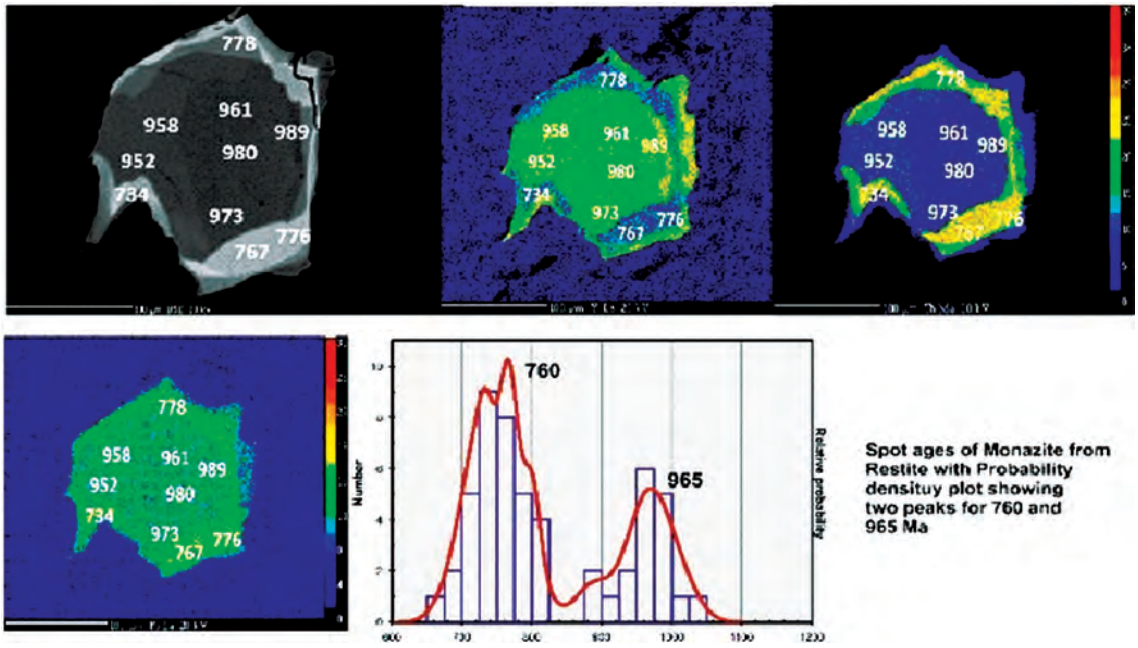


**Fig. 5.6 Unmixed ages of texturally constrained monazites**

ing of the depleted basalt led to the formation of K-rich melt leading to the crystallization of KGGs.

Petrographic observations on rocks from Chilka Granulite complex, Eastern Ghat belt suggest that sillimanite absent melanosomes are possibly representing the restite component of UHT granulites. Moreover, the abundance of coarse biotite along with porphyroblastic orthopyroxene/garnet/cordierite and plagioclase in the melanosomes also impart a restitic appearance. The unmixed chemical ages (~ 40 spots) of texturally constrained monazites shows two major age groups corresponding ~965Ma and ~760 Ma respectively; thus, suggesting the occurrence of Neoproterozoic orogeny in the eastern parts of eastern EGB, India (Figure 5.6). Monazite chemistries are also being interpreted to constrain the metamorphic event.

A new state-of-the-art Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) facility was established at NCESS for in-situ trace element geochemistry and geochronology (Figure 5.7). Installation of LA-ICPMS was successfully conducted and calibration and tuning with different internal and external reference standards are in progress.

### 5.3.4 Classification and Seasonal Distribution of Rain Types based on Surface and Radar Observations over a Tropical Coastal Station

The variation of monthly rain intensity was studied at Thiruvananthapuram using rain radar observations. The study reveals the contribution of liquid water from the four types of rainfall in all the four seasons, which indicate that the stratiform had the highest duration and convective was the highest water contributor except in the winter. A significant amount of water was from transition and mixed type. The maximum contribution was from summer monsoon during rain duration and accumulated water (rainfall), and least from post-monsoon seasons. From day-night variation analysis of rain duration and accumulated water, night rain was more intense than day rain. Also, an inverse relation between duration and accumulated water during day-night rain with seasonal variation was observed.

**Fig. 5.7 Snapshot of LA-ICPMS laboratory**

Figure 5.8 portrays an annual account of rain and its percentage of duration and events. Monthly mean rain intensity (RI) was calculated from monthly accumulated water and total rain duration. A total of 8 years (2005-2013) data from Joss- Waldvogel Disdrometer (JWD), a Micro Rain Radar (MRR) and an Atmospheric Electric Field Mill (EFM) were used for this study. If RI was greater (less) than 10 mm h-1 continuously for ten minutes or more in a rain event, this continuous section of the event was classified as convective (stratiform) type rain. Remaining part (if any) of the event was categorized as transition rain type.

### 5.3.5 Paleomagnetism and Geochemistry of the Proterozoic and Phanerozoic Igneous Units

**Gwalior and Bijawar igneous unit:** Palaeomagnetic and geochemical investigations of mafic igneous units in the Gwalior and Bijawar sedimentary basins have been carried out. Natural Remnant Magnetization (NRM) measurements and step-wise alternating field demagnetization experiments were conducted on a recent collection of 23 samples from 5 previous sites and 10 samples from a new site of the Gwalior traps. Routine rock-magnetic properties were also estimated including magnetic susceptibility measurements, Isothermal Remnant Magnetization, coercivity of remanence and thermomagnetic analysis (susceptibility vs. temperature). The detailed palaeomagnetic results are available from 8 sites (70 samples) of the Gwalior traps and 6 sites (40 samples) of the Bijawar igneous units. Detailed analysis and data interpretation are in progress.

**Deccan basalt across the Koyna drill core:** Characteristic Remnant Magnetization inclination and paleo-intensity determinations and geochemical investigations on the Deccan stratigraphic sequence along 1250 m drill-hole from the Koyna region were analyzed and synthesized. The geochemical work includes major and trace element (including rare earth

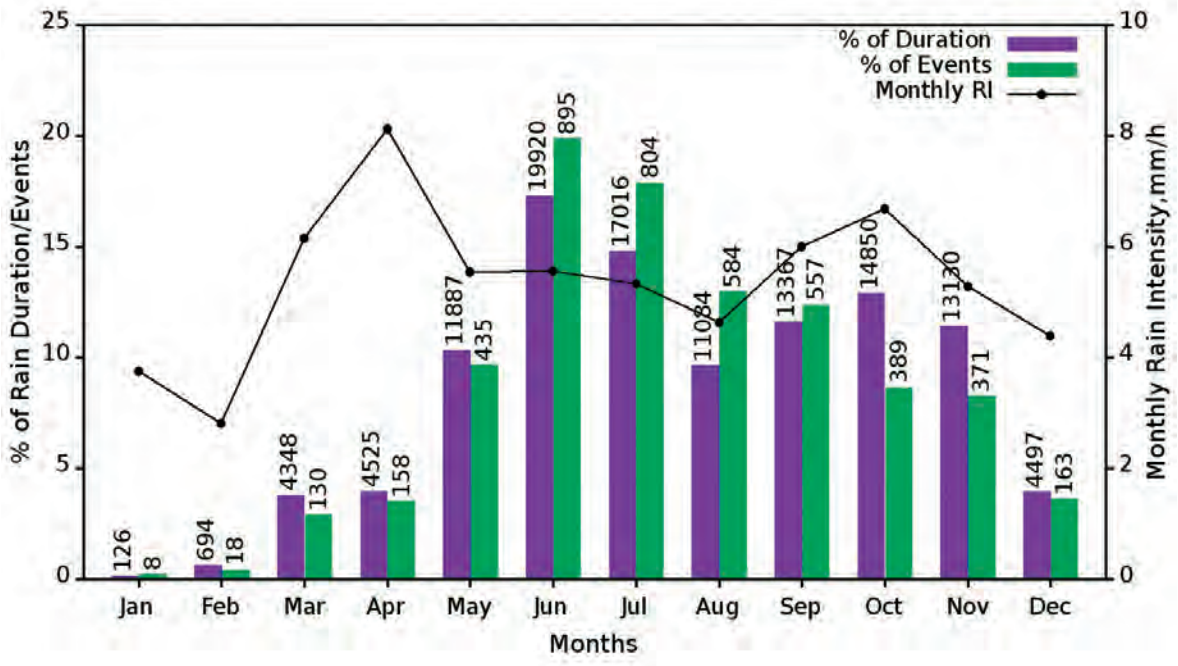


**Fig. 5.8 Monthly distribution of rain duration, number of rain events in percentage and average RI (mm $h^{-1}$). The numbers respective bars show actual duration (minutes) and number of rain events.**

element) analyses using XRF and ICPMS methods. The samples are all iron-rich sub-alkalic tholeiitic basalts in composition. Depth wise variations of selected elements show some subtle variations and that may define stratigraphic formations. More detailed analysis and data interpretation are in progress.

The paleomagnetism and geochemistry were combined with existing geological and geophysical results to explain the mechanism, chronological order and relationships between volcanism, uplift and extension/rifting along the volcanic continental margin. The study reveals that (a) igneous underplating was a cause of initial epeirogeny uplift in the Western Ghat, (b) extension/rifting followed shortly after volcanism and (c) thermal collapse and subsidence caused slumping of basalt basement below sea level, while returning to normal temperatures after the Seychelles-India breakup.

### 5.3.6 Unravelling Submarine Groundwater Discharge (SGD) zones in India – The pilot study

The discharge of groundwater to sea through coastal aquifers (Submarine Groundwater Discharge - SGD) has been recognized as small volumetrically, but quite significant ecologically because SGD offers an important pathway of nutrients, carbon and other geochemical constituents to the ocean. Knowledge of the nature of SGD allows us to estimate optimum extraction levels of potable

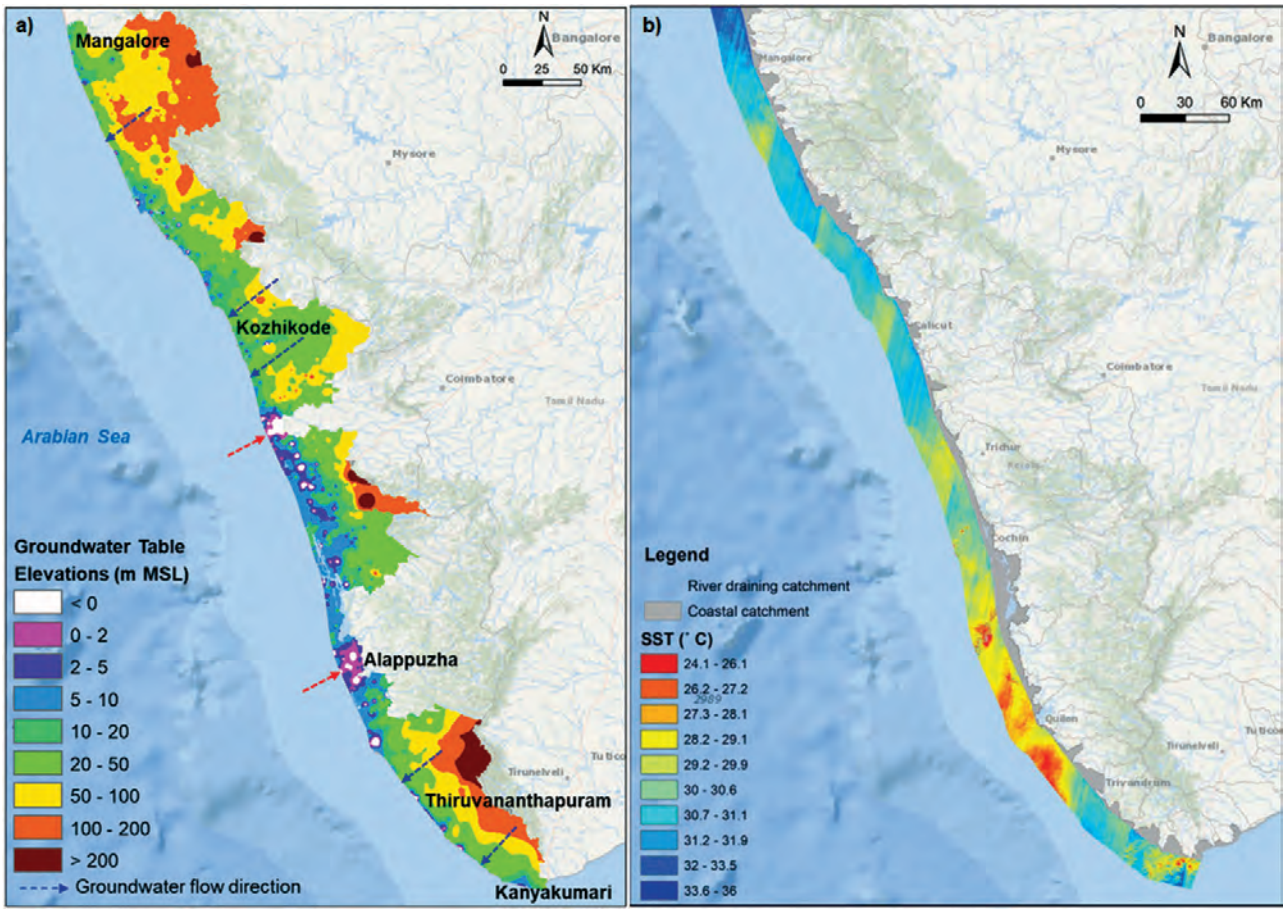


**Fig. 5.9 a) Reflection of coastal groundwater dynamics derived from archival data and b) Sea surface temperature composite from Landsat 8 imagery (Feb-March, 2019)**

groundwater and provide information on feasible waste disposal sites in coastal zones. This study is reportedly the first of its kind being taken up by NCESS on a national level for SGD flux determination in the world. Further, a comprehensive understanding of this component of the water cycle is much more relevant now due to changing climate that affects the coastal hydrology to a large extent. Main objectives of the study are (i) identification of SGD and saltwater intrusion (SWI) along the coastal zone and (ii) computation of SGD flux as well as carbon and nutrient load through submarine groundwater discharge.

To investigate the groundwater dynamics in the pilot project area, archival data from the Central Ground Water Board (CGWB) monitoring wells located across the Kerala coast were utilized to generate the groundwater level map above mean sea level. The undulating nature of the topography is reflected in the water table. The data show that elevated water table positions are seen towards the northern Kerala coast in comparison with the southern side. The high hydraulic gradient towards the shoreline provide clues on groundwater discharge to the sea in such segments. Alternatively, potential zones of seawater ingress are also visible (Fig. 5.9a).

Satellite thermal infrared imaging has been used to identify the location and spatial variability of SGD by exploiting the temperature difference between surface water and groundwater at certain times of the year, particularly summer. The satellite images have allowed mapping several thermal anomalies related to outflows of freshwater plumes with temperatures ranging from $28.2^0$C to $30.6^0$C which is correlated based on the pore water temperature in the study area (Fig. 5.9b). The still lower values of SST in shallow sea could be due to upwelling phenomenon. The image clearly shows spatial variability in SGD along the beach face, information that is extremely valuable in designing appropriate field sampling campaigns.

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# Chapter 6 RESEARCH, EDUCATION, TRAINING AND OUTREACH (REACHOUT)

To fulfil the primary mandate of the Ministry, 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 man-power, 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)

VI. MoES Knowledge Research Centre Network (KRCNet)

## 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. During the current year, a total number of 39 proposals have been sanctioned as shown in the table below.

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

- **Investigation of alternative atmospheric layer scaling properties over complex terrains of Himalaya by GB Pant Institute of Himalayan Environment & Development, Almora**

  The aim of the project is to assess and compare the turbulent eddy size distribution of atmospheric surface layer over two orographic sites. Data from a third flat site (Varanasi) was also used for the study. Four research papers have been published under this project and one student has been appointed as a Junior Research Fellow.

| | Atmospheric Sciences | Ocean Sciences | Geosciences | Seismology | Cryosphere & Hydrology |
|---|---|---|---|---|---|
| Number of proposals | 1 | 4 | 16 | 7 | 5 |

- **Tropospheric and lower stratospheric processes over northern Arabian Sea and their influence on the variability of Indian Summer Monsoon by National Institute of Oceanography, Goa**

  The main aim of the aforesaid proposal was to understand the troposphere-stratosphere interaction and its effect on surface air-sea interaction processes during the onset and active/break phase of monsoon. Under the project, 5 research papers were published and one student was awarded Ph.D. degree.

- **Geodynamics of crustal accretion, growth and related mineralization across the craton-Eastern Ghats Belt contact: an integrated geological and seismic investigation by IIT Kharagpur-Completed**

  Under this project, the Eastern Ghats Mobile Belt (EGMB) and the adjacent Archaean craton contact collisional sutures zones in south-eastern India were investigated for seismological and geological parameters to decipher the major crustal and lithospheric structure of the region. Based on the 27 broadband seismic stations installed along two distinct profiles covering cratons and Eastern Ghats contact boundaries, high resolution seismic images were obtained. One student was awarded Ph.D. under this project.

- **Exhumation and Denudation history of the western and central Arunachal Himalaya - Low Temperature Thermochronology Investigation by IIT, Bombay- Completed**

  The first in-situ thermochronological results based on 197 samples from the study area highlight the stages of growth of the Eastern Himalaya in the study region. Thermochronometric ages from Siang valley samples provide constraints on the timing of duplex formation and passive thrusting of the overlying thrust sheets as also on the development of a tectonic-erosion feedback in the valley post Pliocene. Data from the Mishmi hills are the first report of thermochronometric age constraints from the region. Under the project, 4 M.Sc. dissertations, 6 M.Tech. dissertations and 2 Ph.D.s were awarded.

- **Biogeochemical and Atmospheric Changes during Archean-Proterozoic Transition: Geochemical and Isotopic studies from greenstone belts of Dharwar craton and Cuddapah basin** by NGRI, Hyderabad-Completed

  Precambrian biogeochemical processes were studied through the geochemical and isotopic signatures of Archean and Proterozoic stromatolitic carbonates to understand the paleoenvironment and atmospheric changes. Three greenstone belts of Dharwar Craton and two areas from Cuddapah basin were chosen for studying the Archean and Proterozoic stromatolites respectively. Two Ph. D. have been awarded under this project.

- **A 100 Ka Glaciation-deglaciation history of Ladakh: its comparison with Satluj valley and signatures in the alluvial plains of NW India by University of Delhi, Delhi.**

  The project aims to work out the Late Quaternary stratigraphy, chronology of the glaciations and impact of Himalayan climate on landscape development besides drainage landscape evaluation in the northern margin of the Thar Desert.

Comparative drainage evolution and late quaternary drainage reorganization for the extinct Saraswati river was done and radiocarbon dates from Rakhigarhi (Haryana) established it to be of middle Harappan age.

- **Measurements and Modeling of Evapo-transpiration and other Hydrological Processes in Lesser Himalayas by National Institute of Hydrology (NIH), Roorkee.**

  The project aims to monitor evapotranspiration (ET) by using eddy covariance tower and ET modeling for Lesser Himalayan region. Under this project, the catchment response to various hydroclimatic forces within Lesser Himalayan was evaluated using water balance studies. Hydrological modeling has been studied for better assessment of climate-hydrological interactions in the Lesser Himalayan catchment and future hydrological response under changing climate.

- **Study of solute transport parameters through porous medium by Indian Institute of Technology (IIT), Mandi.**

  This project deals with the study of chemical transport through porous media. Linear sorption isotherm and scale dependent dispersion coefficient have been developed from the numerical codes of various equations. Batch sorption studies for soil fluoride have been conducted and experiments with candle soot to extract fluoride from solution phase are being explored.

- **Development of remote sensing based method for the rapid reconstruction of time series of formative water discharges of the Ganga and Bramaputra rivers in the Himalayan foreland by Indian Institute of Science Education and Research (IISER), Bhopal.**

  This work aims to establish a width-discharge regime relationship for the Ganga Brahmaputra Rivers based on field measurements and thereafter in the estimation of their discharges from channel width measurements. Acoustic Doppler Current Profiler was used to measure the hydraulic geometry of the river channel. Channel depth and flow velocity were measured at regular intervals in a channel section.

- **Estimating Mass balance of glaciers in the Bhaga Basin, Western Himalaya using GPR and Remote Sensing methods by Jawaharlal Nehru University (JNU), Delhi.**

  This project targets to calculate total glacier mass balance in the Bhaga basin using multiple techniques and will elaborate upon the effect of Climate Change on Indian Western Himalayan Glaciers. Water storage in and runoff from glaciers have been studied to denote subglacial drainage system evolution. Thus, this study will be helpful in highly rugged Himalayan terrain where continuous field monitoring is difficult, time consuming and economically unviable.

- **Velocity model of Northwestern India by IIT, Bombay**

  Under the project, surface wave and body wave tomography was carried out to image the lithospheric structure beneath the Malani Igneous Province (MIP) adjoining the Aravalli fold belt in northwestern India. The regional and teleseismic data utilized

was acquired by a network of broadband stations deployed in phases in an area of 300 x 300 sq. kms. in MIP during the period 2011-2017.

- **Delineation and characterisation of the various fault systems in Kachchh and Saurashtra by M.S. University, Baroda**

  A study on neotectonic evolution of active faults in Kachchh and Saurashtra was carried out. Results reveal that neotectonic deformation in Kachchh comprises dominantly of vertical movements along the E-W trending faults due to compressive stresses, however, future earthquake nucleation is most likely to be in the zones where the E-W trending faults intersect with the transverse faults.

- **Characterisation of active faults in the watersheds of Kosi and Ramganga in Kumaun Himalaya, Uttarakhand by Kumaun University, Nainital**

  A total of 28 sub-basins in Kosi watershed and 40 sub-basins in Ramganga (west) catchment for comparative analysis were identified after delineating the drainage pattern from digital elevation model. Morphotectonic analysis has been carried out to draw a better understanding of the relationship between active-tectonics and its geomorphological imprints confirmed by extensive field work particularly in selected transects.

- **Seismic Microzonation of the Bhuj City (Kachchh), Gujarat by ISR, Gandhinagar**

  The seismic microzonation of the Bhuj city (area 56km$^2$) has been accomplished considering seismological, geophysical, geological and geotechnical parameters. The multi-channel analysis of surface waves (MASW) survey at 19 sites and microtremor survey at 42 sites were completed. The geotechnical aspect was covered with drilling of 28 boreholes down to 3 to 21m depth. Various maps including geology and tectonic map of Bhuj city (scale 1:2000) were generated and the surface strong ground motion was estimated.

- **Site characterization and attenuation studies for Garhwal-Kumaun Himalaya and Delhi region by IIT, Roorkee**

  Under the project, site characterization and study of local site effects at 54 strong motion stations located at Uttarakhand and western Uttar Pradesh and 19 strong motion stations sites in Delhi were completed. Using the data collected from the field tests, numerical studies, and earthquake data, a Ground Motion Prediction Equation (GMPE) has been formulated for the region. The developed GMPE is found to be performing well compared to the existing models.

- **Bioinventorying of higher marine fungi colonizing decom-posing mangrove plant substrata in Muthupet, Tamil Nadu, East coast of India** by Pondicherry University – Completed.

  Under this project 78 species of marine fungi were recorded. The study led to discovery of 4 new genera and 24 new species. Twenty-three marine fungal cultures were deposited in the National Fungal Culture collection of India, ARI, Pune. Under this project 7 papers have been published.

- **Heavy metal flow in the Marine food web of Muthupettai Mangrove Ecosystem, East**

**coast of Tamil Nadu** by Bharatidasan University, Tiruchirapalli - Completed.

Under this project, the concentration of heavy metals (Cu, Cd, Pb and Zn) in Muthupet mangroves were studied in both biotic (all biological organisms) and abiotic components (Water and sediment). Seasonal variation of heavy metal concentration was observed throughout the study period. Among the metals studied, Pb was the primary pollutant in the ecosystem followed by Zn, Cu and Cd. Total 4 papers were published and one Ph.D. was completed.

### 6.1.1 Earth System Science and Technology Cells (ESTC)

Presently work on following three ESCTCs is being carried out with active participation of MoES institutes:

a) ESTC on **Satellite Meteorology:** Lidar inversion algorithm was developed to derive the backscattering coefficients and extinction coefficients. Atmospheric aerosol (Backscattering coefficients, extinction coefficients, and depolarization ratio), atmospheric boundary layer height and vertical cloud distributions of the clouds were generated over the period 2016-2018. Also, the comparison of the ABL height between MPL and GPS RO is carried out for the period 2016-2018. In total 25 simultaneous GPS RO and MPL observations within $0.5^0$ x $0.5^0$ latitude X longitude is obtained.

b) ESTC on **Coastal and Ocean Technology:** Experimental investigation were carried out to study the effect of net horizontal forces acting on the test model in comparison with theoretical formulae (Goda; Sainflou). It is observed that 'Goda' formula underestimates the wave forces, whereas 'Sainflou' overestimates the wave forcers in comparison with experimental values.

c) ESTC on **Marine Biotechnological Studies:** Work is being carried out on the implications of engineered nanoparticles and bionanocomposites on aquatic animal health; Surface modification nanotechnological approach for antifouling and anticorrosion applications; Enhancement of marine microbial by-products for biomedical applications; Biofunctionalization nanoparticles for anticancer applications using marine bio-sources; Isolation and identification of bioactive compounds from marine sponges for white spot syndrome virus control.

### 6.1.2 Human Resource development & Capacity Building

- Memorandum of Understanding (MoU) for continuation of User-oriented M.Tech. programme on Ocean technology at IIT Madras was extended for 5 more years.
- Memorandum of Understanding (MoU) was renewed for continuation of Human Resource Development through Sponsorship of M.Tech and PhD students in Atmospheric-Oceanic Sciences & Technology at IIT Delhi.
- The Indo-Norwegian Fellowship Program was supported under the MoU signed between Norwegian Polar Institute (NPI) and National Center for Polar and Oceanic Research (NCPOR). Two selected students will work in the area of Arctic ocean modelling and Antarctic glaciological studies. The students will be jointly

supervised by researchers at NPI, NCPOR and the approved University in Norway, where the students would be registered for Ph.D.

## 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 subject areas relevant to the mandate 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 21 Exhibitions. The Ministry's pavilion at the Indian Science Congress-2019 has been adjudged as "Most Interactive". The Ministry's pavilion at India International Trade Fair 2019 has been adjudged First for excellence in Display and was awarded the "Gold Medal".


**MoES Pavilion at the Indian Science Congress 2019**


**Ministry's pavilion at ISC 2019 has been adjudged as 'Most Interactive'**



**MoES Pavilion at India International Trade Fair 2019, New Delhi**

### 6.2.2 Earth Day Celebration-2019

The theme for the "Earth Day" celebrations on 22nd April 2019 was as "Protect our Species". Various competitions like drawing and painting, debate, essay writing, etc. for various age groups were organized at 43 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.




**Competitions for "Earth Day" celebrations on 22nd April 2019**


**The Indian team with mentors and observers at the 13th International Earth Science Olympiad (IESO) at Daegu, Republic of Korea.**

### 6.2.3 Participation in International Earth Science Olympiad

The Ministry had sponsored the participation of Indian contingent in the 13th International Earth Science Olympiad, organized during 26th Aug-3rd Sept. 2019 at Daegu, Republic of Korea. Children from **41** Countries and 43 teams participated in the event. Indian team won ten medals (Gold medals-3, Silver medals-4 and Bronze medals-3).

### 6.2.4 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, 91 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.

### 6.2.5 MoES Foundation Day

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27th July 2019 at the Vigyan Bhavan, New Delhi. Dr. Harsh Vardhan, Honourable Union Minister for Sciences & Technology, Earth Sciences and Health & family Welfare was the Chief Guest. The foundation day lecture was delivered by Dr. Peter Molnar, Distinguished Professor, Geological Sciences, University of Colorado, USA.

**Dr. Harsh Vardhan, Honourable Union Minister for Sciences & Technology, Earth Sciences and Health & family Welfare was the Chief Guest at the MoES Foundation Day.**

This year the Life Time Excellence Award was awarded to Professor J Srinivasan, for his wide range of contributions to climate science. The National Awards for Ocean Science & technology was presented to Dr. Doraiswamy Shankar, NIO, Goa. Prof. S. K. Sateesh, IISc,



**Secretary, MoES and Dr. Peter Molnar, Distinguished Professor, Geological Sciences, University of Colorado, USA addressing the gathering on MoES Foundation Day**

Bengaluru received the National Award for Atmospheric Science & Technology. The National award for Geoscience & Technology was presented to Prof. G.V.R. Prasad University of Delhi. Dr. C. Manikyamba, NGRI, Hyderabad received the National award for the women scientist. The Young Researcher Awards was presented to Dr. Ruma Antony, NCPOR, Goa; Dr. Abhishek Saha, NIO, Goa, Dr. Prashant Kumar, SAC, ISRO, Ahmedabad for their outstanding work in Earth Science & Technology. In addition, certificates of merit were also presented to scientists from different institutions of MoES. The winners of Silver Medal and Bronze Medal of 12th International Earth Science Olympiad (IESO) and Earth day painting competetion winners were also felicitated during the function.

## 6.3 BIMSTEC- CENTER FOR WEATHER AND CLIMATE (BCWC)

BCWC was established at NCMRWF following a Memorandum of Association (MoU) signed between MoES, India and BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Member countries. The activities of BCWC include (i) operational forecast products for the region, (ii) Training Workshops, capacity building, and (iii) enhancing observing system for BIMSTEC region for both process understanding and forecast skill improvement.

Four scientists from National Centre for Hydrology and Meteorology (NCHM) and Agriculture Research and Development Centre (ARDC), Bhutan visited BIMSTEC Centre for Weather and Climate (BCWC), NCMRWF for two weeks during 12-26 Dec 2019 for training on model outputs and also to have discussions on model based product development for weather and Agriculture applications for Bhutan region. The training and discussions were aimed at upgrading visitor's knowledge in usage of model products in medium and extended range fore-casting of weather, agriculture planning and decision support. The basic of modelling and data assimilations were also covered during the training.

## 6.4 INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANO-GRAPHY (ITCOocean)

The ITCOocean continued its operations using the state-of-the art facilities of INCOIS, Hyderabad. During January - till date 159 persons

were trained of which 121 are from India and 38 from 19 other countries. The newly constructed ITOoocean building along with facilities for faculty, students was handed over to INCOIS and classes will commence in this building starting from 2020.

In total 12 courses are conducted during the period, which covered various topics like remote sensing of marine phytoplankton, discovery and use of operational ocean data products and services, Coastal Vulnerability studies using QGIS, Ocean color remote sensing, IOCINDIO workshop etc. This year, 3 courses on self fund basis were conducted. Good response was received for these courses. Also there were training sessions conducted exclusively for officers from Indian Coast Guards and National Hydrography Office. The Governing Body of Category 2 Center is formed with the approval of MoES and the first meeting of the Governing Body is planned to be held in the first week of January 2020.

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

Development of Skilled manpower in Earth System Sciences (DESK) was initiated to create a large pool of trained and dedicated multidisciplinary earth system and climate research manpower in the country. Under the MoES Research Fellow program (MRFP), first batch of 27 Junior Research Fellows (JRF) have joined on 16th September 2019 and are undergoing the initial six-months mandatory training at IITM. Also, about 16 short and medium duration courses/workshops and lectures were organised on specific or targeted areas of skilled manpower development as well as for education, research and operational organizations in the country.

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# CHAPTER 7 | INTERNATIONAL COOPERATION

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.

## 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. The Statement of Intent (SoI) on the collaboration under NOAA-MoES Technical cooperation on "Development of Predictive Capabilities on Marine Fisheries and Harmful Algal Blooms (HAB)" was extended for further three years with effect from 16th Aug 2019 to 15th August 2022. An Indo-US Science workshop on Moored buoy Data Analysis was conducted at NIOT, Chennai from 02$^{nd}$-05$^{th}$ July 2019. Fifteen mentors from premier institutions in India and abroad and thirty students from fifteen institutions participated in the workshop.

Some of the significant outcomes of the cooperation with NOAA are given 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. During the reporting period, 3 RAMA cruises have been undertaken for 84 days covering 11166 NM which included 46 deployments, 19 retrievals and 10 CTD operations.
- **Technical cooperation for the study of dynamical short range, extended range and seasonal prediction for Indian summer monsoon rainfall -** Under this IA, dynamical prediction systems have been set up for seasonal, extended-range and short range dynamical predictions with specific emphasis on monsoon variability. 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 2019 Monsoon desk provided technical support in many model development activities.
- **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. The coupled version of Hurricane WRF (HWRF) with two different ocean models POM

(Princeton Ocean Model) and HYCOM (HYbrid Cordinate Ocean Model) have been implemented in 2019 for real-time forecasting of the tropical cyclones over the North Indian Ocean.

## 7.2 Cooperation with United States Geological Survey (USGS)

Under the Memorandum of Understanding (MoU), signed between MoES and USGS on 1st November 2018, a list of probable topics/ projects for joint cooperation have been shared with USGS in June 2019, which include Tsunami modelling and coastal processes. These topics will be undertaken through various modes such as exchange of technical information, visits, training, and cooperative research consistent with ongoing programs of both MoES and USGS.

## 7.3 Cooperation with UCAR

In line with the joint activities outlined in the MoU, a few US scientists visited IITM Pune from the National Center for Atmospheric Research (NCAR), for capacity building to develop air pollution prediction systems for Delhi. A joint collaboration between MoES and UCAR has resulted in the development of an early warning system for Air Quality at Delhi which was launched on 15 October 2018. The high-resolution Air Quality Early Warning System for Delhi has since been made operational. The warning system also provides an air quality forecast for a few more cities in the northern region of India at 1 km resolution.

## 7.4 Cooperation with UK Met Office (UKMO)

### 7.4.1 Consortium Agreement

The Consortium Agreement signed in 2016 with UKMO core partners for weather and climate forecasts was renewed for a further period of 5 years, till 2024. The UM partners participated in the "celebration of Science and Service Delivery from the UM Partners from the last 5 years" on 5th March 2019 at Wellington, New Zealand 2019. Two meetings of the Unified Model Partnership namely, "Reducing the Risks from Weather and Climate: The Global Unified Model Partnership "and UM Partner Board Meeting were held in Wellington, New Zealand during 5-6 March 2019. Next Generation Modelling System and a GC Teleconnections workshop was conducted during 24-26 June 2019 in London alongside a special session of UM partner board meeting during 19-20 June 2019. NCMRWF developed and implemented the latest UM based Hybrid 4D-Var global data assimilation system with all sky radiance assimilation capabilities. UM Partnership in collaboration with US Air Force & NCAR has organized the 4th Convective Scale Modelling Workshop at NCAR, Boulder during 28-31 January 2020. Six scientists from various units of MoES have participated in the workshop.

### 7.4.2 MoU with UK Met Office

The Statement of Intent signed between MoES and the UK Met office on 22nd March 2018 to jointly develop weather and climate science for efficient delivery of climate services, was converted into an MoU between Ministry of Earth Sciences and Met Office, United Kingdom on Cooperation in Weather and Climate Sciences. Following the signing of the MoU, an Implementation Agreement on WEATHER AND CLIMATE SCIENCE FOR SERVICE PARTNERSHIP INDIA **(WCSSP India)** has been signed between MoES and UK Met Office on 7th February 2019. A science plan consisting of 3 work packages was finalized with a focus on enhancing our capabilities in modelling high impact weather

and inform services that help reduce exposure to damaging weather and climate impacts like the flooding during the South Asian summer monsoon, lightning and landslides; tropical cyclones bringing heavy rains, storm surges/flooding and strong winds; drought; hail and dust storms.

An "Impact Based Forecasting" workshop was organized at IITM Pune during 29-30 November 2019-20 with an aim to provide an overview of the current research being undertaken within this field in India and the UK. A WCSSP Programme Science Workshop was hosted by the Department for Business, Energy and Industrial Strategy in London during September 23-24 2019 with an aims to bring together partners of WCSSP to share scientific highlights, facilitate knowledge sharing and explore ways to maximize the benefits and scientific advances across the whole programme.

## 7.5 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 further by a period of five years in August 2018. The progress on the ongoing three IAs signed under this MoU is as follows

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

The APHH-India programme "Atmospheric Pollution and Human Health in an Indian Megacity" includes 5 well-coordinated and cross-cutting research projects, involving 4 Agencies from UK and India, with 4 years duration and with the main focus on the megacity New Delhi. While the observational part is mostly completed, laboratory analysis work is in progress. An international workshop with various stakeholders is planned in March 2020 to synthesize the results obtained.

### 7.5.2 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 project "*Up-scaling catchment process for sustainable water Management in Peninsular India (UPSCAPE)*" aims 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. The 2nd project "*Coupled Human and Natural Systems Environment (CHANSE) for water management under uncertainty in the Indo-Gangetic Plain"* aims to build understanding of the hydrologic response of the coupled human-natural system of the Indo-Gangetic Plain (IGP) to current and future climate and anthropogenic pressures. The 3rd project entitled *Sustaining Himalayan Water Resources in a changing climate (SusHi-Wat)* envisages how water is stored in, and moves through, a Himalayan river system (Beas and Sutlej catchments) in northern India at daily to decadal timescales and to use the resulting insights to develop and test a robust model of the whole system that can be used to inform current and future decision makers to support the sustainable development and management of the region's water resources.

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

The progress of the "India-UK Virtual Joint Centre on Water Security" (IUKWC) was reviewed in the 4th meeting of the Steering Group held on 17th May 2019. Since its inception,

the Centre has convened four Science Workshops; supported thirteen Researcher Exchanges (eight Junior scientists and five Senior scientists); funded three Pump Priming projects; organised one User Engagement Initiative (UEI); and run two Grassroots Field Exposure Sessions (GFES). The IUKWC has produced six water briefs and eight activity reports. The membership of the network has grown over the 3 years with membership of more than 800.

## 7.6 Cooperation with Belmont Forum Countries

MoES is a member of the Belmont forum which is a group of the world's major and emerging funders of global environmental change research and international science councils. MoES signed a MoU in February 2013 to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. During the 13th Plenary meeting held in London, MoES agreed to participate in the Collaborative Research Action (CRA) on "Trandisciplinary Research for Ocean Sustainability" proposed by Sweden. Two meetings of Panel of Experts selected 2 proposals with Indian PIs for funding by MoES out of a total of 11 proposals. The 14th Plenary meeting was held at Taipai, Taiwan during 23-25 Oct 2019. MoES was elected as the steering committee member of the Belmont Forum for a 3 year term starting 1 January 2020. Prior to this, the Belmont Forum celebrated its 10th Anniversary during 21-22 October 2019 at Taipei, Taiwan with participation from more than 25 member countries.

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

Following the first Governing Board meeting held at BIMSTEC center for Weather and Climate (BCWC) being hosted by NCMRWF during 30-31 July 2018 and India being declared the Chairman of the Governing Board for the first term, several BIMSTEC nations have approached NCMRWF for the weather and climate products and capacity building. The BCWC has carried out capacity building of three scientists from National Center for Hydrology and Meteorology, Bhutan with an aim to upgrade their knowledge in the medium range forecasting for agriculture planning and decision support. The 1st BIMSTEC- Intergovernmental Expert Group Meeting on Disaster Management is planned by the National Disaster Management Authority during 14th Feb 2020 at Puri, Odisha.

## 7.8 Cooperation with Norway

Following a joint call with RCN Norway in Feb 2015, 5 projects under Climate System in Polar regions and 3 projects under Geohazards 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. The MoU, which

completed its term in October 2019 has been now extended by a further period of 5 years.

## 7.9 Cooperation with European Union: Horizon 2020

Under the framework of the India-EU Science and Technology Cooperation Agreement, Ministry of Earth Sciences (MoES) and the European Commission (EC) have established a co-funding mechanism (CFM), to support projects on climate change and polar research.

Under the call *LC-CLA-08-2018,* one project namely, *Our common future ocean in the Earth system – quantifying coupled cycles of carbon, oxygen, and nutrients for determining and achieving safe operating spaces with respect to tipping points (COMFORT)* has been selected for funding and will be implemented by NANSEN ENVIRONMENTAL RESEARCH CENTRE (INDIA) LTD as Indian partner.

## 7.10 Cooperation with UNESCO/IOC

### 7.10.1 The International Training Centre for Operational Oceanography (ITCOocean)

The International Training Centre for Operational Oceanography (ITCOocean) was upgraded to UNESCO Category 2 center (C2C) in May 2018 with the state-of-the art facilities at INCOIS, Hyderabad. So far, over 1104 scientists including 844 from India and 260 from 38 other countries have been trained at this centre in various aspects of operational oceanography. International training course on Coastal Vulnerability Mapping and analysis using GIS and QGIS techniques was successfully conducted during 26$^{th}$ to 30$^{th}$ Aug 2019 in ITCOocean at INCOIS. Thirty seven participants including 13 international participants from 11 countries attended the course. Training course on Marine Meteorology and Operational Ocean State Forecasting was also conducted by ITCOocean during 17$^{th}$ to 21$^{st}$ June 2019.

### 7.10.2 LoI between India and UNESCO on cooperation for reducing disaster risks and capacity building in the Earth-Sciences

As per the agreement signed on 25$^{th}$ Nov 2014, India had launched the first International Indian Ocean Expedition-2 (IIOE-2) in December 2015. A Joint Project Office was established at INCOIS, Hyderabad. A number of activities have been initiated which includes exchange of ideas of scientists active in the Indian Ocean. An International Indian Ocean Science Conference - 2020 (IIOSC-2020) is proposed to be organized during 16-20 March 2020 at Goa marking 5 years of IIOE-2 to highlight the scientific achievements under IIOE-2 during this period.

## 7.11 Cooperation with International Seabed Authority (ISA)

### 7.11.1 Contract with ISA on extraction of Polymetallic Nodules

Under the exploration contract, geo-statistical assessment is completed and is under review. Environmental Impact Assessment Statement is under preparation based on the acquired data. Research and development in extractive metallurgy is continuing. Work is continuing for developing mining system in a stage-wise manner. The extraction of target metals viz. Copper, Nickel, Cobalt have been demonstrated in semi continuous pilot plant at Udaipur. Research and development in extractive metallurgy is continuing. India organized a side event on 17th July 2019 during the 25th session of International Seabed Authority at Kingston, Jamaica and projected the work carried out pertaining to exploration of deep sea minerals

including Polymetallic Nodules in last four decades.

### 7.11.2 Contract with ISA on extraction of Polymetallic Sulfides

Under the 15-year Contract of Government of India with ISA for exploration on Polymetallic sulfides signed in September, 2016, the work on exploration of hydrothermal sulfides is continuing. Marine geophysical Surveys have been carried out and work on environmental baselines is progressing. Cruises have been under-taken in Central Indian Ridge near Rodrigues Triple Junction point in the area allocated to India to explore the areas of hydrothermal vents. The geophysical and oceanographic data are being collected along with rock samples.

## 7.12 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. Following a joint workshop in 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. The model results obtained from JAMSTEC and IITM model to understand the predictability of Indian Ocean Dipole, ENSO, Monsoon and interactions among them were exchanged between JAMSTEC and IITM for inter-model comparison.

## 7.13 Cooperation with International Continental Scientific Drilling Programme (ICDP), Germany

The Membership of MOES with the ICDP 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 (i) Results of study on formation of fluids/gases in the Koyna pilot borehole have been finalized jointly with ICDP, and published in the international journal Geofluids in September 2019 (ii) Instrumentation of Koyna pilot borehole for long term monitoring is planned with technical support of ICDP.

## 7.14 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. This was extended for a period of 5 years from 1st October 2013 to 30th September 2019. The MoU has been further extended for a period of four years until 30th September 2023. As part of the MoU, Indian scientists have been participating on various IODP expeditions. 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. A site survey proposal entitled "IODP drilling on the southern-western Indian

margin (SWIM) for Neogene-Quaternary records of monsoon climate, oceanographic and tectonic changes" was prepared in collaboration with international scientists and submitted to IODP. This collaborative site survey proposal has recently been reviewed with a ranking of very high to excellent.

## 7.15 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. Nepal and Somalia became the 21st and 22nd Member States respectively by signing RIMES Cooperation Agreement during 2019. Twenty-six other countries that are collaborating under RIMES are in the process of completing the formalities of Agreement signing. RIMES facilitated organizing 14th and 15th South Asia Climate Outlook Forums (SASCOF) at Kathmandu, during 22-23 April 2019 and at Thiruvananthapuram, 23-25 September 2019 respectively. RIMES also facilitated conduct of Monsoon Forums in Myanmar, Papua New Guinea, Cambodia, Timor Leste, Sri Lanka, Nepal, Bangladesh and Bhutan during the current year.

## 7.16 Cooperation with Argentina

A Memorandum of Understanding (MoU) on "Antarctic co-operation" between the Ministry of Earth Sciences and the Ministry of Foreign Affairs and Worship of the Argentine Republic was signed on 4th April 2019. The potential areas of scientific and logistic cooperation under the MoU were discussed with the delegation of Argentina during the Antarctic Treaty Consultative Meeting held in Prague, Czech Republic during 1-11 July 2019.

## 7.17 Cooperation with China

In December 2015, the 1st Joint SOA-MoES Workshop was held in Guangzhou to identify the areas of cooperation particularly in the field of polar research, Marine science and ocean observations. Accordingly, the 1st Joint Committee Meeting (JCM), constituted to review implemen-tation and to screen joint project proposals on yearly/half yearly basis, was held in Beijing, China on 17th May 16. The JCM approved a set of 8 projects for long term sustainable cooperation between China and India.

### 7.17.1 MoU between India and China concerning cooperation in the field of earthquake sciences and earthquake engineering

The MoU between India and China was signed on 15th May 2015 for a period of 5 years. First Joint Indo-China Committee meeting was held in January 2016 in New Delhi. A joint call for proposal covering specific themes was agreed upon. Draft implementation mechanism sent by MoES has been agreed to by China Earthquake Administration (CEA). CEA, China has requested MoES for a one to one in-person interaction to discuss the strategy for generation and implementation of joint projects.

## 7.18 Collaboration with Sweden

A Letter of Intent between India and Sweden on Mutual collaboration in Polar & Ocean Research was signed between NCPOR and Swedish Institute of Space Physics (IRF) on 1st June 2015 for collaboration in Antarctica on Atmospheric Research. Under this collaboration,

the Movable Atmospheric Radar for Antarctica was set up and is currently in operation at Maitri station. The data from the Movable Atmospheric Radar is being analysed to study the atmospheric boundary layer processes over Maitri station, Antarctica. An MoU on cooperation in Polar Science with Ministry of Education and Research of the Kingdom of Sweden was signed on 2nd December 2019 during the visit of The Majesties of the Kingdom of Sweden to India. The MoU covers scientific, technical and infrastructural collaboration in Polar research.

## 7.19 Himalayan Science Council meeting under the BIMSTEC

The First Meeting of the BIMSTEC National Security Chiefs held in India on 21st March 2017 decided to establish a BIMSTEC Expert Group to prepare a Concept Paper and a Plan of Action with regard to the establishment of Himalayan Science Council. Accordingly India had prepared a draft Concept paper and circulated to all member countries.

The First Workshop of Experts on Himalayan Science Council(HSC) was held during 05-06 December 2019 in Goa, India at the invitation of the Government of India. Director, NCPOR chaired the meeting. The delegations from the People's Republic of Bangladesh, the Kingdom of Bhutan, the Republic of India, the Republic of the Union of Myanmar, Nepal, the Democratic Socialist Republic of Sri Lanka and the Kingdom of Thailand attended the workshop. In order to highlight the scientific activities that can be taken up under HSC, several invited talks were held on various topics namely Glaciology and Hydrology, Geosciences and Hazards, Oceanography and Environmental Studies, Meteorology and Atmospheric Sciences. The workshop also discussed the Concept Paper on establishment of HSC under the BIMSTEC" drafted by India and circulated by the Secretariat on 23rd March 2017. In principle, all member states agreed to establish the HSC.

## 7.20 Cooperation with Pacific Island countries

**Setting up an "Institute for Sustainable Coastal and Ocean Research" in Fiji/Papua New Guinea a part of Forum for India Pacific Islands Cooperation (FIPIC)**

A delegation with subject experts from the National Centre for Coastal Research (NCCR), Centre for Marine Living Resources and Ecology (CMLRE) and MoES, Government of India visited Fiji and Papua New Guinea (PNG), on the behest of MEA, on a scoping mission from 22nd to 26th July 2019 for understanding the requirements, identification of the location and suitable partners, establishment of the facilities/infra-structure in the proposed countries. The Indian delegation discussed various aspects of ocean and coastal research and identified some of the gap areas of research, potential partners, establishment of the facilities/infrastructures and capacity building of manpower at Fiji/ Papua New Guinea which will serve all the member countries in the Pacific Island countries for sustainable management of the coastal/ocean resources and research. Based on the discussions, field visit and interaction with the Ministers and senior Government Officials, the scoping mission has recommended setting up an " Institute for Sustainable Coastal and Ocean Research". The detailed organizational structure, financial model of support and manpower requirements of the proposed institute are being worked out with MEA and High Commissions at Fiji and PNG.

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# Chapter 8 | Publications, Awards and Honours

| | ACROSS | OSMART | PACER | SAGE | TOTAL |
|---|---|---|---|---|---|
| **Total no. of Publications** | 258 | 97 | 40 | 34 | **429** |
| Cumulative Impact Factor | 702.7 | 189.1 | 123.3 | 107.8 | 1122. 9 |

**ACROSS**

**(IITM + IMD + NCMRWF)**


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■

# CHAPTER 9 | Administrative Support

## 9.1 Citizen's Charter

| Our Commitments | | | |
|---|---|---|---|
| **S.No.** | **Our Services and Transactions** | **How we measure our performance in this area** | **Our Service Standard** |
| 1. | Weather monitoring, forecasts and warnings | Weather forecast and warning to General Public and Meteorological support for Pilgrimage, tourism, mountain expedition, sports, etc. | 06 Hrs |
| | | Agro-meteorological advisories at district level | 05 Days |
| | | Meteorological support for Civil Aviation | 30 Mins. |
| | | Rainfall Monitoring | 1 Day |
| 2. | Ocean Forecast | Fishing advisory | 24 hrs |
| | | Ocean State Forecast for General Public, Fishing, Industry and Defense/Security/Researchers | 6 hrs |
| 3. | Early warning of natural hazards | Tsunami Bulletin | 10 mins. |
| | | Earthquake Bulletin (after) | 10 mins. |
| | | Cyclone Warning Bulletin | 3 hrs |
| 4. | Processing of Proposals of holding of Seminars/ Symposia | Approval of Seminars/ Symposia proposals | 2 Months |
| 5. | Processing of extra-mural proposals | Processing of proposals from Scientists/ Scientific institutions | 6 Months |
| 6. | Payment to Vendors | Payment to vendors on submission of bills | 4 weeks |
| 7. | Processing of requests for filling of scientific positions received from various centers | Timely processing of proposals received from various centers | 4 Months |
| 8. | Grievance Redressal | Timely redressal of grievances | |
| | | (a) Acknowledgement | 7 days |
| | | (b) Final Response | 60 days |
| 9. | Release of funds to centers of the Ministry | Timely Processing of proposals received | 60 days |
| 10. | Implementation of RTI Act, 2005 | Timely disposal of applications and appeal under RTI Act, 2005 | |
| | | 1. Acknowledgement of application | 1 day |
| | | 2. Disposal of RTI application and appeal | As per RTI Act |

## 9.2 Implementation of the 15 Point Programme on Minority Welfare

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

## 9.3 BUDGET AND ACCOUNTS

(Rs. In crore)

| Sl. No. | Major Head of Account | 2017-18 Actuals | | | 2018-19 Budget Estimates | | | 2018-19 Actuals | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Revenue | Capital | Total | Revenue | Capital | Total | Revenue | Capital | Total |
| **REVENUE SECTION** | | | | | | | | | | |
| 1. | 3403- Oceanographic Research | 533.45 | 0.00 | 533.45 | 716.00 | 0.00 | 716.00 | 692.34 | 0.00 | 692.34 |
| 2. | 3425- Other Scientific Research | 53.73 | 0.00 | 53.73 | 82.63 | 0.00 | 82.63 | 102.04 | 0.00 | 102.04 |
| 3. | 3451- Secretariat Economic Services | 33.70 | 0.00 | 33.70 | 36.20 | 0.00 | 36.20 | 36.58 | 0.00 | 36.58 |
| 4. | 3455- Meteorology | 876.99 | 0.00 | 876.99 | 869.45 | 0.00 | 869.45 | 830.14 | 0.00 | 830.14 |
| | **Total (Revenue)** | **1497.87** | **0.00** | **1497.87** | **1704.28** | **0.00** | **1704.28** | **1661.10** | **0.00** | **1661.10** |
| **CAPITAL SECTION** | | | | | | | | | | |
| 1. | 5403- Capital Outlay on Oceanographic Reasearch | 0.00 | 9.96 | 9.96 | 0.00 | 15.00 | 15.00 | 0.00 | 13.16 | 13.16 |
| 2. | 5455- Capital Outlay on Meteorology | 0.00 | 45.47 | 45.47 | 0.00 | 85.00 | 85.00 | 0.00 | 73.07 | 73.07 |
| | **Total (Capital)** | **0.00** | **55.43** | **55.43** | **0.00** | **100.00** | **100.00** | **0.00** | **86.23** | **86.23** |
| | **Grand Total** | **1497.87** | **55.43** | **1553.30** | **1704.28** | **100.00** | **1804.28** | **1661.10** | **86.23** | **1747.33** |

## 9.4 Report of the Comptroller and Audit 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:

**Annexure-2**

**Report of the Comptroller and Auditor General of India**

**The number of Action Taken Notes (ATN's) 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/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 Schemes and Diversion of Funds"). | NIL | NIL | NIL | NIL |
| 2 | 2014 | NIL | NIL | NIL | One (Para No. 5.2 of Report No. 27 of 2014 on "Irregular Payment of Gratuity (NIOT)"). | 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 | One (Para No. 7.2 of Report No. 17 of 2017-"Irregular Implementation of promotion sheme"). | NIL | NIL | One (Para No. 7.1 of Report no. 17 of 2017 on "Non-recovery of fuel charges due to improper contract management"). | NIL |
| 6 | 2018 | One (Para no. 8.1 of Report no. 02 of 2018 on "Avoidable expenditure toward rent of bonded warehouse"). | NIL | One (Para no. 8.2 of Report no. 02 of 2018 on "Irregular protection of pay NIOT, Chennai"). | NIL | NIL |

## 9.5 STAFF STRENGTH

Strength of all groups of Ministry of Earth Sciences including all the constituents of the Ministry is as below:

| S.No. | Groups of Posts | MOES + CMLRE + NCCR | NCMRWF | IMD | NIOT | NCPOR | INCOIS | IITM | NCESS | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| 1 | Group A | 142 | 65 | 549 | 87 | 46 | 42 | 181 | 70 | 1182 |
| 2 | Group B | 113 | 14 | 3760 | 52 | 18 | 29 | 73 | 29 | 4088 |
| 3 | Group C (including MTS) | 74 | 17 | 2732 | 25 | 23 | 0 | 60 | 57 | 2988 |
| | **TOTAL** | **329** | **96** | **7041** | **164** | **87** | **71** | **314** | **156** | **8258** |

MOES = MINISTRY OF EARTH SCIENCES
NCMRWF = NATL. 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 NATL CENTRE FOR OCEAN INFORMATION SERVICES
IITM = INDIAN INSTITUTE OF TROPICAL METEOROLOGY
NCESS = NATIONAL CENTRE FOR EARTH SCIENCE STUDIES

## Administrative Support - MoES (Proper), CMLRE, NCCR

| Ministry/ Attached Offices | Scientific/ Technical Posts | Non-Technical Posts | Grand Total |
|---|---|---|---|
| Ministry (Proper) including NCS+Koyana Project | 69 | 181 + 15 | 265 |
| Centre for Marine Living Resources &Ecology (CMLRE), Kochi | 28 | 11 | 39 |
| National Centre for Coastal Research, Chennai | 18 | 07 | 25 |
| **Total** | 115 | 214 | 329 |

*Including 15 nos. sanctioned strength of personal establishment of HMoES

## Representation of Persons with Disabilities in Government Services

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

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

| Group | Representation of SCs/ STs/ OBCs as on 1.1.2019 | | | | Number of appointments made during the calendar year 2018 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | By Direct Recruitment | | | | By Promotion | | | | By Deputation | | | |
| | Total No. of employees | SCs | STs | OBCs | Total | SCs | STs | OBCs | Total | SCs | STs | OBCs | Total | SCs | STs | OBCs |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Group A | 49 | 9 | 4 | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Group B | 43 | 8 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Group C including MTS | 58 | 22 | 4 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 150 | 39 | 11 | 14 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

## 9.6 PROGRESSIVE USE OF HINDI OFFICIAL LANGUAGE ACT AND RULES

Rajbhasha 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 Translation Officers and one Junior Translation Officer along with 2 Data Entry Operators. Rajbhasha Section is mandated to undertake entire translation work and implement the Official Language policy of the Union of India in the Ministry, 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 there under.
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 check-points.

**REVIEW**

i) The Annual programme for the year 2019-2020 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 of the Ministry.

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 in official work.

iii) A Meeting of Joint Hindi Salahkar Samiti of Ministry of Science and Technology and Ministry of Earth Sciences was held on 01 March, 2019. To fulfil an assurance given in the meeting of Hindi Salahkar Committee held on 01 March, 2019, a grand Kavi Sammelan was organised on the eve of Foundation Day of Ministry of Earth Sciences on 26th July, 2019 where 6 eminent Hindi Poets mesmerized the audiences with their poems full of patriotism, dedication to promote Hindi as Official Language, feminine feelings and eloquence.

iv) There has been a long series of organizing National Conference on Scientific Subjects in Hindi since 1990. The series was discontinued after 2013. This scheme has been revived this year. On 13th September 2019, a national symposium was organized on the theme of **"Air and Water Pollution: its impact on Humanity and Nature"**. Prof (Dr.) Devesh Sinha, Former Head of Deptt of Geology, Delhi University delivered the Keynote Address. Senior Scientists from various attached offices and autonomous bodies under the control of the Ministry along with senior faculties from some prestigious universities like Lucknow University, Sukhadia University, Udaipur presented research papers on the subject. Shri Mahesh Chand Sharma, Former Mayor

of Delhi was the Guest of Honour in the program.

**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) Entries have been invited under Prithvi Vigyan Maulik PustakLekhan Yojna – 2018. The response is tremendous.

iii) The Ministry observed Hindi fortnight from 13.09.2019 to 30.92019. During this fortnight 12 competitions were organized with a view to encourage the Officers/ employees to use Hindi in official work. Prizes were distributed by the Secretary, MoES in Hindi Pakhawara and Swachchhata Pakhawara - 2019 Closing and Prize Distribution Ceremony held on 09 October, 2019.

**OTHER ACTIVITIES**

i) Four workshops were organized to impart training to the staff in noting and drafting in Hindi, how to do work in Hindi on computers and also to guide how to fill up quarterly progress reports.

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

iii) The Committee of Parliament on Official Language has inspected IMD offices at Delhi, Mumbai, Chennai and NIOT, Chennai.

iv) Rajbhasha Section of the Ministry of Earth Sciences carried out Official Language Inspection of NCMRWF, Noida, NCS Delhi, NIOT and NCCR Chennai.


भारत सरकार
वैज्ञानिक विषयों पर हिंदी में राष्ट्रीय संगोष्ठी–2019
डॉ. हर्षवर्धन जी


पृथ्वी विज्ञान मंत्रालय
हिंदी पखवाड़ा
एवं
स्वच्छता पखवाड़ा-2019


एवं
स्वच्छता पखवाड़ा-2019


## 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 judgements/ orders of the CAT

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

## 9.9 Vigilance Activities and Achievements

Dr. M.P. Wakdikar, Scientist 'G' has been appointed as Chief Vigilance Officer (CVO) of the Ministry w.e.f. 31.12.2014. Senior level Officers have been appointed as Vigilance Officers (Vos) in attached/subordinate offices and autonomous bodies of the Ministry. A preventive as well as punitive vigilance monitoring is rigorously pursued through the Chief Vigilance Officer (CVO) and Vigilance Officers (VO). Independent External Monitors have been appointed by the Ministry with the approval of Central Vigilance Commission (CVC) for 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 (107 questions) and Rajya Sabha (49 Questions) last year.

## 9.11 Significant Audit Point Printed in the Audit Reports of 2019

Two audit points have appeared in the audit reports of 2019.

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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 as also the Parliamentary Committee on Rajbhasha for their constant support, guidance and en-couragement.

The various committees constituted by the Ministry which participated in the on-going activities and programmes are described below. We gratefully acknowledge their valuable contribution:

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, Physical Research Laboratory, Ahmadabad.
7. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, 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, 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. Independent Review Committee (IRC) for the evaluation of the ACROSS Umbrella Scheme chaired by Prof. J. Srinivasan, IISc, Bengaluru
18. Independent Review Committee (IRC) for the evaluation of the O-SMART Umbrella Scheme chaired by Dr. B. N. Suresh Chancellor, Indian Institute of Space Science and Technology, Thiruvananthapuram
19. Independent Review Committee (IRC) for the evaluation of the PACER Umbrella Scheme chaired by Dr. R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO, Bengaluru
20. Independent Review Committee (IRC) for the evaluation of the SAGE Umbrella Scheme chaired by Dr. S. K. Tandon, Professor Emeritus, University of Delhi
21. Independent Review Committee (IRC) for the evaluation of the REACHOUT Umbrella Scheme, chaired by Prof G. S. Bhat, IISc, Bengaluru

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सत्यमेव जयते

**Government of India**
**Ministry of Earth Sciences**