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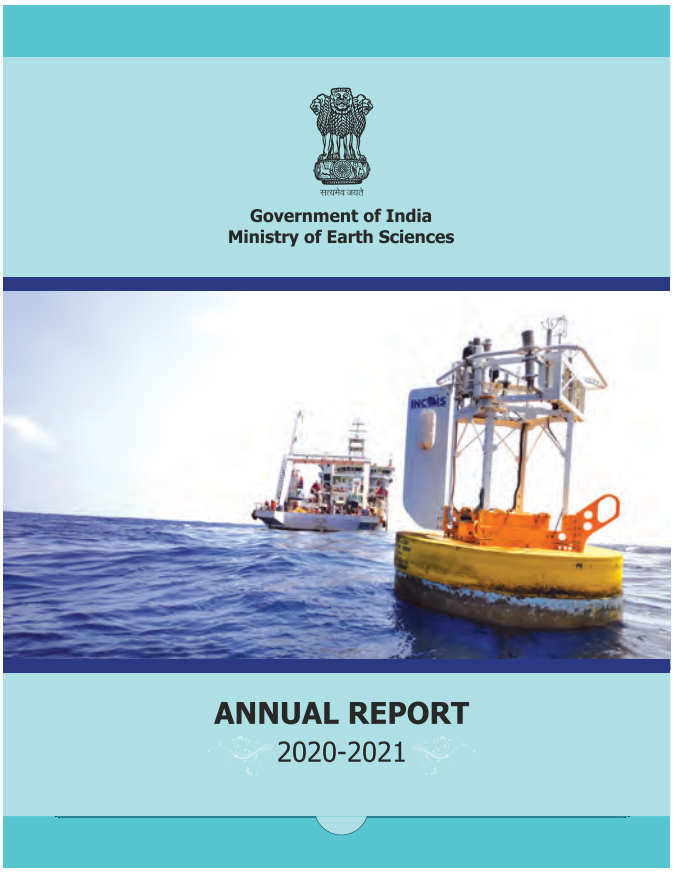
Government of India
Ministry of Earth Sciences

ANNUAL REPORT

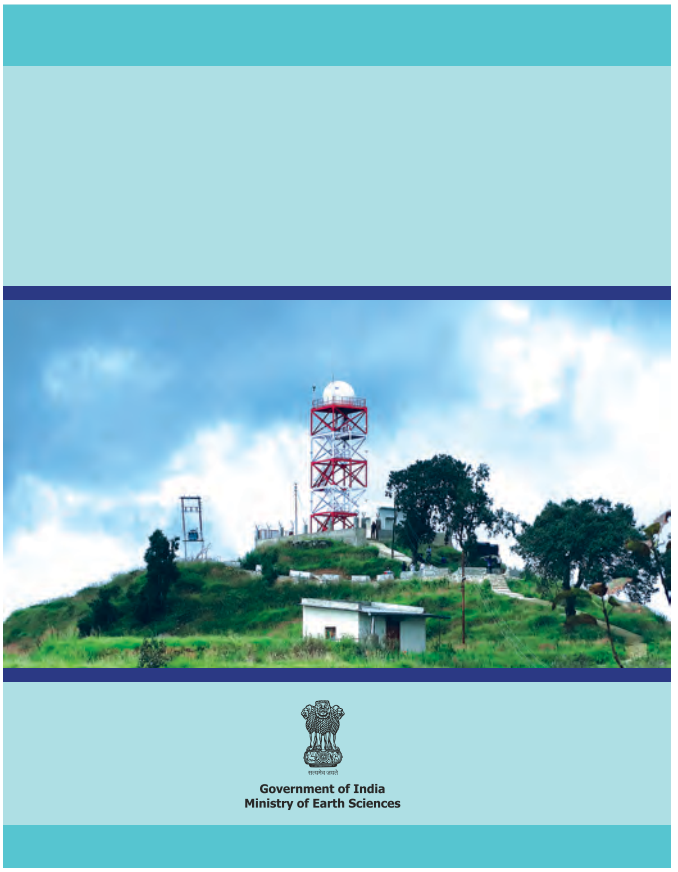
2020-2021

FRONT COVER



INCOIS Flux Buoy with ORV Sagar Nidhi in the backdrop during the recovery operations. First of its kind in the Indian Ocean, the buoy measured high resolution surface marine meteorological and sub-surface oceanographic data including direct covariance fluxes for understanding the air-sea interactions of the monsoon regime.

BACK COVER



IMD has recently installed an indigenously manufactured X band, dual polarized Doppler Weather Radar at **Mukteshwar (Uttrakhand).** This radar will play a vital role for providing information on the rapid development of severe weather events in the Central and Eastern region of Uttarakhand and adjoining areas within a range of 100 Kms.

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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 new application areas have been identified for providing weather forecasts like Energy sector. Several major milestones have been accomplished under the five major schemes of MoES during the last year, which are illustrated below:

1.1 Atmospheric and Climate Research-Modelling Observing Systems and Services (ACROSS)

Accurate and timely prediction of the tropical cyclones Amphan, Nisarga and Nivar by the India Meteorological Department (IMD), combined with fieldwork by disaster management agencies, has helped save thousands of precious lives. The track and intensity forecasts of tropical cyclones have improved considerably in the past few years. Errors in the 24-hour forecast in track prediction and the landfall have reduced from 141 km to 73 km, and from 99 km to 18 km, respectively between 2006 and 2020. IMD Launched the Flash Flood Guidance Services, the first of its kind for South Asian countries namely India, Bangladesh, Bhutan, Nepal and Sri Lanka.

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

i) Meteorological Observatory (MO) Leh was upgraded into full-fledged Meteorological Centre (MC) after Ladakh became a union territory on 31 October 2019. The Meteorological Centre at Leh was inaugurated on 29th December 2020 by Hon'ble Minister for Earth Sciences, Dr Harsh Vardhan.

ii) Seventeen High Wind Speed Recorders (HWSR) were installed at Vishakapatnam, Machilipatnam, Chennai, Goa, Cuddalore, Bhubaneswar, Kakinada, Puri, Ongole, Digha, Kavali, Haldia, Pamban, Gopalpur, Kanyakumari, Veraval and Bhuj.

iii) IMD has set up a countrywide network of 25 nos. of Global Navigation Satellite System (GNSS) stations for to drive integrated precipitable water vapor (IPWV).

iv) The 6th phase of Winter Fog Campaign (WIFEX) is being conducted at IGI Airport, New Delhi and Hissar during November 2020 - March 2021.

IMD has established Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS satellites through a MoU with M/s Antrix Corporation Ltd., ISRO. Dedicated New Earth stations have been setup under MMDRPS Project, which have the capability to receive the data from INSAT-3D, INSAT-3DR and upcoming INSAT-3DS satellites.

In the year 2020, 45 District Agromet Units were established in the premises of Krishi Vigyan Kendras jointly by IMD and ICAR. At present, 310 District Agromet Units prepare medium range weather forecast based biweekly agromet bulletin at district and block level. Currently these bulletins are issued for 690 districts and 2256 blocks in the country.

IMD's new **Mobile App "Mausam"** was launched by Dr Harsh Vardhan, Hon'ble Minister of Science and Technology, Health and Family Welfare and Earth Sciences on 27th July 2020. This mobile app is extensively used by the users for knowing location specific forecasts.

NCMRWF has started receiving and utilizing many new observations in its global and regional

atmospheric data assimilation system during this period. Global Navigation Satellite System - Radio Occultation (GNSS-RO) data from satellites, data from wind profiler observations over Europe etc. are such new global data sets which are now assimilated in global data assimilation system. Both global and regional DA systems of NCUM have been upgraded to incorporate scientific and technological advancements in data assimilation. The new DA system has the capability to assimilate some of the cloud-affected satellite microwave observations. During the year, NCMRWF has generated two high resolution reanalysis data sets, (i) regional reanalysis, for 40 years period, 1979 to 2018 over the Indian region at 12 km resolution using the NCUM model and (ii) global reanalysis, 20 years period 1999 to 2018 at 25 km resolution using NGFS system.

The GEFS ensemble forecast of 21 members for 10 days are being made available to TIGGE global archive since 1 July 2020. IMD GEFS T1534 forecast for 21 members and for 10 days lead time, are being shared with TIGGE (The International Grand Global Ensemble) archive at ECMWF since 1 July 2020.

A method for probabilistic forecasting for the health sector (forecasting occurrence of malaria etc) in extended range time scale (2-3 weeks in advance) has been developed by MoES scientists. It is based on an unsupervised pattern recognition technique that uses meteorological parameters as inputs and which can be applied to any geographical location over India. Based on this system, operational forecasts will be prepared from 2021 monsoon season.

A very high-resolution (400 m) operational air quality prediction system was developed to predict extreme air pollution events in Delhi and issue timely warnings to take necessary steps as per the newly designed Graded Response Action Plan (GRAP) of Government of India. This system was developed jointly by MoES scientists and the National Centre for Atmospheric Research (NCAR), USA. Another operational air quality prediction system was developed and operationalized by IMD in collaboration with Finnish Meteorological Institute.

A new open access book on Assessment of Climate Change over the Indian Region was published in June 2020. This is the first National climate change assessment report for the Indian region. The report discusses the influence of human-induced global climate change over the Indian subcontinent, the adjoining Indian Ocean, the Himalayas and on the regional monsoon.

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. This will be an unique facility for international research community.

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

The flagship service of Indian National Centre for Ocean Information Services (INCOIS) - Potential Fishing Zone (PFZ) advisories have been disseminated continuously for the period of January to November 2020 in smart map and multilingual text form on daily basis subject to satellite data availability, fishing-ban period and adverse sea-state. Small Vessel Advisory and Forecast Services System (SVAS) was launched to provide Ocean state information to numerous small fishing vessels that ply the coastal waters of India.

IOC-UNESCO conferred the Certificate of Recognition and Certificate of Appreciation as Tsunami Ready communities to Venkatraipur and Noliasahi village communities and OSDMA Officials, through a virtual event organized on 7 August 2020, which is first of its kind in the Indian Ocean region. The Digital Ocean (DO), an innovative web-application project to manage ocean data was inaugurated by Hon'ble Minister for Earth Sciences on 29 December 2020. The DO provides a dynamic framework to efficiently integrate and manage heterogeneous ocean data

along with advanced visualization (including 3D and 4D animations) and analysis tools.

A coastal water quality index (CWQI) map was prepared for the Andhra Pradesh coast based on the results obtained from the cruise conducted in August 2020. Shoreline change rate for the entire Indian coast is analysed using Indian satellite images and field measurements. 526 numbers of shoreline change maps (1:25000 Scale) have been generated using standard protocol using 11 data sets for 1990-2018.

In Collaboration with Disaster Management Department, Municipal Corporation of Greater Mumbai (MCGM), National Centre for Coastal Research (NCCR), Chennai has developed the Integrated Flood Warning system for Mumbai referred to as iFLOWS-MUMBAI, which was launched on 12th June 2020 by Hon'ble Minister for Earth Sciences and Hon'ble Chief Minister of Maharashtra. The system was proven very useful during the 2020 monsoon season.

Six deep sea buoys were moored to provide open ocean data which are disseminated in real-time to INCOIS and IMD and also used for tsunami early warning. One Low Temperature Thermal Desalination (LTTD) plant has been successfully commissioned at Kalpeni, Lakshadweep in January 2020. Experimental scale mass culture of marine Spirulina in 2 tonne raceway with F/2, for production of pharmaceutical important lutein from marine microalgae was developed and the technology was transferred to M/s Vectrogen Biologicals Private Limited, Hyderabad through National Research Development Corporation (NRDC). Indigenization of Drifting Buoy with INSAT Communication has been completed and technology licensing agreement is signed with the two Indian industries under NRDC for commercialization.

1.3 Polar and Cryosphere Research (PACER)

All scientific projects and logistics operations were successfully completed during the 39th Indian Antarctic Expedition. After resupplying stations of food and provisions, fuel, spares, etc., the expedition vessel MV Vasiliy Golovnin sailed for the return voyage on 26 March 2020.

An expedition to the Chandra basin in the Himalayas was undertaken during September-October 2020. Various field activities like stake networking, snow pits measurements for snow/ice accumulation and ablation, discharge site maintenance, water level data collection, Automatic Weather Station (AWS) data collection and maintenance, observation of the debris cover influence on the glacier surface melting, GNSS survey for snout monitoring and glacier ice velocity were carried out.

The Third meeting of the BRICS Working Group on Ocean and Polar Science and Technology was organized online on 23 September 2020. About 50 delegates from Brazil, Russia, India, China, and South Africa joined the meeting and 21 scientific presentations were made. The current research programs and future activities of each BRICS country in the field of ocean and polar sciences as well as bilateral and multilateral cooperation initiatives between BRICS countries were discussed.

1.4 Seismology and Geoscience Research (SAGE)

A total of 1527 earthquakes were located in and around the country during the period from January to November 2020. Out of these, 65 events were of magnitude M:5.0 and above, 277 events of micro nature, and remaining events fall within the category of small earthquakes. The calendar year has been quite challenging, as there have been several episodes of microearthquake / swarm activity in different regions of the country, like Delhi; Palghar, Maharashtra and Idukki district of Kerala etc. A detailed analysis was carried out by considering earthquakes of magnitude 2.5 and more on past events in and around Delhi during the last two decades. The analysis showed that i) over Delhi, the earthquake activity has a seasonal cycle with maximum frequency of earthquakes during April-May-June and, on an average, 4-5 events of magnitude of 2.5 or more occur during this period and ii) there is no definite pattern in frequency of earthquake occurrence during the period of data analysis which could suggest any increase in earthquake activity.

The seismic microzonation work of four cities, namely, Bhubaneswar, Chennai, Coimbatore, and Mangalore, started about two years back, is in advanced stage of completion.

This year, one scientist from India participated in IODP-378 expedition in the far southern Pacific Ocean during 03 Jan - 06 Feb 2020. The expedition was aimed at investigating the record of Cenozoic climate and oceanography through a drilling transect.

NCESS, Thiruvananthapuram established an Isotope Geochemistry Facility (IGF) that host a 213nm Nd: YAG Laser Ablation Microprobe (Teledyne CETAC) which can be coupled with a Quadrupole ICP-MS (Agilent 7800) and a Multi-Collector ICP-MS. By utilizing high resolution imaging techniques using SEM or EPMA, the internal structure of different accessory minerals such as zircon, monazite, rutile etc. can be studied. This powerful combination of technique is now being applied routinely in NCESS-IGF to resolve many outstanding geological problems in Indian shield specially to understand deep time evolution of Precambrian terranes such as the Southern Granulite Terrain (SGT) in South India. Under the Scientific Deep Drilling project in the Koyna Intraplate Seismic Zone, Maharashtra, integration of stress and fracture datasets yielded new insights into reservoir triggered seismicity (RTS) in the region.

1.5 Research, Education, Training and Outreach (REACHOUT)

MoES announced a special call for research proposals under the artificial intelligence/machine learning applications in Earth sciences. Nearly 200 submissions were received and are currently under assessment.

The ITCOocean continued its operations using the state-of-the art facilities. ITCOOcean was recognized as Regional Training Centre (RTC) RTC under UNESCO - Ocean Teacher Global Academy 2 (OTGA-2) for a period of 3 years from 2020 - 2023. During January 2020 - November 2020, **1731** persons were trained of which 1150 (Male: 642, Female: 508) are from India and 581 (Male: 345, Female: 236) are from 73 other countries. Three online training courses were also conducted.

MoES Webinars - a series of Live Talks on "Earth Sciences Popular Lectures" have been organized since May 2020. **As of now, 38 Live talks on various topics have been delivered and archived on IITM YouTube channel.** DESK organized three International workshops/Conferences in collaboration with other International agencies. DESK also organized seminars and other activities on the occasion of World Water Day, World Environment Day, World Ozone Day and National Pollution Control Day.

MoES engaged the National Centre for Applied Economic Research (NCAER), Delhi to study the economic benefits of the Monsoon Mission and HPC acquired by the Ministry through estimating the income gain to the farmers in rain-fed areas, livestock owners and fishermen by adopting the weather and ocean state forecast respectively. The report also examined the economic benefits from gender perspective. The report highlights that India's investment of nearly 1,000 crores in the Monsoon Mission and HPC facilities would provide benefits worth rupees 50 thousand crores to nearly 10.7 million below poverty line (BPL) agricultural households and 0.53 million BPL fisherfolk households in the country over a 5 year period. About 26.6% of this benefit is attributed to women folk.

The Knowledge Resources Centre Network (KRCNet) a unique initiative of the MoES was inaugurated on 27th July 2020 by Hon'ble Minister for Earth Sciences. It integrates all knowledge and intellectual resources of MoES and its institutes on a single, dynamic, web portal. Under the Digital India Initiative of the Government of India, the portal is a one-of-its-kind digital system to collect, collate, catalogue, store and retrieve the knowledge products of MoES and its institutes 24X7 from around the globe.

1.6 International Collaborations

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. MoES and National Ocean and Atmospheric

Administration (NoAA) entered into a Memorandum of Understanding in 2008 on Earth Sciences and Observations and the agreement formally came into force in 2010 after the exchange of diplomatic note and had a duration of ten years. The MoU was renewed on 23 October 2020 in a virtual event. The Indian ambassador to the United States Mr Taranjeet Singh Sandhu signed the MoU on behalf of the Ministry.

Under the Memorandum of Understanding (MoU), signed between MoES and USGS on 01 November 2018, a joint collaborative work with USGS on development of Earthquake Early warning System for India as a pilot project is being considered. A virtual meeting with USGS was organized on Sep. 01, 2020 to discuss "Development of Earthquake Early warning System for India" which was attended by representatives of USGS, US Embassy in Delhi, Director, NCS and senior scientists.

Three projects under the "Sustaining Water Resources for Food, Energy & Ecosystem Services in India" covering three main geographic regions of India: the Himalayas, the Indo-Gangetic Plain and Peninsular India jointly funded by MoES and NERC-UK has been completed. A virtual final review meeting of MoES, NERC, PIs and Co-PIs was organised on 24th November 2020 to review the highlights and outputs from these projects. A webinar was also organised on 25th November 2020 to showcase the research, successes and lessons learned from the SWR programme.

As a follow-up to the Joint Task Force on Blue Economy for Sustainable Development taken up under the Memorandum of Understanding signed between India and Norway in January 2019, a letter of Intent (LoI) was signed on 18 Feb 2020 between MoES and Norwegian Ministry of Climate and Environment and Norwegian Ministry of Foreign Affairs on "Integrated Ocean Management & Research Initiative". BIMSTEC Secretary General His Excellency M. Shahidul Islam, visited BIMSTEC Center for Weather and Climate (BCWC) being hosted by NCMRWF on 13 February 2020. The first BIMSTEC-Intergovernmental Expert Group Meeting on Disaster Management was organized by the National Disaster Management Authority during 14 February 2020 at Puri, Odisha.

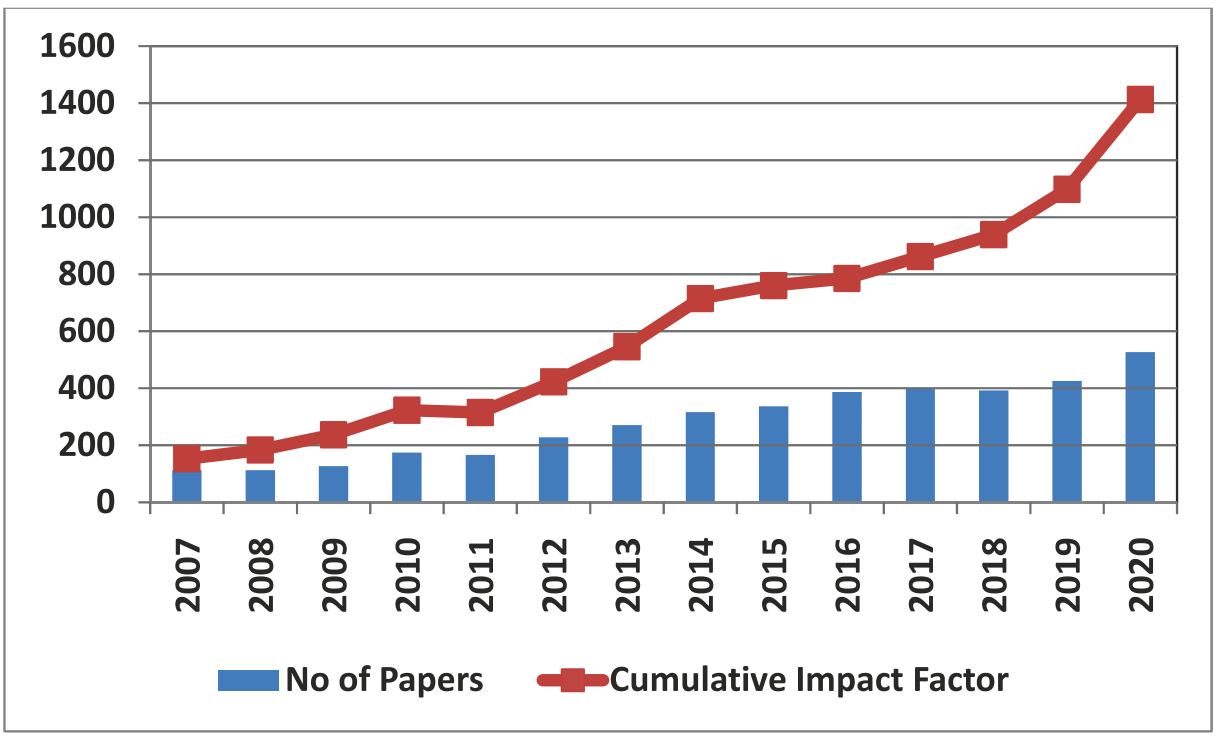


Fig. 1.1: Number of research papers and cumulative impact factor year wise

The 11th RIMES Council Meeting was held at Bangkok, Thailand during 20-22 January 2020. The 12th RIMES Council Meeting was held in a virtual mode during 25-26 November 2020. Despite the many restrictions associated with the COVID pandemic, RIMES was able to continue to provide uninterrupted services to its Member and Collaborating States. A Memorandum of Understanding (MoU) for Scientific and Technical cooperation between Ministry of Earth Sciences of the Republic of India and National Center of Meteorology, Ministry of Presidential Affairs UAE was signed on 23rd November 2020.

1.7 Scientific Publications

A total number of 527 research papers were published during 2020 by MoES scientists under various programs of the Ministry, the highest since the inception of MoES. The number of research papers published and the total impact factor **(1413.296)** are comparatively much higher as compared to the previous years **(Fig. 1.1).** The average impact factor of research papers was 2.7.

1.9 Budget Expenditure

The total outlay for the Ministry for the year 2020-21 was Rs.2070.00 crores which was reduced to Rs. 1300.00 crores at the RE stage. The expenditure profile for the last 13 years is shown in the table below. There is a regular growth in BE as well as actual expenditure during the last 13 years except in 2020-21.

Year	BE	RE	Actual Expenditure
2007-08	887.95	655.85	562.03
2008-09	972.90	820.00	751.69
2009-10	1213.20	1137.20	1080.51
2010-11	1305.25	1281.06	1098.07
2011-12	1569.12	1227.01	1174.58
2012-13	1672.29	1198.66	1177.14
2013-14	1693.73	1311.12	1248.15
2014-15	1702.23	1336.88	1294.35
2015-16	1622.68	1420.98	1296.80
2016-17	1672.45	1579.11	1459.76
2017-18	1719.48	1597.69	1547.73
2018-19	1800.00	1800.00	1745.63
2019-20	1901.76	1809.74	1722.59
2020-21	2070.00	1300.00	968.67*

*As on 31/12/2020

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 program, ACROSS by the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and National Centre for Medium Range Weather Forecasting (NCMRWF).

During the year, many significant achievements have been made in providing weather and climate services. Major improvements have also been made in the observing systems and data assimilation in numerical models. Intense observational campaigns have been taken up as special atmospheric observations help us to understand model deficiencies and to improve the accuracy of models. Details of significant achievements made under the program ACROSS are given below:

2.1. Observing Systems and Field Campaigns

Meteorological Observatory (MO) Leh was upgraded into full-fledged Meteorological Centre (MC) to cater to the needs of theLadakh region. The new MC was inaugurated by Hon'bleMinister of Earth Sciences,Dr Harsh Vardhan on 29th December, 2020, in which Shri R.K. Mathur, Hon'ble Lieutenant Governor, Ladakh, and Shri JamyangTseringNamgyal, Hon'ble Member of Parliament also attended the event. To help the administration and the people of Ladakh, IMD will provide a range of weather forecast services, ranging from short (3 days) and medium (12 days) to extended (1 month) period to all the stakeholders on a daily basis for both the districts (Leh and Kargil).

The following observational systems have been installed during the period.

- Seventeen (17) High Wind Speed Recorders (HWSR) were installed at Vishakapatnam, Machilipatnam, Chennai, Goa, Cuddalore, Bhubaneshwar, Kakinada, Puri, Ongole, Digha, Kavali, Haldia, Pamban, Gopalpur, Kanyakumari, Veraval and Bhuj.
- Five (5) numbers of Manual Surface Observatory have been established at Nayagarh, Boudh, Chhatrapur (Ganjam), Paralakhemundi (Gajapati) and Rayagada by M C Bhubaneswar in collaboration with Odisha Govt. during the month January 2020.

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

- New sensors for Lightning Location Network have been installed at Dhanbad, Kullu, Palampur, Leh, Portblair, Ajmer, Vishakhapatnam, Vijayawada and Anantapur and Aizwal thereby by increasing the total sensors of the network to 83 across the country. The DAMINI LIGHTNING ALERT Mobile App has been developed and released in May 2020. The App is available on iPhone apps store for download.
- To study the carbon sequestration potential of the Kaziranga forest in northeast India, a soil CO_2 sensor was installed to calculate the soil-CO_2flux.

2.1.1 Atmospheric Research Testbed (ART) facility in central India

IITM Pune has initiated work for establishing the Atmospheric Research Test Bed (ART) facility on the ~100 acres of land in Silkheda village of Sehore District, Madhya Pradesh. 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. This is a unique facility of international standards. IITM has signed a MoU with Central Public Works Department (CPWD), Bhopal in March 2020 for development of civil and electrical infrastructure at the ART site. Civil work for

construction of a 20-m tower for installation of C-band radar was started at the ART site. A Radiometric profiler was installed at IMD Bhopal office site.

2.1.2 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. IITM had conducted observational campaign in 2018-19 and in 2019-20, using a seeder (Beechcraft C-90) and an instrumented research aircraft (Beechcraft B200), for collecting high-quality observations of cloud and precipitation related processes in natural and seeded clouds over the rain shadow region. The science experiment (CAIPEEX Phase IV) was conducted for formulating protocols for cloud seeding and rain enhancement over the rain shadow region of Western Ghats. As part of the experiment, IITM has established an observational facility including a dual polarimetric C-band radar at Solapur, and Tuljapur, Maharashtra for collecting long term observations. 125 rain gauges were established in the seeding area for detailed observations of surface rainfall. The 2018 and 2019 airborne component of the experiment resulted in 480 hours of observations. Suitable conditions under which cloud seeding becomes successful are investigated with in situ physical experiment, statistical experiment and with numerical simulations as per recommendations of the World Meteorological Organization (WMO). The experiment has resulted in 234 randomized cloud seeding samples, which has been evaluated in the year 2020. Statistical experiments indicate that results are significant within an area of 10x10 km^2 downwind of seeding.

2.1.3. High Altitude Cloud Physics Laboratory (HACPL)

An **Integrated Flood Warning System for Mumbai (IFLOWS-Mumbai) has been jointly developed** by NCCR Chennai, IMD, IITM, & NCMRWF for Municipal Corporation of Greater Mumbai (MCGM). The system was launched by Maharashtra Chief Minister Shri Uddhavji Balasaheb Thackeray and the Union Minister Dr. Harsh Vardhan on 12 June 2020. It provides three to six hours now cast as well as 72-hour early warnings for flooding specially during high rainfall events and cyclones.

2.1.4. National Facility for Airborne Research (NFAR)

The Unmanned Aerial System (UAS) laboratory named as "Lower Atmospheric Research using Unmanned Aerial System (LARUS) Facility" has been established with basic infrastructure at IITM. IITM-UAVs have been listed in the Digital Sky Platform of DGCA, and also obtained *Unique Identity Numbers (UIN)* from DGCA. *Standard Operating Procedures (SOP)* for UAS operations in India has been prepared.

2.1.5. Satellite products for weather forecasting services

Recently, IMD has established Multi-Mission Meteorological Data Receiving and Processing System (MMDRPS) for INSAT-3D, INSAT-3DR and INSAT-3DS satellites through a MoU with ISRO. Dedicated New Earth stations have been setup under MMDRPS Project, which have the capability to receive the data from INSAT-3D, INSAT-3DR and upcoming INSAT-3DS satellite. MMDRPS systems consist of advance & latest state of art servers capable to process the complete set of data within 7 minutes after completion of scanning along with the storage capacity of order 2.0/2.0PB (Main/ Mirror) & 324TB SSD which will facilitate online sharing of processed data for all Indian meteorological satellites to the registered users. All available past satellite datasets starting from 1983 will be kept in online mode in due course of time.

IMD has hosted Real Time Analysis Product & Information Dissemination (RAPID) for visualization and analysis tool for satellite data on a real-time basis. The rapid scans data and INSAT 3DR data have been integrated in RAPID since October 2019 for real time visualization and analysis of weather events.

IMD has set up a countrywide network of 25 nos. Global Navigation Satellite System (GNSS) stations for "Earth and Atmospheric studies" to derive integrated

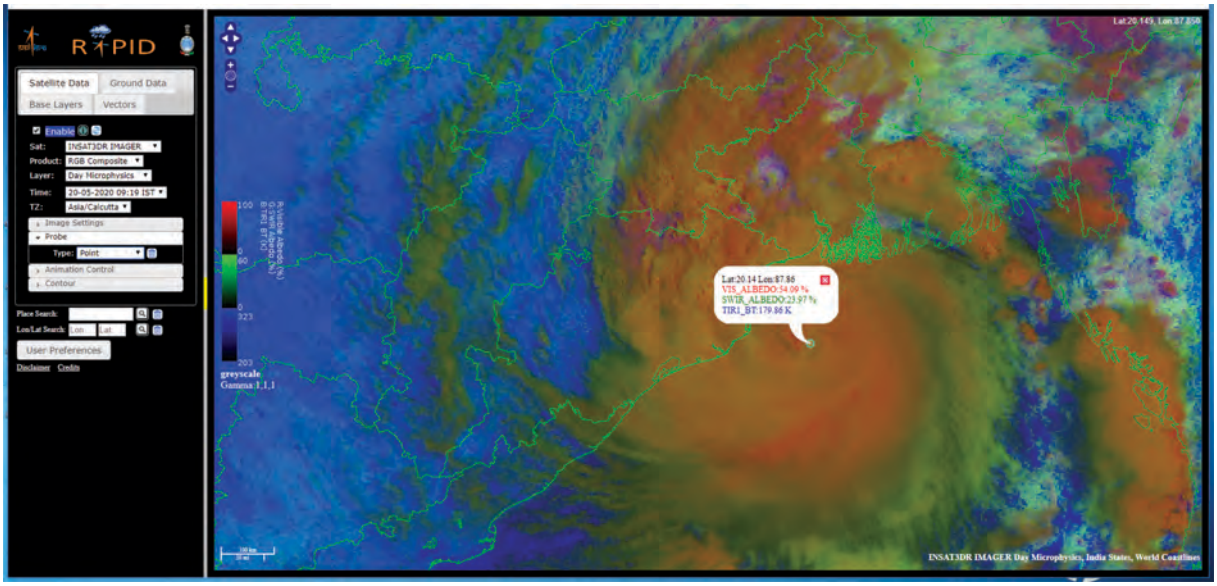


Fig. 2.1. Utilization of RAPID during a cyclonic event.

precipitable water vapor (IPWV). The IPWV data is being used for nowcasting and assimilation in NWP models to improve weather forecasting. The satellite and lighting merged products are also operationalized at IMD website. The merged lightening & satellite cloud top temperature operational product is a joint collaboration of IMD, IITM & IAF. Work is going on to merge (all 3 types of instrument data) Satellite, RADAR and Lightning data for weather forecasts.

2.2. Modelling work at NCMRWF

2.2.1. Global Observations and Data Assimilation

Global Navigation Satellite System - Radio Occultation (GNSS-RO) data from platforms of KOMPSAT-5, COSMIC-2, METOP-C, PAZ, FY-3C & FY-3D etc. and wind profiler observations over Europe (Fig. 2.2), are received and utilized in the NCMRWF global and regional atmospheric data assimilation system. These observations have considerably compensated for the significant reduction (~ 70%) in the amount of aircraft observations worldwide during the COVID-19 lockdown period, thereby maintaining the quality of global analysis and forecasts.

Nowcasting products like Rapidly Developing Thunderstorm (RDT), Convective Rainfall Rate (CRR), Cloud Top Temperature Height (CTTH), High Resolution Winds (HRW), etc. are derived using (a) the Meteosat-8 Indian Ocean Data Coverage (IODC) received at NCMRWF through EUMETCAST reception system (b) First guess fields from Global Forecast System (IMD-GFS -1534) (c) Real time ground lightning observations from IITM-IAF network and (d) Sea surface temperatures.

Both global and regional Data Assimilation (DA) systems of NCUM have been upgraded in 2020 to incorporate scientific and technological advancements in data assimilation. The new DA system has the capability to assimilate some of the

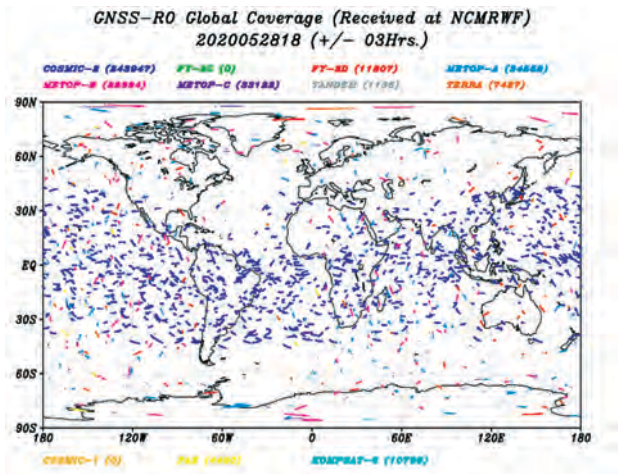


Fig. 2.2: GNSS-RO Global Coverage received at NCMRWF for 18UTC of 28th May 2020.

cloud-affected satellite microwave observations. The assimilation system uses an advanced version of fast radiative transfer model RTTOV-12 for satellite radiance processing and assimilation.

New satellite radiances from GOES ABI, NOAA20 CrIS& ATMS and cloud affected radiances from some of the ATOVS channels (from various satellites) are included in the NCUM operational DA system. GPS radio occultation observations from COMSC-2 satellite constellation and PAZ satellite are also included in the NCUM operational assimilation systems. Successful experimental assimilation of advance technology Aeolus satellite's horizontal line-of-sight (HLOS) wind observations in NCUM after detailed verification of its quality is another major milestone in the DA developments in this year.

NCMRWF has generated two high resolution reanalysis data sets, (i) regional for 40 years period, (1979 to 2018) over the Indian region at 12 km horizontal resolution using NCUM and (ii) global 20 years period (1999 to 2018) at 25 km resolution using NGFS system. A data portal (https://rds.ncmrwf.gov.in) has been developed for sharing the reanalysis data sets with the global research and user community. It is seen that both the reanalysis are comparable with other similar reanalysis products (ERA-5) during monsoon period and perform better than ERA-5 during the pre-monsoon and post monsoon phase. Fig. 2.3 shows plot of probability density of precipitation intensity from different reanalysis products NGFS, IMDAA, ERA5 and observations (IMD). Re-forecasts for 20 years have been carried out using NGFS reanalysis data. It is found re-forecasts can predict extreme temperature events over Indian region with a lead time of 7 days and extreme rainfall events with a lead time of 3 days.

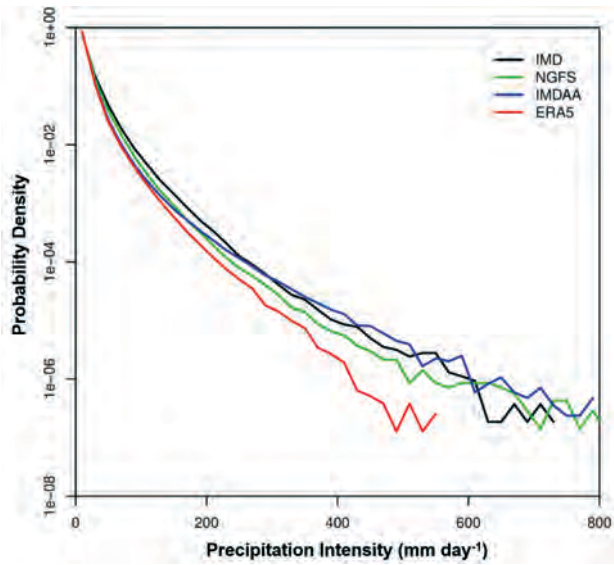


Fig. 2.3: Probability density of precipitation intensity from reanalysis products NGFS, IMDAA, ERA5 and observations (IMD).

2.2.2 Global/Regional Atmospheric Model

NCUM global model was upgraded to the latest version (PS43) in June, 2020 which includes modifications in global land surface model with multi-layer snow scheme, improved treatment of gaseous absorption in the radiation scheme, new warm rain microphysics and improved deep convection scheme. The NCUM regional model (NCUM-R, 4km) was also upgraded and includes the use of realistic surface fluxes from JULES land surface schemes, the multi-layer snow scheme, tuning of lightning parameterization, inclusion of visibility parameterization schemes and climatological aerosol in the surface layers.

Delhi Fog Model (DM) with the two inner domains (at 1.5km and 330m resolutions) was further upgraded by introducing realistic aerosol-chemistry feedback effects (namely DM-Chem) through use of a reduced version of UK Chemistry and Aerosols (UKCA) sub-model. The upgradation also included a new visibility parameterization scheme, emission inventories data bases EDGAR (1.5km domain) and IITM (330m domain), and real-time daily-varying fire emission data from the Global Fire assimilation System. This upgraded DM model has been made operational for the 2020-21 winter season.

2.2.3. Global/Regional Ensemble Prediction Systems

The unified model based global ensemble prediction system of NCMRWF (NEPS-G) at 12 km resolution and with 22 ensemble members has been further updated by modifying its physics configuration to address various science issues which include the large precipitation bias over Indian region. The location specific probabilistic forecast products of NEPS-G in

the form of EPSgram are being generated and shared with Indian Air Force. A set of ensemble forecast products from NEPS-G is also being generated for Bhutan.

The initial conditions of unified model based regional ensemble prediction system of NCMRWF (NEPS-R) has undergone a major change, wherein the perturbations generated by Ensemble Transform Kalman Filter (ETKF) of NEPS-G are added to the analysis prepared by the regional 4DVar data assimilation system to provide the perturbed initial conditions for NEPS-R. Both global and regional ensemble runs (NEPS-G and NEPS-R) provided valuable probabilistic forecasts of two consecutive tropical cyclones 'Amphan' and 'Nisarga'. The intensity and track forecasts of NEPS-R were found to be better than those of NEPS-G.

2.2.4. Atmosphere Model Verification and Applications

Verification of Numerical Weather Prediction (NWP) products of Global Data Processing and Forecasting System (GDPFS) has been carried out, which helps NWP centers to compare and further improve their forecasts skill scores. These scores are exchanged among the participating NWP centers via the lead centres. NCMRWF has started contributing to the deterministic forecast verification scores to the lead center (ECMWF) and the monthly statistics and an inter-comparison with other major centres is available on **http://apps.ecmwf.int/wmolcdnv/).** A typical comparison for the various parameters over northern hemisphere (NH, 90°N-20°N, inclusive, all longitudes), is shown in **Fig. 2.4.**

The verification scores for NEPS-G forecasts are being shared since May 2020 with the lead center (Japan Meteorological Agency) for verification of ensemble prediction system. Verification statistics of ensemble predictions of leading NWP centres (UKMO, ECMWF, JMA) are compared with that of NEPS at NCMRWF. NCMRWF is also providing NCUM-G and NCUM-R models forecasts on a daily basis for the monsoon season (JJAS 2020) as an input to the flood forecasting model for *iFlows*, Integrated Flood Warning System of Mumbai. Overall, the performance of global and

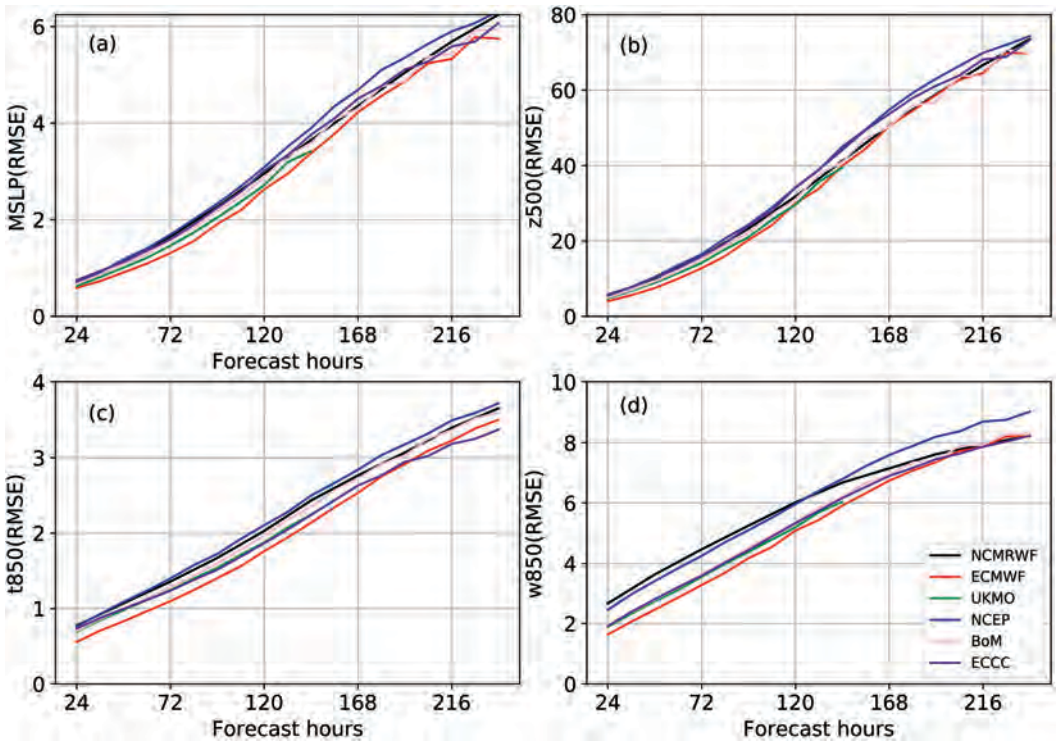


Fig. 2.4: Comparison of root mean square error (RMSE), for different parameters (MSLP, 500 hPa Geop. Height, 850 hpa Temperature and 850 hPa Winds) computed over NH during August 2020 amongst various leading NWP centers.

regional models in representing the magnitude and spatial distribution of rainfall for extreme rainfall events (>200mm/day) is fairly good.

2.2.5 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 seasons. From monsoon 2020, a new seasonal forecast system based on this model was added to the MoES family of coupled models producing extended and seasonal forecasts in real-time.

Seasonal Forecasts: NCMRWF Global Coupled Model with 60 km Atmosphere (NCUM) and 25 Km Ocean (NEMO) is used to issue seasonal forecasts. Twenty-three years hindcast run of the coupled model using 6 members per year (1993-2015) is analysed. It is found that the model picked the correct signal of monsoon extremes 10 out of 18 times during 1998-2015 for April Initial Conditions (IC) and 15 out of 18 times for May forecasts. Categorical forecast percentiles of 2020 monsoon season, using total 45 members are shown in **Fig. 2.5.** Hindcasts are used to define threshold for tercile categories for probabilistic forecasts. The "above normal" forecast for 2020 seasonal monsoon forecast was realized.

2.2.6 Ocean Modelling and Ocean Data Assimilation

The air-sea interaction plays crucial role in the tropical cyclone intensification. The upper ocean provides the heat to the atmospheric boundary layer. During the Tropical Cyclone(TC) Amphan (12-20 May 2020), the Tropical cyclone heat potential (TCHP) forecasts from the stand-alone NEMO ocean model forecast are verified against its analysis. **Fig. 2.6** shows the comparison of TCHP forecast (Day-1 to Day-9) with respect to NEMO analysis valid for 19 May 2020. NEMO forecast captures the TCHP evolution very well.

2.2.7. Polar Sea-Ice Forecasts

NCMRWF coupled model also has sea-ice initialization and forecast modules integrated to the analysis-forecast system producing the polar sea-ice forecasts in real-time in medium, extended and seasonal time scales. These are very useful for India's operations in polar regions. Fig. 2.7 shows the skill of sea-ice extent for Arctic from ERP's 23 year mean

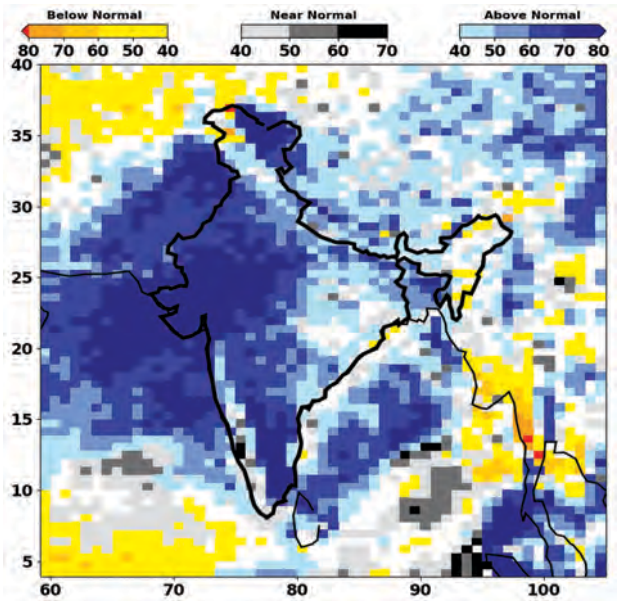


Fig. 2.5: Tercile categories for probabilistic forecasts of monsoon season (JJAS) 2020 rainfall from NCMRWF coupled seasonal forecast Model.

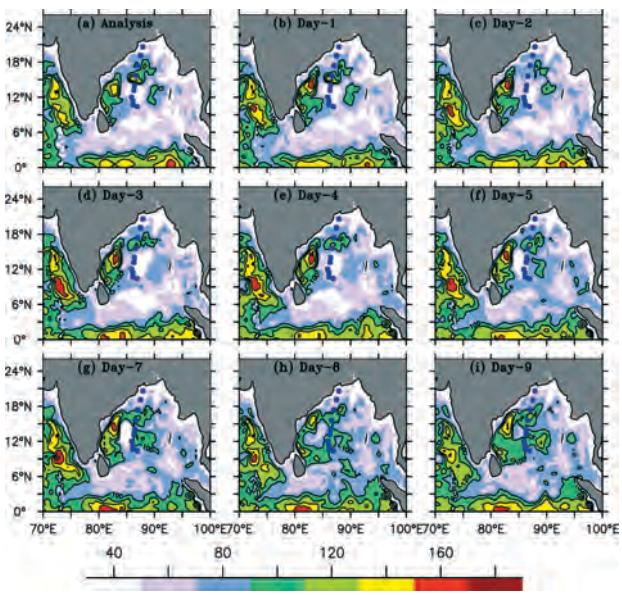


Fig. 2.6. Tropical Cyclone Heat Potential 'TCHP' (KJ cm-2) from the stand-alone NCMRWF NEMO global ocean model forecast valid for 19 May 2020 along with cyclone track.

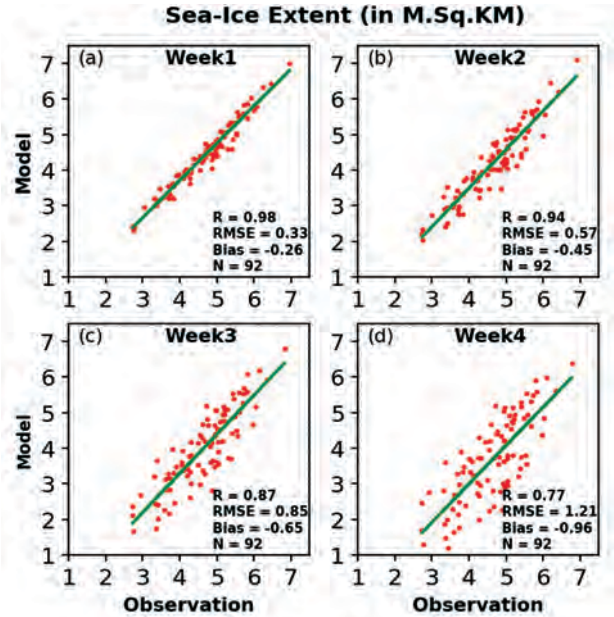


Fig. 2.7: Arctic Sea-Ice extent verification for September (peak melting season) from 23 years mean (1993-2015) ERP hindcast for week-1 through week-4.

hindcast validated against Glorys2V12 sea-ice extent data. Hindcast climatology of September demonstrates high correlation, small bias and marginal RMSE in sea ice extent compared to observations.

2.3 Global and Regional modelling at India Meteorological Department (IMD)

2.3.1. Global Forecasting System

Global Forecasting System (GFS T1534L64) model run operationally at IMD four times in a day (00, 06, 12 & 18 UTC) to give deterministic forecast in the short to medium range upto 10 days. The real-time GFS T1534L64 model outputs are generated daily at IMD. This 4DEnsVar data assimilation system has capabilities to assimilate various conventional as well as 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.

2.3.2. WRF model

During southwest monsoon season 2020, the WRF model (ARW) was used to generate three days forecasts at 3 km horizontal resolution four times daily at 00, 06, 12 and 18 UTC with hourly interval. The data assimilation component, regional GSI (Global Statistical Interpolation) takes global GFS analysis and all other conventional qualitycontrolled observations

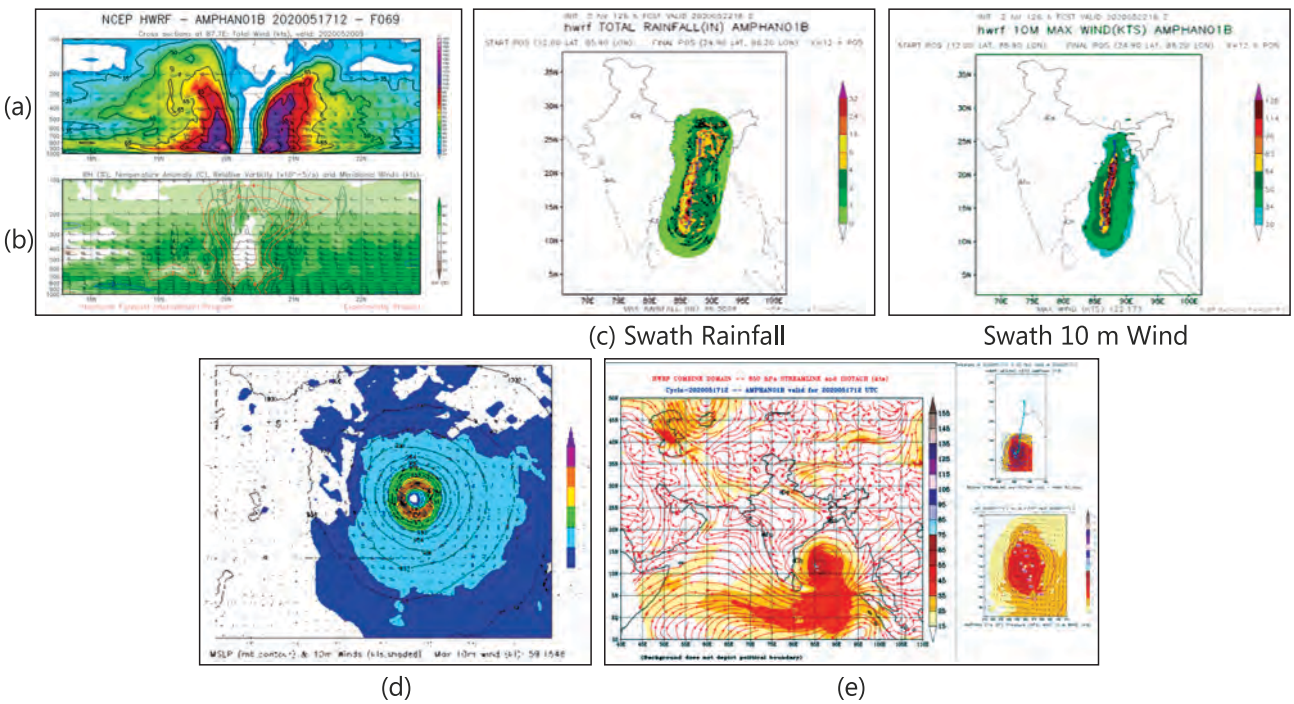


Fig. 2.8 SuCS AMPHAN Zonal Cross-section of (a) Total wind & (b) Humidity and temperature, (c) Swaths of Rainfall & 10 m wind, (d) 10m wind and MSLP of 2 km core domain and (e) Streamlines and Isotachs of combine domain (18x6x2 km).

as its input and generates mesoscale analysis at 3 km resolution. The model produced forecasts over a domain spanning about 5° S to 41° N in north-south and 49° E to 102° E in east-west directions respectively.

2.3.3. HWRF-Ocean (HYCOM/POM-TC) coupled model

During pre-monsoon and post-monsoon cyclone seasons of 2020, the movable triple nested HWRF-Ocean (HWRF/POM-TC) coupled model with horizontal resolutions of 18 km, 6 km and 2 km delivered 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 of HWRF, regional GSI Data Assimilation, generated mesoscale analysis for intermediate and innermost nests which are then merged to generate analysis for all three domains. The model parent domain (18 km horizontal resolution) remained stationary whereas the intermediate domain (6 km horizontal resolution) and the inner most domains (2 km horizontal resolution) moved to track the storm centre. The Fig. 2.8 represents the different product generated from operational HWRF-HYCOM coupled model for the Super Cyclone AMPHAN during May 2020.

2.3.4. Verification of Extreme Events

- **Heavy rainfall events**

During the 2020 monsoon season, probability of detection (POD) for heavy rainfall warning varied between 77% to 59% from day-1 to day-5. Critical Success Index (CSI) varied between 55% to 45% for Day-1 to Day-5 forecasts. False alarm rate varied between 32% and 25%.

- **Heat wave forecasts**

During April-June season of 2020, probability of detection (POD) for heat waves varied between 100% to 62% for Day-1 to Day-5 forecasts and Critical Success Index varied between 41% to 37%. However, false alarm rate for prediction of heat waves was very low. It varied from 3% to 1%.

2.3.4.Thunderstorm Nowcasts

During the year 2020, about 200 stations were added to the Nowcast list for thunderstorms. Thus the total number of stations for the nowcast has gone upto 894 in 2020.

Thunderstorms associated with the severe weather phenomenon were well predicted during the pre-monsoon season 2020(March to June). The skill scores pertaining to thunderstorms predictions are given in the table below.

Table 2.1 Skill Scores for 24 hour Thunderstorm IOP Verification for FDP STORM Period - 2020 (March to June)

Month	Ratio Score	POD	FAR	CSI	ETS
March	0.78	0.80	0.42	0.50	0.35
April	0.74	0.85	0.35	0.59	0.33
May	0.74	0.88	0.31	0.63	0.32
June	0.65	0.70	0.29	0.55	0.15
FDP-2020	**0.73**	**0.80**	**0.33**	**0.57**	**0.30**

2.4. Monsoon Mission

2.4.1.Seasonal Prediction

The operational seasonal forecast of southwest monsoon 2020 was prepared by using Monsoon Mission Climate Forecast System (MMCFS), which was developed at IITM, Pune. The forecast based on the MMCFS model was issued in two stages. The first stage seasonal forecast issued on 15th April 2020 suggested that the seasonal monsoon rainfall during 2020 averaged over the country as a whole was likely to be above normal, i.e., more than 104% of the Long Period Average (LPA). This was followed by the second stage of seasonal forecast by MMCFS issued on 1st June 2020 suggesting that the rainfall during the 2020 monsoon season averaged over the country as a whole was likely to be 107 % +/- 4% of LPA. The country received 109% of LPA (i.e., "above normal") rainfall during the four-month monsoon season, suggesting that MMCFS model provided accurate seasonal forecast for the 2020 SW monsoon season.

Model development for climatic applications in hydrology and agriculture by integrating river runoff in the climate model 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.

2.4.2. Extended Range Prediction

The extended range forecasts are being generated from a multi-model ensemble prediction system and issued throughout the year. The forecasts are issued once in a week for the next four weeks. 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. The skill of the model in comparison with the UK Met Office (UKMO) Glosea5 model in predicting the JJAS rainfall on subdivisional scale is depicted in **Fig. 2.9.**

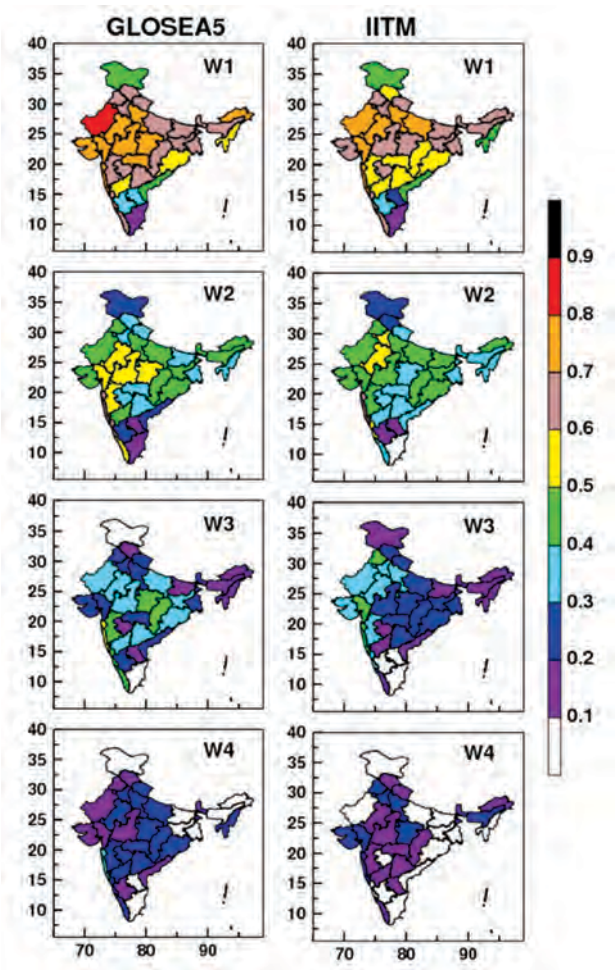


Fig. 2.9: Week wise lead (week 1-4) anomaly correlation coefficient (CC) of JJAS rainfall for UKMO Glosea5 vs IITM prediction system for met subdivisions over India.

The major achievements in the model development activities include: (a) development of an improved genesis potential parameter to predict cyclogenesis in real-time, (b) dynamical downscaling of extended range forecasts to improve the prediction of extreme weather events, and (c) development of an early health warning system based on the extended range forecasts. In addition to these, efforts are underway to develop a multi-physics multi-model ensemble prediction system to improve the forecast skill.

2.4.3. Global Ensemble Forecast System (GEFS) for Short Range Deterministic Forecast

The GEFS based cyclone tracker has been operationalized during the episode of Super Cyclone AMPHAN. The GEFS based cyclone tracker has successfully predicted the ensemble track, landfall and strike probability for the AMPHAN, NISARGA, GATI and NIVAR cyclones, with longer lead as show in **Fig. 2.9** for the AMPHAN cyclone. The GEFS based track was found to have least error compared to deterministic GFS forecast.

The GEFS based Probabilistic Quantitative Precipitation Forecast (PQPF) has also provided reasonable forecast at block level of affected districts of South 24 Pargana, Hooghly, Kolkata. The probabilistic forecasts for all the river basins of India have been developed and shared with IMD for use by IMD's Flood Monitoring Offices. Accurate Wind and Solar forecasts (GFS downscaled with WRF) are being issued to POSOCO, Mumbai and other stakeholders on experimental basis.

2.4.4. 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 forecasts every day and the same is made available on a dedicated website. A

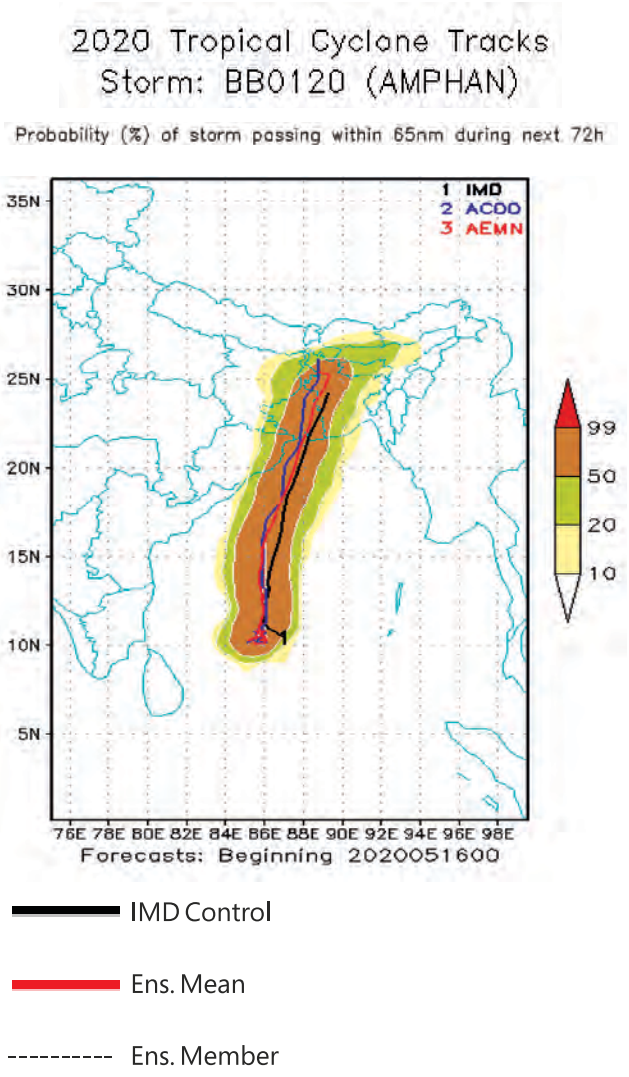


Fig. 2.10 Strike probability based on 17 May 2020 0000 UTC initial condition for super cyclone "AMPHAN (ACOO: control run; AEMN: ensemble mean; IMD: observation).

preliminary analysis of 2019 and 2020 operational forecast during pre-monsoon seasons suggests an average Probability of Detection of 0.90, and False Alarm Rate of 0.64 over the whole region for all months These forecasts and related information are available at: http://srf.tropmet.res.in/srf/ts_ prediction _system/ index.php. GEFS based probabilistic forecast tools for predicting thunderstorms, hails and gusty wind have been developed and operationalized at IMD. WRF based lightning potential index has been developed from the operational IMD WRF output and the tools provided forecast guidance of lightning potentials over lightning prone regions.

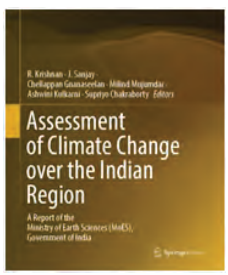
2.5. Centre for Climate Change Research

2.5.1. Assessment of Climate Change over the Indian Region: - A Report of the Ministry of Earth Sciences (MoES), Government of India

A new open access book on Assessment of Climate Change over the Indian Region has been published in June 2020. This is the first climate change report for the Indian region from the Ministry of Earth Sciences, and discusses the influence of human-induced global climate change over the Indian subcontinent,, the adjoining Indian Ocean, the Himalayas and on the regional monsoon. It also briefly discusses policy relevant information based on robust scientific analysis and assessments of the observed and future projected climate change over the Indian region. The assessments presented in this book are based on peer-reviewed scientific publications, published IPCC reports, analyses of long-term observed climate records, paleoclimate reconstructions, reanalysis datasets and climate model projections from the WCRP through their CMIP and the CORDEX South Asia scientific projects. Details are available at:https: //cordex.org/2020/07/03/new-book-on-assessment -of-climate-change-over-the-indian-region/

A Training Workshop on Regional Climate Change Projections:

Climate change analysis using CORDEX regional climate models over South Asia was organized online during 12-21 Oct 2020 with an aim to build underpinning knowledge and skills for analysing regional climate change projections using CORDEX regional climate model simulations. Details are available at: https://www.icimod.org/event/ regional-climate-change-projections-cordex/. CCCR-IITM is a



Springer Nature, 2020, DOI:10.1007/978-981-15-4327-2, 1-226(Open Access, http://www.springer.com /gp/book/9789811543265)

The front page of the national climate change assessment report modeling

partner in the five year (2020-2024) International CORDEX Flagship Pilot Study (FPS) project entitled: *High resolution climate modeling with a focus on mesoscale convective systems and associated precipitation over the Third Pole (TP) region*. This FPS aims to better understand the regional characteristics of water cycle and its variability and changes over the TP and adjoining regions using a set of coordinated high resolution regional climate downscaling experiments. Details are available at: http://rcg.gvc.gu.se/cordex_fps_cptp/

2.5.2 Short Term Climate Variability and Prediction (SCTP): IITM is developing the Decadal Prediction System (DPS) using the CFS2

Different bias/drift corrections methodologies are explored/applied to enhance the skill of the decadal predictions produced in-house as well as CMIP5/CMIP6, with special emphasis to Indian region. A new approach to decadal sea level prediction based on OGCM, forcing from the NCEP CFSv2 (decadal hindcast) is developed. The sea level prediction skill is found to improve significantly, compared to the coupled models.

2.6 South west Monsoon 2020

Southwest Monsoon during June to September Onset

The forecast for the date of monsoon onset over Kerala was issued on 15th May 2020. The onset of southwest monsoon over Kerala was predicted to be slightly delayed as compared to normal date of onset. The monsoon onset date over Kerala was forecast as 5th June with a model error of ± 4 days.

Long Range Forecast

The first stage forecast predicted South-west monsoon rainfall for the country as a whole to be normal (96-104%). Quantitatively, the monsoon seasonal (June to September) rainfall was predicted to be 100% of the Long Period Average (LPA) with a model error of ± 5%. The LPA of the season rainfall over the country as a whole for the period 1961-2010 is 88 cm.

Forecast verification of Southwest Monsoon Rainfall 2020

The actual seasonal rainfall for Southwest monsoon season 2020 the country as a whole was 109% of LPA, which was 4% & 3% 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 16 subdivisions (44% of the total area of the country) and excess in 13 subdivisions measuring 36% of the total area of the country and large excess in 2 subdivisions measuring 6% of the total area of the country. However, the season rainfall was deficient in 5 subdivisions constituting 14% of the total area of the country.

Verification of Long-Range Forecast Southwest Monsoon 2020

The Table 2.2 gives the summary of the verification of the Long Range forecasts issued for the 2020 Southwest monsoon. Fig. 2.11 shows the per cent

Table 2.2 : Verification of long-range forecast southwest monsoon 2020

Region	Period	Forecast (% of LPA)		Actual Rainfall
		15th April	1st June	(% of LPA)
All India	June to September	100± 5	102± 4	109
Northwest India	June to September		107± 8	84
Central India	June to September		103± 8	115
Northeast India	June to September		96± 8	106
South Peninsula	June to September		102± 8	130
All India	July		103± 9	90
All India	August		97± 9	127
All India	August to September		104± 8	118

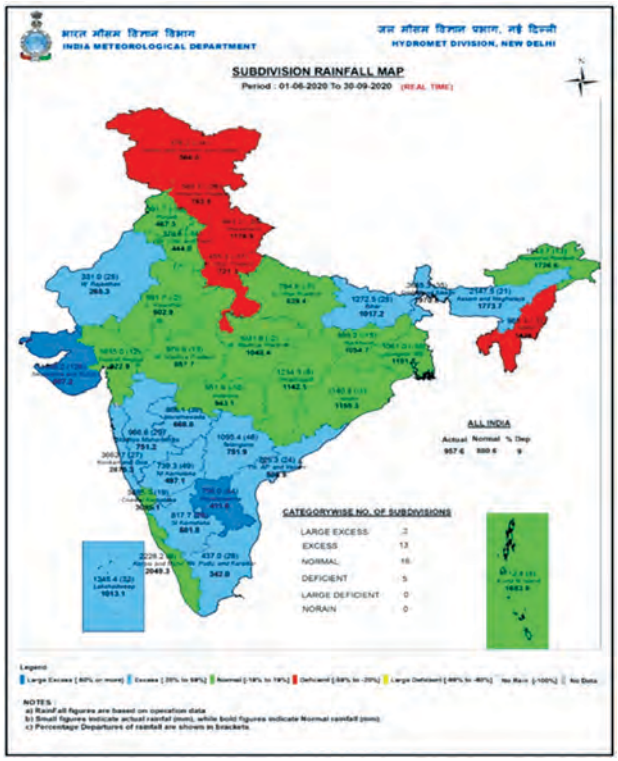


Fig. 2.11. Subdivision-wise southwest monsoon rainfall during June to September, 2020

departure rainfall for 36 meteorological sub divisions during the 2020 Southwest monsoon season.

2.7. Meteorological Services

2.7.1 Metropolitan Air Quality and Weather Services

A gridded COVID-19 lockdown emission inventory for Delhi and Mumbai has been developed. The SAFAR-air quality forecasting model provided a scientific interpretation of unusually elevated levels of CO during lockdown in Delhi and traced sources of CO in central part of India where synoptic scale transport played a significant role. A study was carried out to understand the association of COVID-19 mortality and morbidity with several environmental and weather markers in 6 major metro cities of India namely, Delhi, Mumbai, Kolkata, Chennai, Ahmedabad and Pune. It revealed two unique findings, viz. (a) the baseline levels of $PM_{2.5}$ and NO_2 have been experimentally achieved for the first time due to COVID-19 induced lockdown. It is a level that is naturally present in the atmosphere with minimal anthropogenic emissions under fair weather conditions; (b) a strong association of COVID-19 mortality with baseline $PM_{2.5}$ levels (80% correlation) is found **(Fig. 2.12).** Results also suggest that the warmer temperatures show some sign in minimizing the infections.

2.7.2. Air Quality Early Warning System for Delhi

High-resolution (400 m) operational air quality early warning system for Delhi, India: A first of its kind, high-resolution (400 m) operational air quality prediction system was developed to predict extreme air pollution events in Delhi and issue timely warnings to take necessary steps as per the newly designed Graded Response Action Plan (GRAP) of Government of India. This modeling framework consists of a high-resolution fully coupled state-of-the-science Weather Research and Forecasting model coupled with

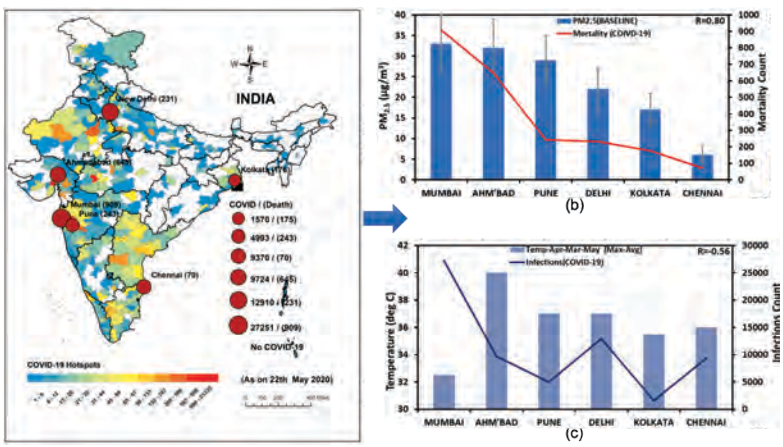


Fig. 2.12 (a) Covid-19 infection counts as on 22nd May 2020; (b) correlation of baseline PM2.5 with mortality; (c) PM2.5 baseline levels and correlation of infection with temperature.

Chemistry (WRF-Chem) and three-dimensional Variational (3DVAR) framework. The system assimilates satellite Aerosol Optical Depth (AOD) retrievals at 3 km resolution, and surface data from 260 air quality monitoring stations in India and high-resolution emissions from various anthropogenic and natural sources including dust and stubble burning. This integrated modeling framework provides forecast at 10 km resolution for entire south Asia region for short range (3-Days) and medium range (10-Days) and short range forecast at 2km resolution for major cities such as Pune, Mumbai, Hyderabad, Kolkata, Patna, Bangalore, Lucknow. The chemical data assimilation is further integrated with dynamical downscaling to obtain improved chemical conditions for the 400 m resolution domain. To efficiently disseminate air quality forecasts to the public and decision-makers in Delhi, a website for Early Warning system **(https://ews.tropmet.res.in) has been lauched.** Fig. 2.13 (a) presents a schematic of the operational air quality forecasting setup and (b) the hourly forecast verification of PM2.5.

Under the Finnish Meteorological Institute (FMI)-IMD Collaborative project, improved System for Integrated Modelling of Atmospheric composition (SILAM v5.7) and ENvironmental information FUsion SERvice (ENFUSER) models have been operationalized at IMD for Air Quality Forecast. Hourly air quality forecast for 72 hours of all criteria pollutants (PM10, PM2.5, O_3, CO, NO_2, SO_2) is generated for the domain (28.362N-28.86N, 76.901E-77.56E) at 30m spatial resolution. The model uses and assimilates a large amount of Geographic Information System (GIS) data to describe the modelling area on a high resolution. This includes a detailed description of the road network, buildings, land-use information, high-resolution satellite images, ground elevation, population data, traffic density, etc. The air quality forecast services have been extended for several non-attainment cities (Kanpur, Varanasi, Allahabad, Bengaluru, Chennai, Kolkata, etc).

2.8. Tropical Cyclone Monitoring and Predictions

During 2020, Nine cyclonic disturbances (CDs) including depressions and cyclones were formed over the north Indian Ocean (NIO) including 5 over the Bay of Bengal (BoB) and 4 over the Arabian Sea (AS) against the normal of 12 CDs per year over the NIO. The year 2020 witnessed 5 cyclones (3 over BoB and 2 over AS) and 4 depressions/deep depressions (2 over BoB and 2 over AS). Both the cyclones over the AS were severe & above intensity cyclones and out of 3 cyclones over BoB, 2 were severe & above intensity cyclones and one was a cyclonic storm.

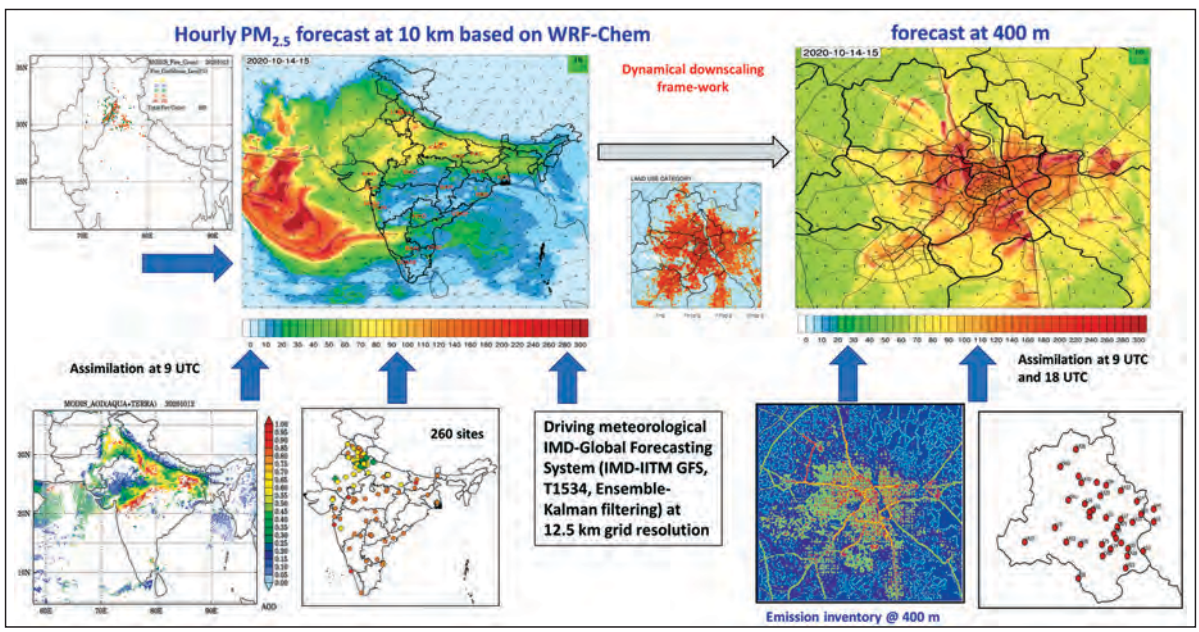


Fig. 2.13. Quick Overview of operational air quality forecasting setup

Details of these CDs over the north Indian Ocean in 2020 are listed below:

(i) Super cyclonic storm (SuCS) AMPHAN over Bay of Bengal (BoB) during 16-21 May

(ii) Depression over south coastal Oman and adjoining Yemen during 29 May-01 June

(iii) Severe cyclonic storm (SCS) NISARGA over the Arabian Sea (AS) during 01-04 June

(iv) Deep depression (DD) over the BoB during 11-14 October

(v) Depression over the AS during 17-19 October

(vi) Depression over the BoB during 22-24 October

(vii) Very severe cyclonic storm (VSCS) GATI over the AS during 21-24 November

(viii) VSCS NIVAR over BoB during 22-27 November

(ix) CS BUREVI over the BoB during 30 November-05 December

Arabian Sea witnessed above normal activity during 2020 with the formation of 4 CDs including 2 cyclones (Nisarga&Gati). The activity over the BoB was subdued this year with the formation of only 3 cyclones during 2020 against the normal of 4 per year. However, the frequency of severe category of cyclones was normal over BoB with the formation of 2 severe category storms (Amphan&Nivar) against the normal of 2 per year. Considering seasonal distribution, while one cyclone (super cyclonic storm Amphan) and another (severe cyclonic storm Nisarga) formed during pre-monsoon and monsoon season respectively, three cyclones (very severe cyclonic storm, Gati and Nivar and cyclonic storm Burevi) formed during post-monsoon season. No CDs formed over BoB during monsoon season.

All the cyclones during 2020 exhibited unique characteristics w.r.t track, intensity and landfall. SuCSAmphan in May, 2020 was the first super cyclone over BoB after the Odisha super cyclone of 1999. Nisarga in June, 2020 was the first severe cyclonic storm (SCS) which crossed Maharashtra coast as a severe category storm after the SCS that crossed Maharashtra coast on 24th May, 1961. GATI in November, 2020 was the first very severe cyclonic storm crossing Somalia coast during satellite era. Gati was the 5th cyclone crossing Somalia coast after a cyclonic storm in November, 1994, Murjan in 2012, Sagar in 2018 and Pawan in 2019. Nivar, the first cyclonic storm over BoB during the post monsoon season caused intense rainfall over activity over north Tamil Nadu & Puducherry, Rayalaseema and south coastal Andhra Pradesh during 24th-26th November. Burevi was the 14th cyclone that crossed Sri Lanka coast during the period 1891-2019.

Brief description of major cyclones during 2020 is given below:

Super cyclonic storm AMPHAN over the Bengal during 16-21 May

The Super Cyclonic Storm (SuCS) "AMPHAN" originated from the remnant of a low pressure area which developed over southeast BoB on 13th May morning. It concentrated into a depression (D) over southeast BoB in the early morning of 16th May. It intensified into the cyclonic storm "AMPHAN" over southeast BoB in the evening of 16th. It intensified into a super cyclonic storm (SuCS) around noon (0600 UTC) of 18th. Thereafter, it weakened slightly and crossed West Bengal - Bangladesh coasts as a VSCS, across Sundarbans, near latitude 21.65°N and longitude 88.3°E during 1530-1730 hrs IST of 20th May, with maximum sustained wind speed of 155 - 165 kmph gusting to 185 kmph. It weakened into a well marked low pressure area over north Bangladesh and neighbourhood around mid-night of 21st May.

First information about genesis of Amphan was provided in the extended range outlook issued on 7th May (about 6 days prior to formation of LPA, 9 days prior to formation of depression and 13 days prior to Landfall) indicating that the system would intensify into a cyclonic storm and move initially northwestwards and recurve north-northeastwards towards north BoB. The landfall point forecast errors for 24, 48 and 72 hrs lead period were 5.5, 11.0, and 35.2 km respectively. The landfall time forecast errors for 24, 48 and 72 hrs lead period were 0.5, 0, and 2.0 hours respectively. The observed and forecast track of

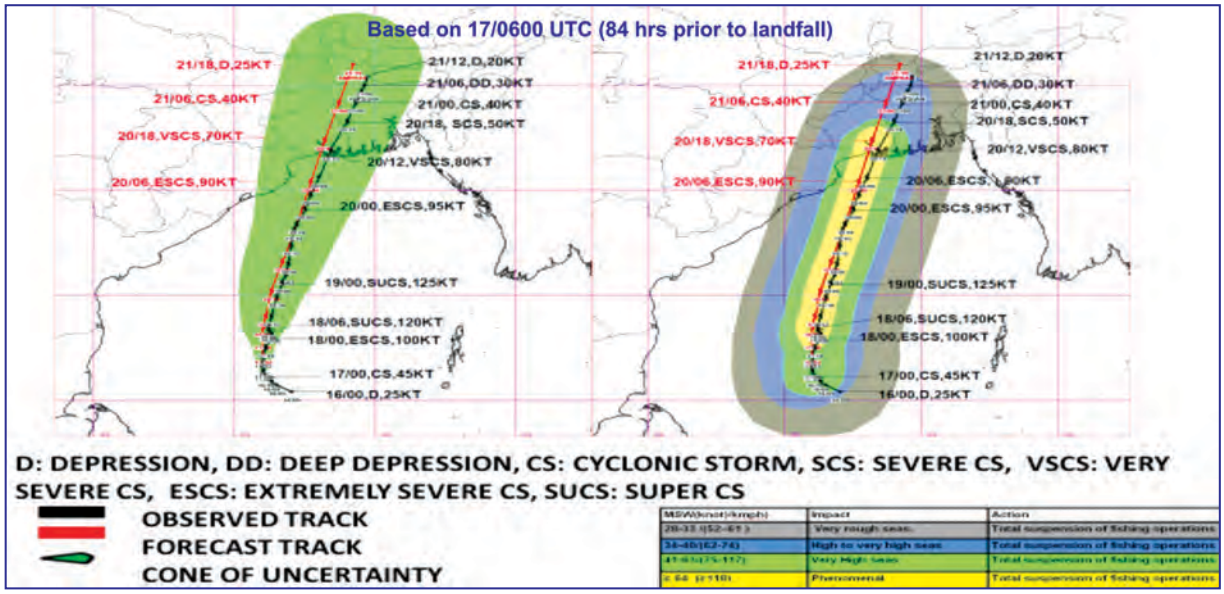


Fig. 2.14 Observed and forecast track along with cone of uncertainty and quadrant wind distribution based on 0600 UTC of 17th May (84 hrs prior to landfall) of SuCS AMPHAN indicating accuracy in landfall, track & intensity predictions.

the system demonstrating accuracy in track, landfall and intensity prediction is presented in Fig. 2.14.

Severe Cyclonic Storm "NISARGA" over the Arabian Sea during 01st-04th June

Severe Cyclonic Storm "NISARGA" developed from a low pressure area which formed over southeast AS in the early morning of 31st May. It concentrated into a depression over eastcentral AS in the early morning of 1st June. It intensified into the cyclonic storm **"NISARGA"** in the noon of 2nd June. It intensified into a severe cyclonic storm in the early morning of 3rd June. It crossed Maharashtra coast close to south of Alibagh as a severe cyclonic storm during 1230-1430 hrs IST of 03rd June. It weakened into a low pressure area over southeast Uttar Pradesh and adjoining Bihar in the afternoon of 5th June.

First information about development of low pressure area over southeast Arabian Sea was given in the extended range outlook issued on 21st May about **10 days prior** to the formation of low pressure area over the southeast & adjoining eastcentral Arabian Sea and Lakshadweep on 31st May. **With the formation of** low pressure area over southeast & adjoining eastcentral Arabian Sea on 31st May morning, IMD **issued first bulletin at 0855 hrs IST of 31st May and** indicated that the system would intensify into a cyclonic storm and reach north Maharashtra and Gujarat coasts by 3rd June, **(about 77 hours prior to landfall of severe**

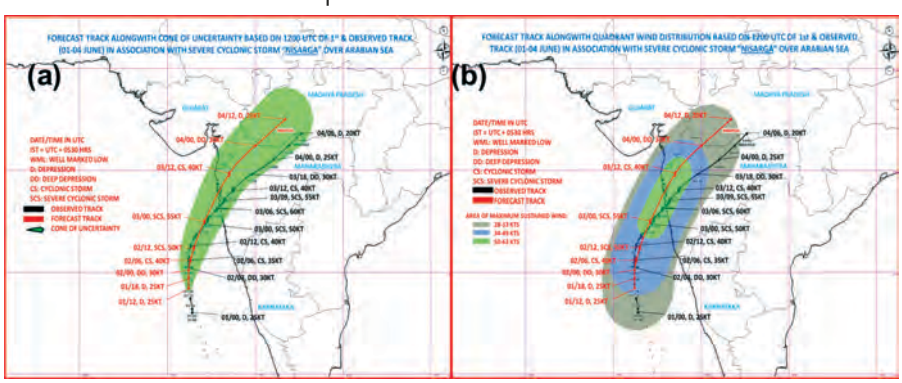


Fig. 2.15. Typical observed and forecast track alongwith cone of uncertainty and quadrant wind distribution based on 1200 UTC of 2nd June (20 hrs prior to landfall) of SCS NISARGA

cyclonic storm NISARGA). Typical observed & forecast track alongwith cone of uncertainty and quadrant wind distribution based on 1200 UTC of 2nd June about 20 hours prior to landfall is presented in **Fig. 2.15.**

Very Severe Cyclonic Storm "NIVAR" over the Bay of Bengal during 22nd -27th November 2020

Very severe cyclonic storm developed from a low pressure area which formed over Equatorial Indian Ocean (EIO) and adjoining central parts of south Bay of Bengal (BoB) on 21st November. It concentrated into a depression over the same region in the early hours of 23rd November. It intensified into the cyclonic storm "NIVAR" in the early morning of 24th over southwest BoB. It intensified into a very severe cyclonic storm in the afternoon of 25th. It crossed Tamil Nadu & Puducherry coasts near Puducherry during midnight of 25th and early hours of 26th as a very severe cyclonic storm. It weakened into a well marked low pressure area over south coastal Andhra Pradesh and adjoining westcentralBoB in the early morning of 27th November.

The track, intensity and landfall of all the cyclonic storms during 2020 were predicted accurately with sufficient lead time by India Meteorological Department leading to significant decrease in loss of lives.

2.9 SASCOF and other Long-Range forecasts (Winter and Summer)

Consensus statement for Northeast Monsoon season (October to December 2020)

Consensus Statement on the Forecast for the 2020 October to December (OND) Season Rainfall and Temperatures over South Asia was issued in 17th Session of the South Asian Climate Outlook Forum (SASCOF-17) held from 23rd to 24thand 28th September, held online due to CoViD-19 pandemic. Summary of the forecast is as follows:

Below-normal rainfall is likely during the 2020 October - December (OND) season over the southern parts of the South Asia including some parts of extreme southeastern India, most parts of Sri Lanka and Maldives, which climatologically receive good amount of rainfall during the season. Below normal rainfall is also likely during the season over the northwestern and northern parts of South Asia including some areas along the foot hills of Himalayas. These areas, however, climatologically receive very low rainfall during OND season.However, above normal rainfall is likely over the land areas around northern and central Bay of Bengal, most parts of north peninsular India and southern parts of Myanmar. Normal rainfall is likely over the remaining parts of the region. During the season, normal to slightly above normal temperatures are likely, over most parts of the region.

Temperature Forecast for Hot Weather (April-June, 2020) Season:

The April-May-June (AMJ) season average maximum temperatures are likely to be warmer than normal by ≥0.5 °C to <1 °C over some of the meteorological subdivisions of northwest, west and western peninsular India. The April-May-June (AMJ) season average minimum and mean temperatures are also likely to be warmer than normal by ≥0.5 °C peninsular India. Above normal heat wave conditions are likely in the core heat wave (HW) zone during the season (April-June).

2.10. Environmental Meteorology Services

IMD contributes in the field of atmospheric environment to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) programme. The main objective of GAW is to provide data and other information on the chemical composition and related physical characteristics of the atmosphere and their trends, required to improve understanding of the behavior of the atmosphere and its interactions with the oceans and the biosphere. IMD maintains the following environmental monitoring network.

a) Ozone Monitoring Network b) Precipitation and Particulate Matter Chemistry Monitoringc) Aerosol Monitoring Network d) Sun-Skyradiometer Network e) Black Carbon Aerosol Monitoring Network f) Multi-wavelength Integrating

Nephelometer Network g) Chemical Characterization of Aerosols h) Air Quality Forecasting and Research i) High Altitude Background Climate Monitoring Station.

2.11. Agro-Meteorological Advisory Services under GraminKrishiMausamSeva

Establishment of District Agromet Unit (DAMU) In the year 2020, 45 District Agromet Units were established in the premises of Krishi Vigyan Kendras jointly by IMD and ICAR under Gramin Krishi Mausam Sewa of MoES. As such, 310 District Units (181 DAMUs along with the existing 130 AMFUs) prepare medium range weather forecast based biweekly agromet bulletin at district and block level. At present these bulletins are issued for 690 districts and 2256 blocks in the country. SMS advisories to ~43 million farmers through mKisan portal of DAC&FW and PPP partners and 1084 WhatsApp Groups have been formed.In collaboration with ICAR-CRIDA, Extended Range Weather Forecast based Agromet Advisory Service Bulletins is also issued on Friday every week.

Establishment of North Karnataka Agromet Forecasting & Research Centre (NKAFC)

The Tripartite MOU among University of Agriculture Sciences (UAS) Dharwad, Karnataka State Natural Disaster Monitoring Centre (KSNDMC) Bangalore and India Meteorological Department (IMD) was signed to start the activities from NKAFC of IMD located in UAS Dharwad. The centre started issuing weather and crop specific AAS bulletins for 11 districts of North Karnataka on daily basis. Biweekly AAS bulletin on every Tuesday and Friday is also issued from August 2020.

2.12 Hydro-meteorological Services

Flood Meteorological Offices (FMOs, 14 in all over India) of IMD provide Meteorological support in the form Quantitative Precipitation Forecast (QPF) for 153 sub-basins to Flood Forecasting Divisions (FFDs) of Central Water Commission (CWC) to help them issue "Flood warnings/Flood alerts". The meteorological support is provided in terms of sub basin wise 'Quantitative Precipitation Forecast (QPF)' and 'Probabilistic Quantitative Precipitation Forecast (PQPF)' in different categories 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 flood season.Sub basin-wise

Quantitative Precipitation Estimate for Day-1, Day-2, Day-3 using WRF ARW,for Day-1 to Day-5 using MME and for Day-1 to Day-7 using GFS based by IMD are computed anduploaded on IMD website operationally. Similarly, new sub-basinwiseproducts of NCUMmodel based on 00UTC data for Day 1 to Day 7 was made operational anduploaded in the IMD website.Sub-basinwise probabilistic QPF based on dynamical model. GEFS and NEPS was made operational in the IMD website. A special QPF and HM bulletinwere provided operationally to the Central Water Commission in respect of 10 Major river basinsfor flood management under the supervision of MHA.

During the year 2020, design storm studies of fourteen (14) projects have been completed and results communicated to the concerned project authorities. An amount of Rs.35,13,408/- has been collected for carrying out the design storm studies in respect of projects received from private/profit earning agencies.

South Asia Flash Flood Guidance System (SAsiaFFGS)

Secretary, Ministry of Earth Sciences dedicated Flash Flood Guidance Services, first of its kind for South Asian countries namely India, Bangladesh, Bhutan, Nepal and Sri Lanka on 23 October 2020. The system was launched virtually in the presence of distinguished DG's & PR's of all member countries, delegates from WMO, HRC, NDMA, CWC, IIT and other dignitaries from National & International institutions. Following activities are performed by SAsiaFFGS:

- National & South Asia Regional Guidance bulletins are regularly being monitored & sent to all stakeholders in operational mode through Email & Social Media, WhatsApp Group. w.e.f. 24th Oct 2020.

- Flash Flood Guidance Services of South Asia is being communicated & updated regularly through social media and received appreciations from National & International stakeholders.
- International Operational SAsiaFFGS training for forecasters of about 150 trainees across the region from India, Bangladesh, Nepal, Bhutan, Sri Lanka, WMO and HRC, USA was organised through VC during 8 to 10 July 2020

2.13 Aviation Services

Airport Fog Monitoring and Forecasting system in 2019-2020

Fog is one of the major aviation weather hazards. In each winter seasons, Airports across plains of north India are highly vulnerable for 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. Absence of desired visibility by aviators causes of delay/cancellation and diversion and sometimes serious safety issues for flights. Hence, information on fog formation, intensification and dissipation at RWY, visibility and trend forecasts from time to time are prime needs for airlines, airport operators and ATC.

In December, 2019-January, 2020, observations of dense fog as reported by 30-minute airport surface visibility data, 3-h surface visibility data and INSAT 3D fog products show the major dense to very dense fog spell developed and intensified with visibility <50m from 15 Dec 2019 over airports located in the Amritsar- Delhi sectors mainly covering the western parts across Indo-Gangetic plains. Extensive dense fog was further observed across most of the northern plains by 18 December when Lucknow, Gaya, Patna and Varanasi had recorded very dense fog. This dense fog spell continued to persist across this vast region till 3 Jan 2020. Thereafter, in Jan 2020, dense fog spells were of shorter spells with 10-13 Jan 2020 mainly observed over airports located over central parts of IGP region covering Lucknow, Varanasi, and Gaya while during 16-19 Jan 2020, it was only restricted to its western parts covering Amritsar- Delhi sectors. With such higher number of dense fog events observed at Delhi during 2019-20, under WIFEX 2019-20, it could also able to capture world class data jointly with IITM Pune by deploying around 31 types of equipment at IGIA along with 20 m flux tower.

Forecasters across the airports in IMD have effectively used INSAT 3D day-night time detection RGB channel which provides fog areas at 30-minute gap, surface visibility data, RVR and NWP based customized fog models providing fog model forecast products runs upto 380 m resolution for Delhi airport and at 2-4 km for other airports. IMD also expanded its real time fog forecast and early warning system and issued 6-hourly fog forecasts updates at 12 airports across north India via IMD web page and OLBS. All such new rapid development in the field have helped in reducing the flight disruption and helped for better safety practice for winter 2019-2020 and present season 2020-21.

Winter Fog Campaign (WIFEX)

The 6th phase of winter fog experiment was started at IGI Airport, New Delhi and Hissar during November 2020 - March 2021. New visibility instruments were installed at IGIA, New ATC tower. Additionally, Hissar measurement site was made operational by installing visibility meter, soil sensors, automatic weather sensors and net radiation sensors on 10 meter flux tower. All the sensors were connected to Pune server for real-time data access. Empirical relations for predicting visibility based on microphysical data based on WiFEX campaign (NC, LWC, visibility) has been developed and incorporated in the operational forecasting system. Fog forecasting system based on physics ensemble was developed for Delhi (2 km and 400 m resolution) and northern region of India (4 km resolution), and forecast was generated for both visibility and LWC.

Chapter - 3 | Ocean Services, Modelling, Application, Resources and Technology (O-SMART)

The O-SMART scheme is being implemented by the Ministry towards providing services related to continuous observation of our oceans, development of technologies and exploratory surveys for sustainable harnessing of our oceanic resources (both living and non-living) and promotion of front-ranking research in ocean sciences. The scheme is implemented through MoES institutes viz. Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), National Centre for Polar and Ocean Research (NCPOR), National Centre for Coastal Research (NCCR) and Centre for Marine Living Resources and Ecology (CMLRE). The highlights of major achievements under the O-SMART scheme during the year are stated below:

3.1 Ocean Sciences and Services

3.1.1 Tsunami Warning Services

Indian Tsunami Early Warning Centre (ITEWC) at Hyderabad monitored 23 earthquakes of magnitude ≥ 6.5 during the period January 2020 - November 2020, of which only 2 earthquakes had occurred in the Indian Ocean region. Careful assessment of these earthquake events did not lead to Tsunami threat alerts. Being the Tsunami Service Provider (TSP) for the Indian Ocean, necessary bulletins were also sent to Indian Ocean Rim countries and Intergovernmental Oceanographic Commission (IOC). INCOIS, along with the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) of Intergovernmental Oceanographic Commission (IOC), UNESCO, organized the Indian Ocean Tsunami Exercise (IOWave20) on 13th and 20th October 2020 (Fig. 3.1). World Tsunami Awareness Day was celebrated at INCOIS by organizing a Webinar on "Tsunami Awareness & Preparedness" in coordination with National Disaster Management Authority (NDMA) and Odisha State Disaster Management Authority (OSDMA) on 5th November, 2020. Around 190 participants from coastal disaster management organizations, scientific and academic institutions attended this webinar. IOC-UNESCO conferred the Certificate of Recognition and Certificate of Appreciation as Tsunami Ready communities to Venkatraipur and Noliasahi villages communities and OSDMA Officials, through a virtual event organized on 7 August 2020, which is first of its kind in the Indian Ocean region (Fig. 3.1).

3.1.2 Marine Fisheries Advisory Services (MFAS)

The flagship service of INCOIS - Potential Fishing Zone (PFZ) advisories are being disseminated continuously for the period of January to November 2020 in smart map and multilingual text form on daily basis subject to satellite data availability, fishing-ban period and adverse sea-state. During the same period, INCOIS

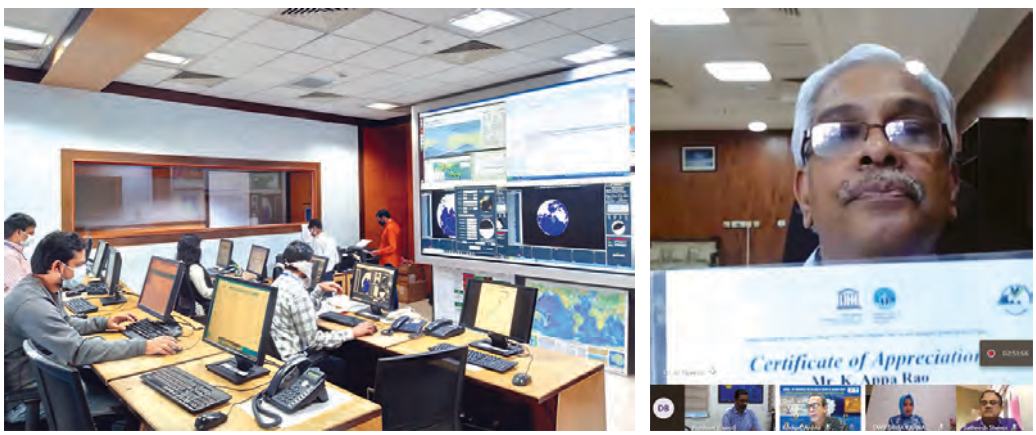


Fig. 3.1 (a) IOWave20 exercise participation (b) Tsunami Ready certification by IOC-UNESCO

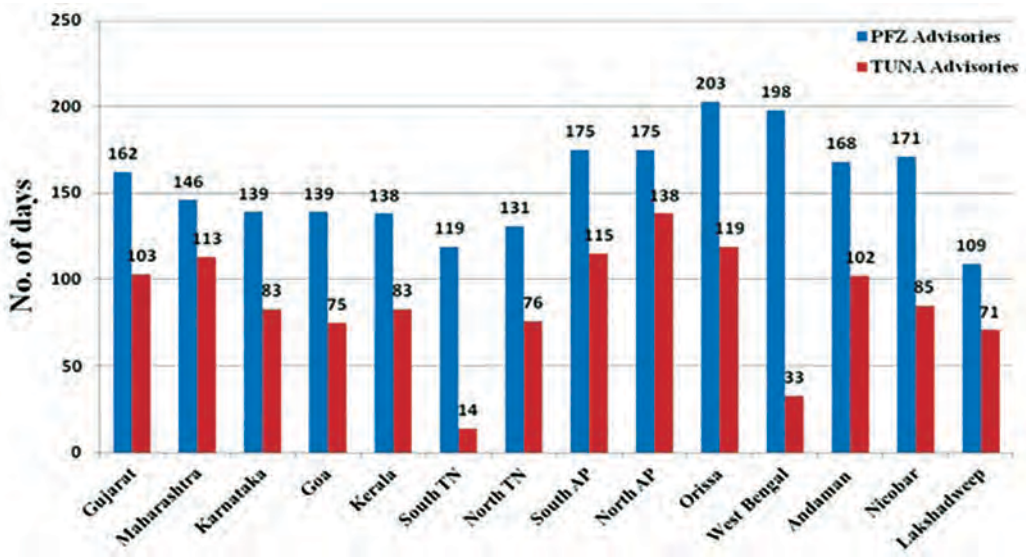


Fig.3.2 Number of PFZ and Tuna PFZ advisories issued during January -Nov, 2020.

also disseminated Yellowfin Tuna advisories with the maximum fishing depth information (Fig. 3.2).

3.1.3 Ocean State forecast Services

Small Vessel Advisory and Forecast Services System (SVAS) launched to provide Ocean state information to numerous small fishing vessels that ply the coastal waters of India. The Swell Surge Forecast System was also launched for coastal population safety. Ocean state during super cyclonic storm Amphan (May 16-21, 2020) in the Bay of Bengal and severe cyclonic storm Nisarga (May 29 - June 4, 2020) in the Arabian Sea was monitored using the models, satellite and in-situ instruments, and forecasts were issued through Joint INCOIS-IMD bulletins. The forecast showed excellent coherence with in-situ observation. These bulletins were regularly updated in the INCOIS website and were sent by email and SMS to the registered users in Andhra Pradesh, Odisha, West Bengal and Andaman & Nicobar Islands. A total of 15 storm surge bulletins were issued during Amphan and 8 storm surge bulletins were issued during Nisarga cyclone (Fig. 3.3).

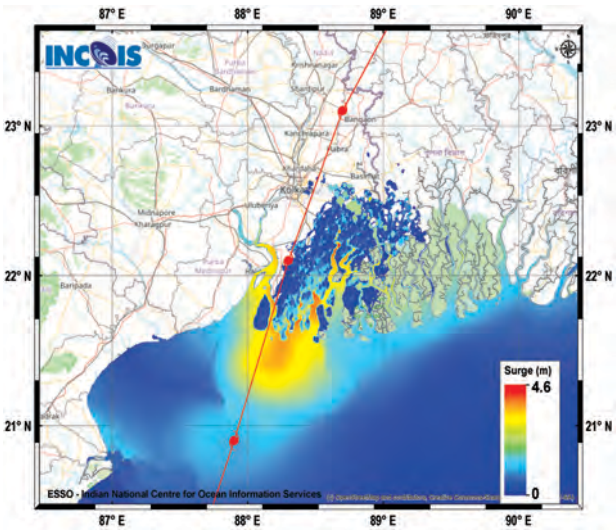


Fig. 3.3 Storm surge and inundation forecast.

3.1.4 Multi-hazard Vulnerability mapping (MHVM) and blending of coastal topography with bathymetry

The 3D Visualization and analysis system (3DVAS) application was integrated with updated data (3D, 2D and geophysical data) and maps. The available high-resolution topographic data (ALTM, CARTOSAT, SRTM) and coastal bathymetry data (NHO, GSI) were blended and together for the entire east coast of India to support the needs of coastal modeling of Tsunami and storm surge (Fig. 3.4).

3.1.5 Coral Bleaching Alert System

Satellite based Coral Bleaching Alerts were provided as advisories on the hotspots, degree of heating and the variation of SST anomalies on bi-weekly basis. There were no events of coral bleaching recorded during 2019-20.

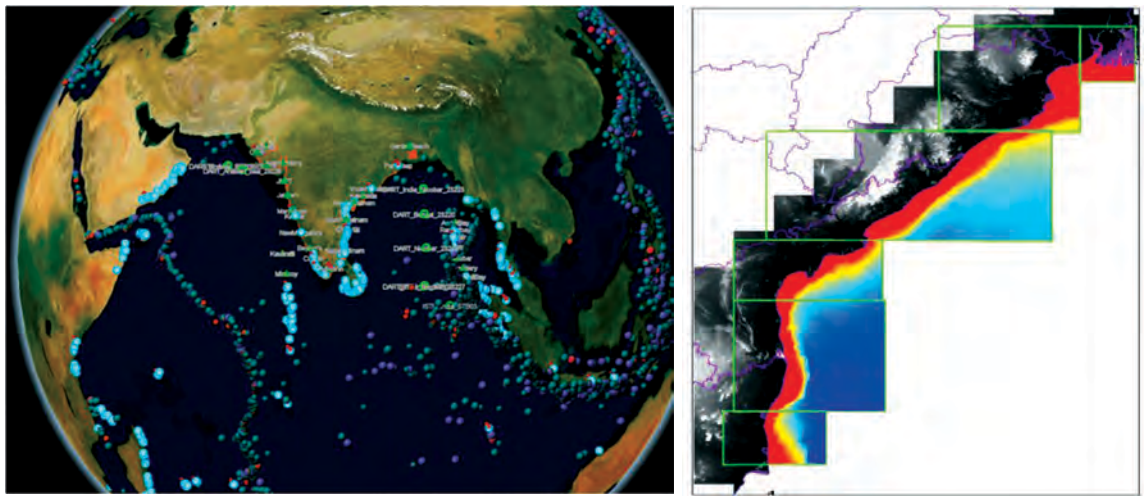


Fig. 3.4 (a) MHVM and (b) merged topography and bathymetry of the east coast of India

3.1.6: Data Centre and Services

The INCOIS data centre is central repository for the oceanographic data, with strengthened real-time data reception, processing, and quality control of surface meteorological and oceanographic data from a wide variety of ocean observing system such as Remote-sensing satellites, Argo floats, moored buoys, drifting buoys, wave rider buoys, tide gauges, wave height meter, ship mounted autonomous weather stations and HF radars. Further, surface met-ocean data has been regularly disseminated to various operational agencies in the country in near-real time.

The data centre also obtained and archived in delayed mode data from various observing systems such as XBT/XCTD observations, Met observations (NODPAC), OMM Cruise data, IMD marine meteorological data, ADCP data, OMNI buoys data etc.

The data centre has made significant progress in developing derived data-products and innovative web-based applications to increase utilization of the data. The development of the Digital Ocean (DO), an innovative web-application project to manage ocean data, is completed (Fig. 3.5). The DO provides a dynamic framework to efficiently integrate and

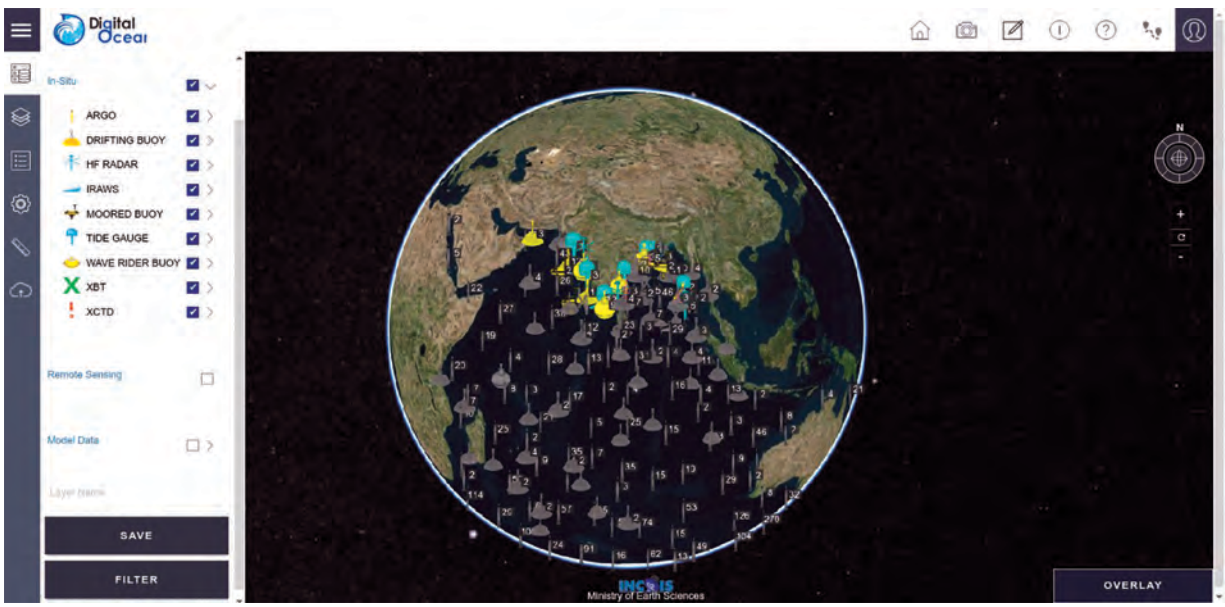


Fig. 3.5 Snapshot of Digital Ocean application: In Situ ocean observing platforms

manage heterogeneous ocean data along with advanced visualization (including 3D and 4D animations) and analysis tools.

It is designed as a one-stop solution for all the data related services such as archiving, visualizing and dissemination for various data products at the INCOIS data centre.

3.1.7 INCOIS Flux mooring

The highly sophisticated Flux Buoy Mooring heavily equipped with surface marine meteorological and sub-surface oceanographic sensors designed by the Woods Hole Oceanographic Institution (WHOI), USA, has been deployed in northern Bay of Bengal at 17.8°N and 89.5°E on 23 May 2019 as part of the "Coupled Physical Processes in the Bay of Bengal and Monsoon Air-Sea Interaction" project under the National Monsoon Mission Program. Such Direct Covariance Flux System (DCFS) is the first of its kind deployed in the Indian Ocean. The complex flux buoy and mooring system was successfully retrieved during a cruise onboard ORV Sagar Nidhi (SN-156) on 07 October 2020. Both latent and sensible heat flux at an annual scale (June, 2019 to July, 2020) has been worked out (Fig. 3.6).

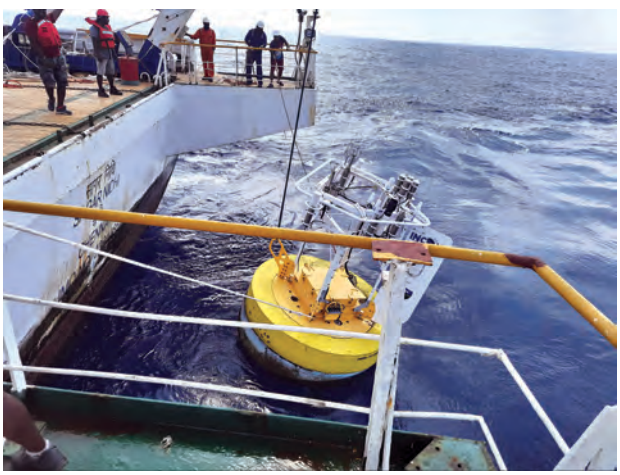
3.1.8 International Training Centre for Operational Oceanography (ITCOocean)

The ITCOocean continued its operations using the state-of-the art facilities. ITCOOcean was recognized as Regional Training Centre (RTC) RTC under UNESCO - Ocean Teacher Global Academy 2 (OTGA-2) for a period of 3 years from 2020 - 2023. During January 2020 - November 2020, **1731** persons were trained of which **1150 (Male: 642, Female: 508)** are from India and **581 (Male: 345, Female: 236)** are from **73** other countries. Three online training courses are conducted, which covered various topics like "Discovery and Use of Operational Ocean Data Products and Services", "Understanding Sea Level: data analysis and applications" and "Fishery Oceanography for Future Professionals".

3.2 Studies in Marine Living Resources (MLR)

3.2.1 Marine Ecosystem Dynamics of eastern Arabian Sea (MEDAS)

The MEDAS programme is being implemented along the eastern Arabian Sea basin with the objective to address the influence of major physical mechanisms viz. upwelling and convective mixing, and their interplay on the biogeochemistry and ecosystem response, and to evaluate the effect of terrestrial inputs on coastal ecosystem. The upwelling was found to influence the mixed layer dynamics of the entire EAS at varying ranges during summer monsoon (SM) and the effect of convective mixing process confined to the north during the winter monsoon (WM). The evaporative cooling during January-March in the north eastern Arabian Sea (NEAS) initiates the convective mixing and triggers the upward transport



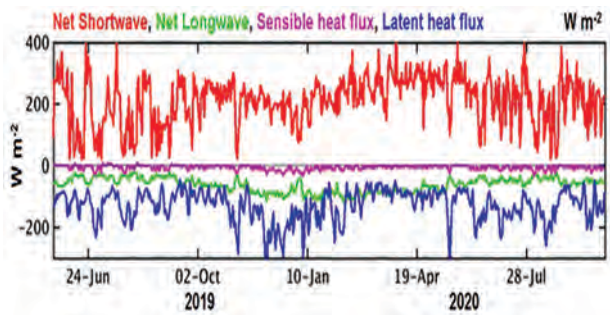


Fig. 3.6 (a) INCOIS flux mooring recovery by INCOIS and NIOT scientists (b) Net shortwave radiation, net longwave radiation, latent heat flux, and sensible heat flux derived from INCOIS flux mooring measurements.

of nutrients from the base of the mixed layer and upper thermocline enhancing biological production. High nutrient ratios (N/P) found along with winter convection at the NEAS and with summer monsoon upwelling significantly enhanced the surface production led to high particulate organic carbon content in the upper column (Fig. 3.7).

Severe oxygen depletion over the western Indian shelf during summer monsoon is the result of surfacing of low oxygen. Further, intense anoxic stress conditions in the central region between 12-18°N during September enforces strong denitrification and sulphur reduction resulting this region to be the hot spot for the production of greenhouse gases like CO_2, N_2O and CH_4, and their effluxes have a significant contribution to regional budgets. Year-long Oxygen Minimum Zone (DO <20 µM) dynamics along the eastern Arabian Sea showed it is thicker and extends beyond 1000m; its thickness decreased from north to south which closely followed the changes in thermocline depth. Moreover, core-OMZ (DO<5 µM) has a perennial southern boundary in the central EAS at ~15°N and it expands seasonally up to 12°N, which is primarily caused by the significant aeration by a poleward undercurrent during the summer monsoon. The phytoplankton community structure using the pigments analysis revealed the dominance of diatoms in the coastal waters of the EAS basin during winter monsoon. In the offshore dominance of cyanobacterial population is observed consisting of large proportions of pico-nano planktons along with considerable micro phytoplankton representing mixotrophic ecosystem.

3.2.2 Resource Exploration and Inventorization System

The density and biomass of macrofauna in the Andaman waters showed a decreasing trend from shallow to deep areas, which was relatively higher along eastern margin than that of western margin. Polychaetes were the dominant taxa, followed by crustaceans, molluscs, other macrofaunal groups and echinoderms. Polychaetes showed a general declining trend with an increasing water depth, while crustacean density increased with depth. Four species of crustaceans (under the infra Order Brachyura and Anomura) new to science were documented. Brittle stars are the most species rich group and diversified among the echinoderms in Indian waters with highest diversity reported from the Andaman Sea followed by the Arabian Sea and Bay of Bengal. Phylogenetic diversity is the highest in the Andaman Sea, followed by the Arabian Sea, and was relatively low in the Bay of Bengal. To understand evolutionary relationship, the amplicons of mitochondrial genes CO1 and 16S of length 650 bp from 18 species of deep sea crabs, 3 species of galatheid squat lobster and 1 species of albinid mole crab were successfully sequenced. The intertidal fauna surveys at Lakshadweep islands documented Polyclads (15 species), Heterobranchs (9 species), Echiurnas, Echinoderms (9 species) and

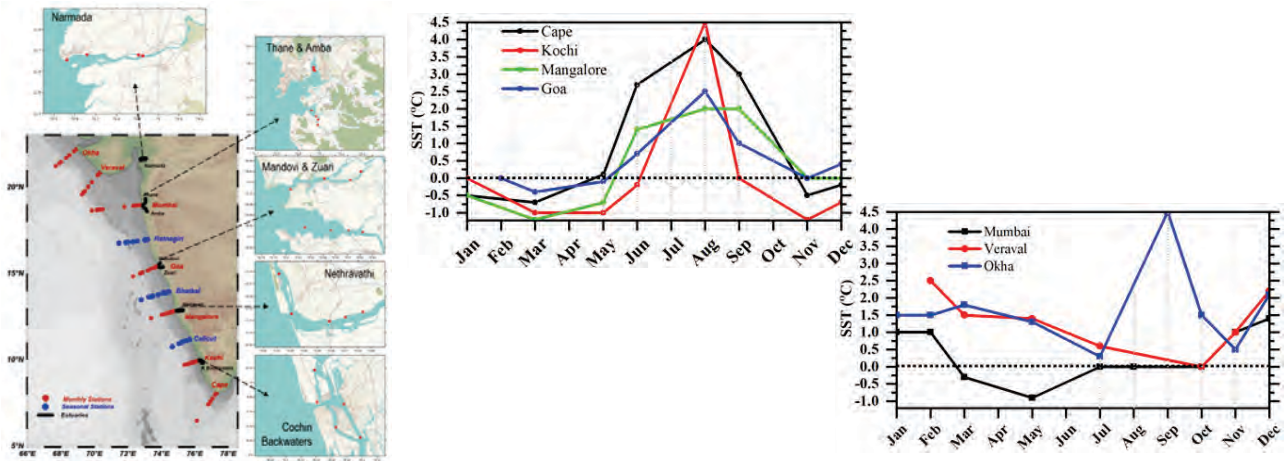


Fig. 3.7 (a) MEDAS locations (b) Monthly Variability of Local Temperature Anomaly as an indicator of upwelling at the MEDAS locations during 2018.

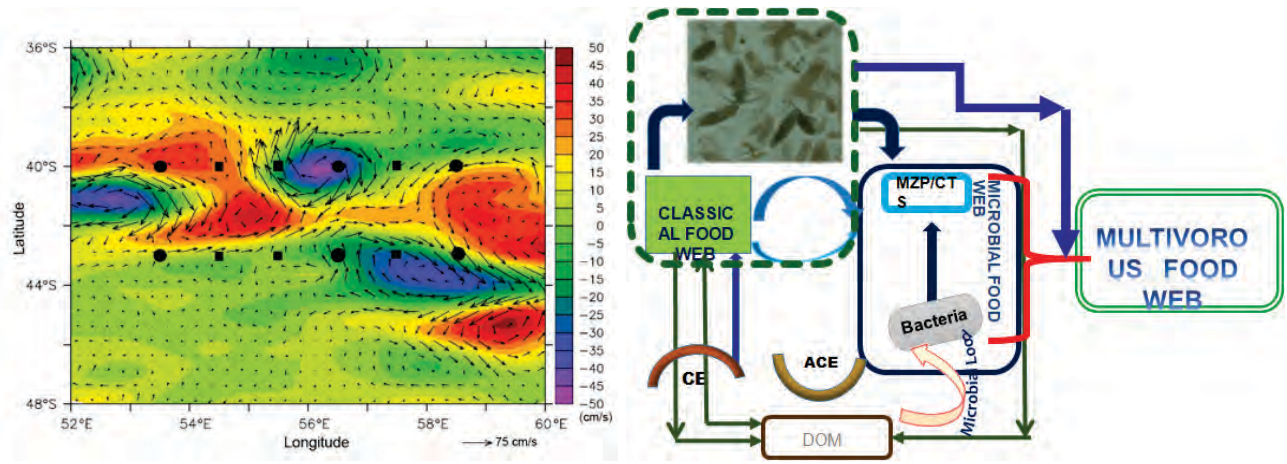
Fig. 3.8 Marine crustaceans reported new to science (a) Crocydocinussaravananei (b) Neolithodesindicus (c) Prionospioatrovita

Polychaetes. Partial Sequencing of taxonomically informative genes such as CO1, 16S, 18S was successfully done in polyclads to differentiate the colour morphotypes (Fig. 3.8).

The deep-sea fish of Order Stomiiforms which significantly contributed to the food web were inventoried and 13 new records to Indian Ocean were documented. Fish otolithas a tool has been used to differentiate between species based on morphology, food and feeding and locomotion strategies among the deepsea fishes. A check list of Lophiiformes from Indian EEZ is revalidated to 36 species under 17 genera and 8 families. Continuous underway fish egg sampler (CUFES) recorded highest number of fish eggs from coastal station of Valappad (1197 nos. $100m^{-3}$) followed by the offshore station along Karwar (572 nos $100m^{-3}$). The marine mammal observations suggest that the eastern Arabian Sea is rich in cetacean diversity. The survey also documented the presence of blue whales from the high seas of Gujarat Coast. The maximum cetacean sighting was noticed at a depth of 500 to 1000m. Marine mammals distribution, Polyclads distribution and 11th southern ocean Expedition has been augmented to Ocean Biogeographic Information System.

3.2.3 Food web structure of Indian Ocean Sector of Southern Ocean

The Southern Ocean is a very dynamic ecosystem comprising many fronts and zones. Among the fronts, the Subtropical Front (STF) is a region of high eddy activity exhibiting spatio-temporal variability. The role of microzooplankton in structuring the planktonic food web structure was elucidated. In a highly dynamic environment like the STF, discriminating the



3.9 (a) Study area showing the dynamic nature of STF (b) Schematic representation of planktonic food web showing the mediatory role of MZP in the STF of the IOSO (CE-Cyclonic Eddy, ACE-Anticyclonic Eddy, DOM-Dissolved Organic Matter, MZP-Microzooplankton, CTS-Ciliates).

relative dominant pathways (microbial & classical) was crucial as the intersection of both pathways was observed in both systems. The hypothesis of multivorous food web in STF holds good, wherein the significance of MZP is inferred as the trophic nexus between microbial and classical food web.

3.3 COASTAL RESEARCH

3.3.1 Marine and Coastal Pollution

Selected locations along the Indian coast are being monitored for the various physicochemical, biological and microbiological characteristics of seawater and sediments to detect the periodical changes in the seawater quality. The data sets generated are providing information on the National Indicator Framework for United Nations Sustainable Development Goal-14 (SDG 14- Life Below Water). A Coastal Water Quality Index (CWQI) map was prepared for the Andhra Pradesh coast based on the results obtained from the cruise conducted in August 2020. (Fig. 3.9)

In order to assess the level of pollution and develop a prediction system for the benefit of the coastal stakeholders, a pilot study was undertaken since December 2019 using an automated sensor buoy system deployed at 11m water depth off Marina beach, Chennai (Fig. 3.10b). A water quality model developed for Chennai coastal waters provides 5 days forecast of coastal water quality and is disseminated to state governments (SPCB) through digital platforms.

Ecotoxicology and Ecological Risk Assessment are being undertaken in Ennore, Uppanar, and Vellar estuaries for protection of coastal and marine organisms from metal pollution. The primary water quality standards for Class SW-III Waters [for Industrial Cooling, Recreation (non-contact) and Aesthetics] and Class SW-V Waters [for Navigation and Controlled Waste Disposal] for metals (Cd, Cu, Hg, Zn, Pb, As, Cr) and pesticide Monocrotophos has been accepted by Ministry of Environment and Forests and Climate Change for considering in the notification.

Marine plastics research is in progress involving international collaboration covering the Indian coastline to prepare the data for evolving marine litter policy and management and to identify the hot spots. Awareness programs on beach litter and pollution and its adverse impact on biodiversity through coastal cleanup efforts have been taken up involving school, college students, government and non-government organization and general public through citizen science approach.

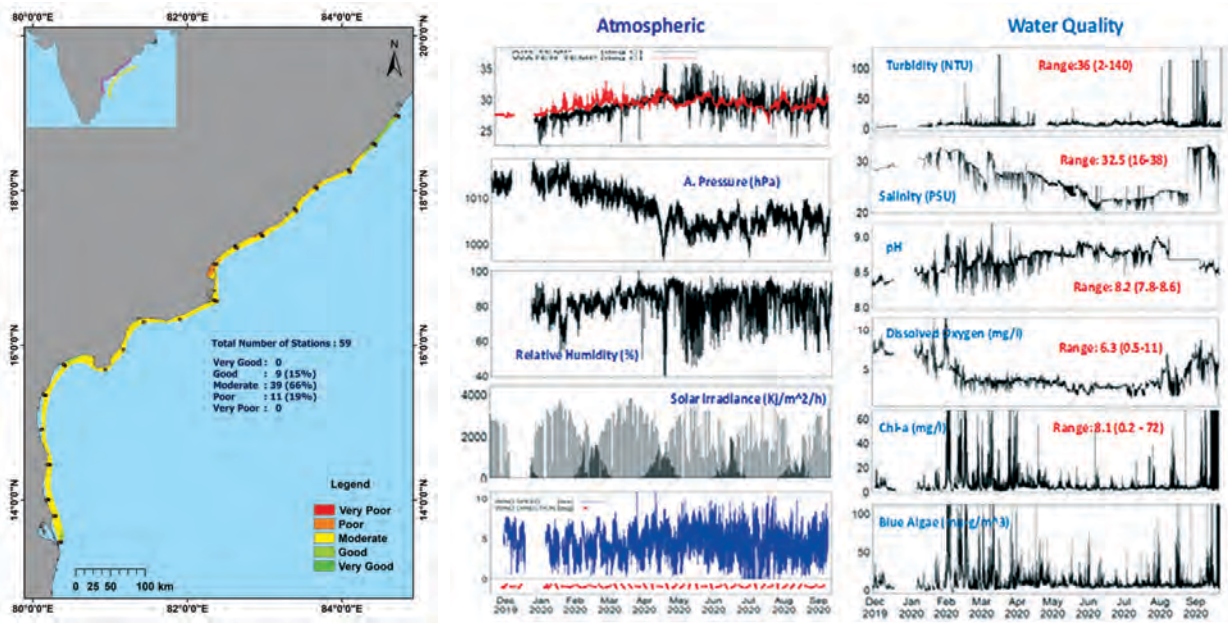


Fig. 3.10 (a) CWQI for Andhra Pradesh coast and (b) buoy measurements off Marina Coast

Fig. 3.11 (a) Training on sea water quality standard to coastal state stakeholders (b) Marine Litter and Microplastics sampling and analysis

3.3.2 Coastal Processes and hazards

Shoreline change rate for entire Indian coast is analysed using Indian satellite images and field measurements. 526 numbers of shoreline change maps (1:25000 Scale) has been generated using standard protocol using 11 data sets for 1990-2018. Web-based coastal change information system has been developed in GIS platform to facilitate various coastal managers to deal with coastal development and management processes. Seasonal monitoring of beach morphology, coastal changes, sediments and littoral environment observation at 14 sites has been also carried out to understand sediment dynamics along the coast. Possible shoreline retreat considering different climate change scenarios i.e RCPs (2.6, 4.5. 6.0 & 8.5) of IPCC AR5, for Cuddalore, Mahabalipuram, Chennai coast has been undertaken.

Ministry of Earth Sciences (MoES) in Collaboration with Disaster Management Department, Municipal Corporation of Greater Mumbai (MCGM), Govt of Maharastra developed the Integrated Flood Warning system for Mumbai referred to as iFLOWS-MUMBAI, This was launched through video conference jointly by Chief Minister of Maharashtra, Shri Uddhav Thackeray and Union Earth Sciences Minister Dr. Harsh Vardhan on 12th June 2020. Extensive bathymetry data collection was undertaken in all rivers by NCCR in association with MCGM and IMD, Mumbai to generate improved output. The system is also planned for working in now cast mode using precipitation data available from the dense network of rain gauges and radars established by the Ministry. A web GIS based decision support system is built to calculate the vulnerability and risk of elements exposed to flood

3.3.3 Coastal Habitats and Ecosystems

Ecosystem modelling studies are being carried out with two projects namely MEDAS (Marine Ecosystem Dynamics of Eastern Arabian Sea) for West coast shelf waters in association with CMLRE and for Pulicat Ecosystem (SE coast). Data pertaining to the various physical and biogeochemical parameters were

Fig. 3.12 (a) National Shoreline Change Information System (b) IFLOWS-Mumbai inauguration and testing during Monson 2020

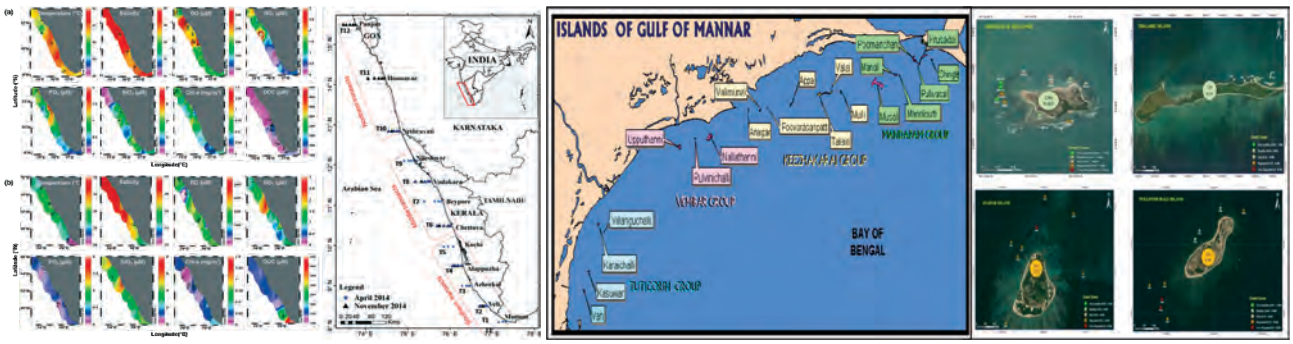


Fig. 3.13 (a) Distribution of various physical and biogeochemical parameters along the shelf water of West coast of India. (b) Monitoring, Mapping and Restoration of Coral Reefs in Gulf of Mannar

collected and analyzed which yielded that the health of the ecosystem is deteriorating particularly upto 2 km from the coast. Coral reef monitoring was carried out at 21 islands of Gulf of Mannar and Palk Bay regions. Time series and the Coral Health Index (CHI) analyses indicate that the reef health have significantly recovered and improved. As part of Coral Reef Restoration Activities a total of 89 frames were installed for study the growth and survival rate in restore coral in Palk Bay regions and it was observed that the 3 months average growth rate of coral species *(Acropora Formosa)* was 1.30 ± 0.63 cm/month.

3.4 Ocean Technology

3.4.1 Ocean observation system

Moored Ocean Observation Network (MOON): Six deep sea buoys were moored to provide open ocean data which are disseminated in real-time to INCOIS, IMD and also used for tsunami early warning. The IndARC V mooring was successfully deployed. The moored buoy network in Bay of Bengal withstood and captured and real time signature was contributed to IMD in issuing cyclone warnings related cyclones (Amphan, Nisarga and Nivar). The World Meteorological Organization, IMD and other service providers recognized the importance of the buoy observations.

Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA): Under the MoES NOAA agreement RAMA buoy network, 25 moored buoys in Indian Ocean has been maintained. One RAMA cruise of 26 days covering 10 deployments, 10 retrievals and one CTD operation were completed.

3.4.2 Energy & fresh water

Establishment of desalination plants in UT Lakshadweep Islands: One Low Temperature Thermal Desalination (LTTD) plant at Kalpeni has been successfully commissioned in January 2020 (Fig. 3.14). Installation of five more LTTD plants with a capacity of 150 m^3/day in Amini, Androth, Chetlat, Kadamat and Kiltan Islands of UT Lakshadweep is in advanced stage.

Fig. 3.14 Views of the Sump, Trestle and Plant building of Kalpeni LTTD Plant

3.4.3 Coastal engineering

Design of the Offshore reef with beach nourishment for coastal protection at Puducherry: A detailed hybrid solution with submerged north reef, offshore south reef and beach nourishment was successfully implemented and resulted in formation of wide beach in Puducherry. The response of the shoreline to submerged reef was regularly monitored through beach profiles and bathymetry survey (Fig. 3.15a).

Feasibility studies on Fixed and floating platforms for offshore Wind Turbine: Technical services were provided for design and implementation of two LiDAR based data collection platform at Gulf of Kutch for M/s Suzlon, Ministry of New and Renewable Energy (MNRE) at Gulf of Khambhat for) (Fig. 3.15 b).

3.4.4 Ocean Science and Technology for Islands

Marine Algal Biotechnology: Pilot scale mass culture of marine Chlorella vulgaris in 25 tonne capacity paddle wheel operated raceway pond at Pamanji yielded a maximum biomass of 1.8 g/L. Experimental scale mass culture of marine Spirulina in 2 tonne raceway with F/2, for production of pharmaceutical important lutein from marine microalgae was developed and the technology was transferred to M/s Vectrogen Biologicals Private Limited, Hyderabad through NRDC.

Microbial Biotechnology: The marine bacterium *Alcanivorax dieselolei* EB3 NIOT capable of degrading polyaromatic hydrocarbons (PAH) was isolated from seawater samples from 3000 m depth off equator. Black pigmented melanin producing non-sporulating yeast *Hortaea werneckii* N129A8 isolated from sediment samples collected from 3500 m depth was cultured in laboratory and a highest production 26 g/L of biomass with maximum concentration of melanin intracellular (355 mg/L) and extracellular (225 mg/L) were achieved. A new strain of *Streptomycin olivaceus* NIOT-Ch-40 producing piericidin (monohydroxy pyridines) and *S. fenghuangensis* NIOT-Ch-34 producing thiostreptone (Cyclic peptide) was isolated from sediment collected from 2000 m depth. Multiplex PCR kit for detection of virulent *Enterococcus faecalis* in food, water and environment samples was developed and the technology was transferred to M/s SAAI Electro Biogenic India Private Limited, Chennai, through NRDC (Fig. 3.16).

Open Sea Cage Culture: Two days hands-on training in open sea fish cage fabrication, deployment and culture management was organized on 11-12 December, 2019 at Kollam, Kerala jointly with the State Fisheries Department, Kerala. The open sea cages at Olaikuda were redeployed in new location to maintain the health of ecosystem. Environmental Impact Assessment studies in sea area in between Rutland and Chidiatappu for the expansion of open sea cage culture initiative of Andaman and Nicobar administration has been completed (Fig. 3.17)

Fig. 3.15 (a) Performance of the Submerged Reef (b) Installed LiDAR based Data Collection Platform, and Geophysical investigation at Gujarat.

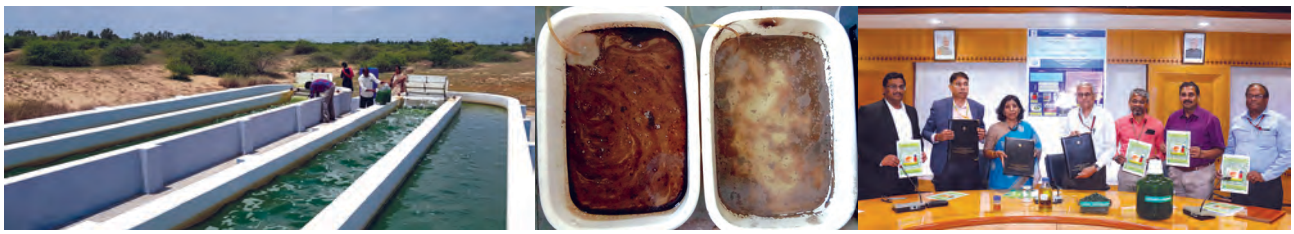


Fig. 3.16 (a) Chlorella culture in 25 T raceway - Pamanji (b) Biodegradation of crude oil by *A. dieselolei EB3* (c) Transfer of technology for production of Lutein from chlorella

Fig. 3.17 (a) Training participants at Kollam (b) Mooring grid preparation training (c) Cobia stalked in cages at North Bay

3.4.5 Deep Sea Technologies and Deep-Sea Mining

Development of an Integrated Mining System for Mining of Polymetallic Nodules from 6000m depth: The developed A tracked mining machine was successfully tested in the Bay of Bengal on very soft water-saturated soil at depths of 3420 m for locomotion, traction, shrinkage and remote control (Fig. 3.18)

Design and Development of 6000 m depth rated Manned Submersible: Indigenous design for the development of a 6000m depth rated Manned Submersible capable of carrying 3 persons with an operating duration of 12 hours and emergency endurance of 96 hours is completed. A 6000m depth-rated 2.1m diameter titanium alloy personnel sphere is being developed in association with VSSC-ISRO and another such for shallow water of 25mm shell thickness with acrylic windows, entry hatch and penetrator plates capable of housing 3 persons was manufactured indigenously. The depth qualification for the shallow water personnel sphere has been successfully carried out at a depth of 180m in the Bay of Bengal (Fig. 3.19a).

Technology for gas hydrates: Sea trials of wire-line autonomous coring system (WACS) capable of taking long core samples for a length of 100 m below the sea floor up to 3000m water depths was developed. Sea trial was conducted using ORV Sagar Nidhi during January 2020, the systems was and deployed at Gas hydrates site in KG Basin (1070 m depth) and subsea drilling was carried out successfully up to 60 m below the sea floor. Deep water drilling brought out two horizons of paleo-venting carbonate platform (Fig. 3.19 b & c)

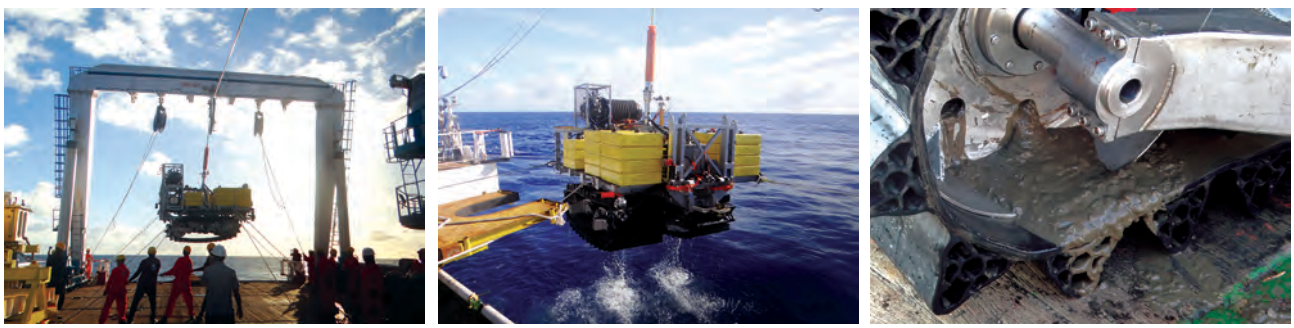


Fig. 3.18 (a) & (b) Mining Machine Sea Trials and (c) seafloor image with track at 3420 m water depth

Fig. 3.19 (a) Shallow water personnel sphere deployment and testing onboard Sagar Nidhi (b) Deployment of Autonomous Coring System at Gas Hydrate Site in Krishna Godavari Basin (c) Subsea operation at 1070 m

3.4.6 Marine Sensors, electronics and Acoustics system

Indigenous 2D/3D Sub-Seabed Imaging SONAR has been developed and sea trial was carried out off Chennai, Royapuram harbor. 2D acoustic images of buried objects and shipwreck were obtained and generated. Low frequency synthetic aperture side scan sonar, array configuration has been worked out with the existing transducers and subsystems, as suggested by the design review committee.

Deep Sea Autonomous Underwater Profiling Drifter (D-AUPD): 500m workable Deep Sea Autonomous Underwater Profiling Drifter (DAUPD) is developed in-house. Prototype units are tested for laboratory cycling test trials and a short duration deployment carried out up to 110 m depth operation at underwater acoustic research facility (UARF) of NPOL in Idukki, Kerala. Pre & Post ballasting and weight trim down of two DAUPD systems are carried out (Fig. 3.20)

Open Sea Fish Cage Culture Technologies: A two metre submergible Spear type fish cage with automatic fish feeder mechanism is developed and demonstrated at Andaman Islands. Moreover, Internet of things (IoT) based bio mass estimation technique has been developed in estimating the fish growth inside the open sea fish cage, the proto system tested at CIBA facility at Chennai.

Indigenization of Drifting Buoy with INSAT Communication: Indigenization of Drifting Buoy with INSAT Communication has been completed and

Fig.3.20 DAUPD - RF Antenna test & Field trials.

technology licensing agreement is signed with two Indian industries under NRDC for commercialization (Fig. 3.21). IRNSS (Indian Regional Navigation Satellite System) based NavIC (Navigation with Indian Constellation) satellite receiver module in DB system implemented and field tested. 3 Nos of DB systems deployed in the equatorial region of Indian Ocean and mapped the mixed layer surface (MSL) current during March - July 2020.

C-Profiler: The C - profiler is designed using a fish which carries conductivity, temperature and depth (CTD) sensors as payload collecting shallow water data which is vital for ocean predictions.

Development of Deep Ocean Ambient Noise Measurement System (DANMS): The deep ocean noise measurement system deployed in Arabian Sea as part of AD09 OMNI mooring (Lat 8° 14′ N, Lon 73° 18′ E) during November 2018 was retrieved successfully. A new Deep Ocean Ambient Noise Measurement System (DANMS) developed for long

Fig. 3.21 (a) Signing of DB Technology Licensing Agreement (b) C--Profiler testing

term deep ocean noise data acquisition and tested in the open sea off Chennai and successfully deployed in Arabian Sea as part of OMNI buoy AD09 (Lat: 08° 10'N, Lon73°17'E) at 2190 m depth.

Ice Melting Noise in Winter in Arctic Kongsfjorden: Subsurface data from IndArc mooring system developed in Arctic region on salinity, currents and water temperature were retrieved and analyzed. Ice melting sounds have been identified in winter 2015, 2016 and 2017 but no melting events in winter 2018 was identified (Fig. 3.22). Winter sea ice melting is associated with positive anomaly of water temperature due to warm seawater entering the fjord as well as the anomalous increase in surface air temperature.

Coordinated Arctic Acoustic Thermometry Experiment (CAATEX)

The Acoustic receiver system of NIOT with NERSC (Nansen Environmental and Remote Sensing Centre Norway) mooring has been successfully retrieved from the Central Arctic Ocean (Lat: 81°47'3.24"N, Long: 22° 0'8.49"E) during September 2020, by the CAATEX Team. The system was acquiring transmitted signals in sea for 360 days, in synchronous with the other acoustic receivers in the experiment.

Vector Sensor Array (VSA) Enhancements towards Coastal Surveillance Applications

A LabVIEW based application has been developed for characterizing underwater acoustic vectorsensors. A

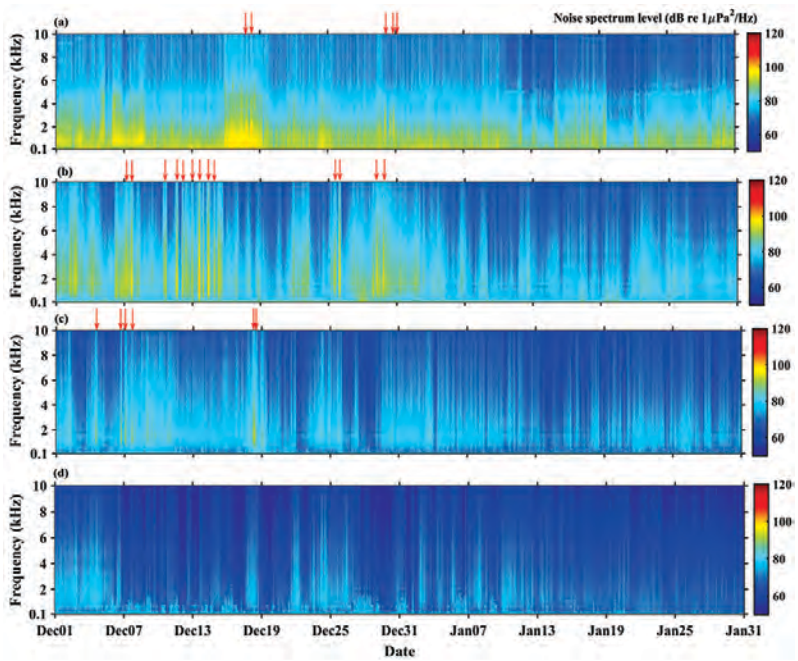


Fig. 3.22 Noise due to sea ice melting in Arctic winter during a. 2015-16 b. 2016-17 c. 2017-18 d. 2018-19

turntable system is used for positioning the VSA in underwater for determining its directionality pattern.

3.5 Ocean survey and mineral resources:

3.5.1 Geoscientific Studies of the Exclusive Economic Zone (EEZ)

Towards improved exploration and utilisation of the wide variety of living and non-living resources along the coastal regions of India, NCPOR has thus far completed 72 cruises for Multibeam Swath bathymetry surveys and covered a total area of 16,92,688 km^2, that comprises ~90.25% of the deep water (>500m) blocks of Indian EEZ. Two survey cruises were undertaken by NCPOR in the Arabian Sea onboard ORV-Sagar Kanya during 2020-21. A total of 39,585 km^2 area was surveyed using Multibeam Echosounder (MBES) along with 8 CTD/SVP stations. Detailed mapping and interpretation of morphotectonic structure of Alleppey-Trivandrum Terrace Complex (ATTC) and its role in the evolution of the margin was undertaken. The analysis and interpretation of bathymetry along Palar basin, Eastern Continental Margin of India (ECMI) reports twenty submarine canyon for the first time and grouped as the Palar Canyon System (PCS) (Fig. 3.23). The Marine Geo-Scientific Database (MGSDB) at NCPOR is being periodically enriched with various datasets acquired by participating organizations viz. NIOT, NIO and GSI.

3.5.2 Extended Continental Shelf Program of India

India submitted its first partial submission to the Commission on the Limits of the Continental Shelf (CLCS) for the Eastern and Western Offshore region in May 2009. A sub-commission was constituted (CLCS) to examine the India's claim in the western offshore region. The proceedings of the sub-commission are currently underway.

3.5.3 Studies on Hydrothermal Sulfides

Hydrothermal sulfides programme aims to identify the potential zones of hydrothermal mineralization and to carry out scientific research in the frontier areas of hydrothermal systems in the mid-oceanic realm. Extensive survey and sampling operations carried out in the area including geophysical surveys, water column sampling, sediment and rock sampling, physical and chemical mapping etc. provided convincing evidence of plume activity in more than a dozen numbers of locations. As per the International Seabed Authority (ISA) protocols, systematic baseline data generation is also carried out. Two cruises were undertaken during March - June 2020 and 13 locations as the potential zones of hydrothermal activity. Two new inactive sulphide mineralization sites were discovered in Cluster A and Cluster B region. Studies of samples recovered showed presence of sulphide mineralization (Fig. 3.24 a) and Demosponges Geodiabarrettiand is unique in SWIR (Fig. 3.24 b). Spherules (Fig. 3.24 c) recovered from the CIR shows the presence of anhedral magnetite, wustite with sub-micron sized sulphide particles showing linkage with hydrothermal process or silica-under saturated magmatic activity (Fig. 3.24 c).

3.5.4 Survey and Exploration for Polymetallic Nodules

An expedition to the Central Indian Ocean Basin (CIOB) was undertaken by CSIR-NIO, onboard *RV*

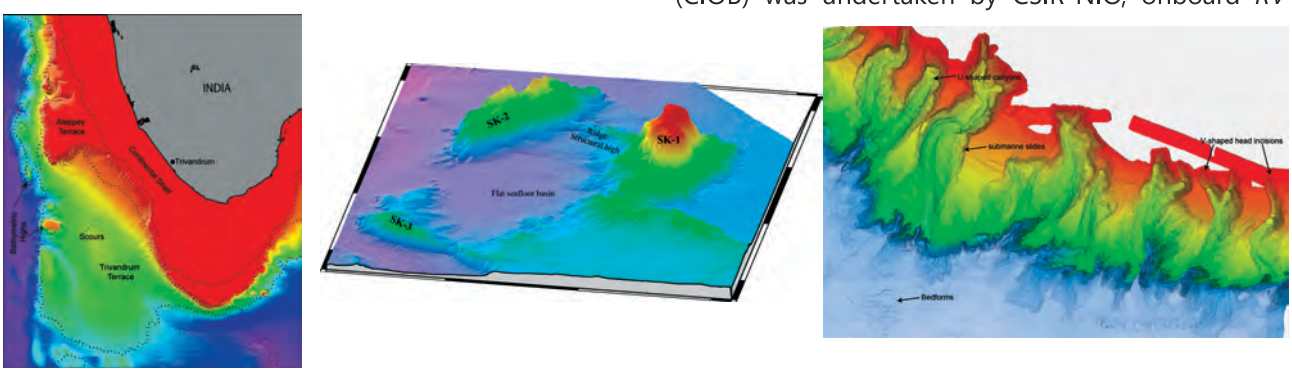


Fig. 3.23 (a) Bathymetric map of the ATTC (b) SKBHC in the Eastern Arabian Basin (c) 3D map showing various canyons in Palar Basin

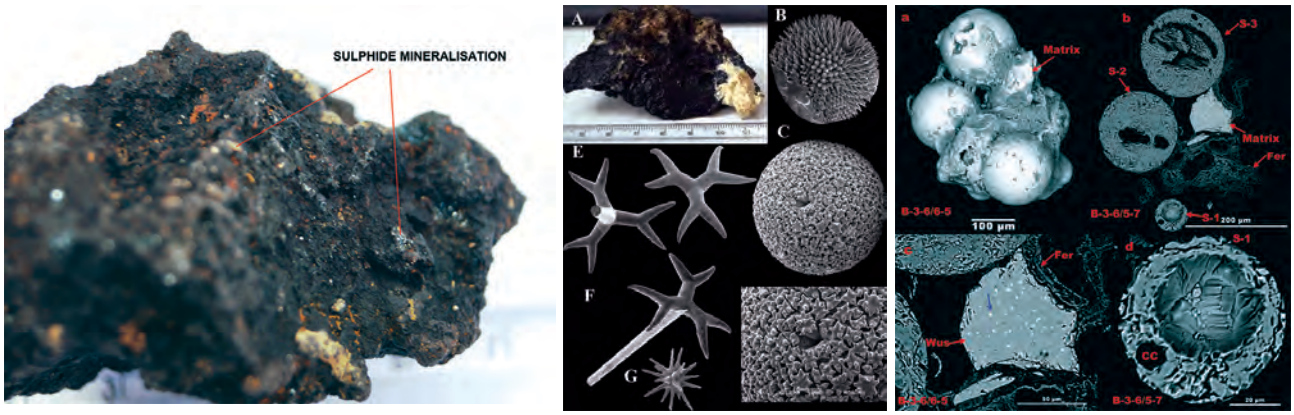


Fig. 3.24 (a) Sulphide samples recovered from Cluster-B. (b) Deep-Sea sponges recovered from SWIR (c) Spherules recovered from CIR sediments.

Sindhu Sadhana (SSD-071) during February-March, 2020 for a period of 32 days, with 6.25 km x 6.25 km grid sampling in the Revised First Generation Minesite (RFGM) Area. Nodule sampling is carried out with Okean Grab and nodule abundance is calculated. The experiment for extraction of Cu, Ni, Co and Mn from nodules is being carried out by Indian Institute of Minerals and materials Technology CSIR-IMMT in bench scale testing following integrated ammoniacal and acid process flowsheet. The metals were separated by solvent extraction from mixed bulk sulphide liquor and leach residues were used in SiMn alloy preparation. The processes are also being tested in 50 L and 5 kg scale respectively.

3.6. Research Vessels

- During the year 2020, ORV Sagar Kanya has undertaken 04 cruises and has been utilized for 100 days at sea. Cruise SK-365 to SK 367 was organized for *Swath bathymetric surveys in the Arabian Sea* under Geoscientific studies of EEZ programmes and SK 368 for IOGL programme in Indian Ocean for recovery of Ocean Bottom Seismometers. The Drydocking and other repairs were carried out.
- Sagar Nidhi has completed survey in Bay of Bengal. Also undertook successful deployment and retrieval of SAIC Tsunami Buoys at Bay of Bengal by SAIC-INCOIS. It was deployed for 176 days for scientific observation at sea during 2020.
- Seawater Quality Monitoring & Micro-plastics study in Bay of Bengal was carried out by NCCR being on-board Sagar Manjusha. It was utilized for 65 days for scientific observation and cruising at sea during 2020.
- Sagar Tara completed three scientific cruises of single beam survey & site selection for construction of desalination plants in Islands of Lakshadweep. This ship was used scientific observation covering 95 days at sea during 2020.
- Sagar Anveshika was used for seawater quality monitoring and micro-plastics study in the Bay of Bengal by NCCR and CSIR-NIO Vizag. This vessel spent 113 days for scientific observation at sea.
- Sagar Sampada was deployed for undertaking work in the area of marine living resources. This ship was used scientific observation covering 100 days at sea during 2020.

Chapter - 4 | Polar and Cryosphere Research (PACER)

4.1. Scientific Studies in Antarctica

4.1.1 Polar Cryosphere and Ice Core Studies

Snow cores were collected during the 39th Indian Scientific Expedition to Antarctica, along a coastal transect in the central Dronning Maud Land, East Antarctica **(Fig. 4.1)** to understand the modern snow accumulation patterns around the ice rises and the remote contribution to the glaciochemical processes in East Antarctica.

4.1.2 Enhanced dust influx to the South Atlantic sector of Antarctica during the late-20th Century: Causes and contribution to radiative forcing

The dust flux profile of an ice core from the coastal Dronning Maud Land (71°20'S, 11°35'E), East Antarctica reveals three stepwise increase during 1905-1929, 1930-1979, and 1980-2005 C.E. time with an average of 0.83, 4.7, and 12.88 mg/m^2/year, respectively. The increased aridity and favourable wind conditions over Southern South America (SSA), a potential dust source to Antarctica, caused an increase in dust production and transport during the late 20th century.

4.1.3 Characteristics of ice rises and ice rumples in Dronning Maud Land (DML) and Enderby Land, Antarctica

Glaciological knowledge and regional datasets (satellite imagery, surface mass balance and ice thickness) of the DML and Enderby Land coasts revealed large changes in the extent and surface morphology of ice shelves and characteristic timescales of ice rises with particular focus on ice rises, over the past several millennia **(Fig. 4.2)**. Based on the findings, ice rises suitable for drilling ice cores for paleoclimate studies as well as ice rises suitable for deciphering ice dynamics and evolution in the region were highlighted.

4.1.4 Biogeochemical process studies in Antarctic Surface Environments

Mesocosm experiments were conducted to understand the impact of photochemical and microbial activities on dissolved organic carbon (DOC) and ionic constituents in cryoconite holes and surface snow environments in Antarctica. Additionally, cryoconite holes in the natural environment were monitored under different light conditions. In-situ measurements of primary and bacterial production were also carried out in the surface snow and cryoconite holes. Mesocosm and natural experiments showed that in the summer, photosynthetic activity led to net DOC accumulation in cryoconite holes. Primary production was found to contribute only 10-15% of the DOC pool in cryoconite holes, with other processes such as viral-induced bacterial lysis, dissolution of organic carbon from the underlying sediment and photochemical production of DOC

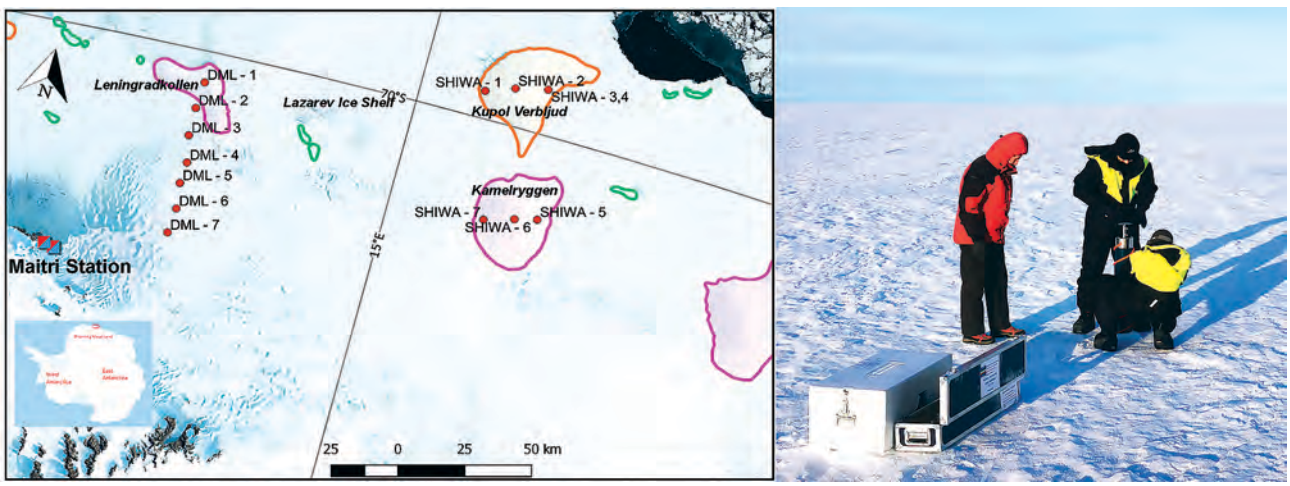


Fig. 4.1 Snow sample locations (Red dots) and snow coring using Kovacs Mark V Ice Drill in coastal Dronning Maud land, east Antarctica.

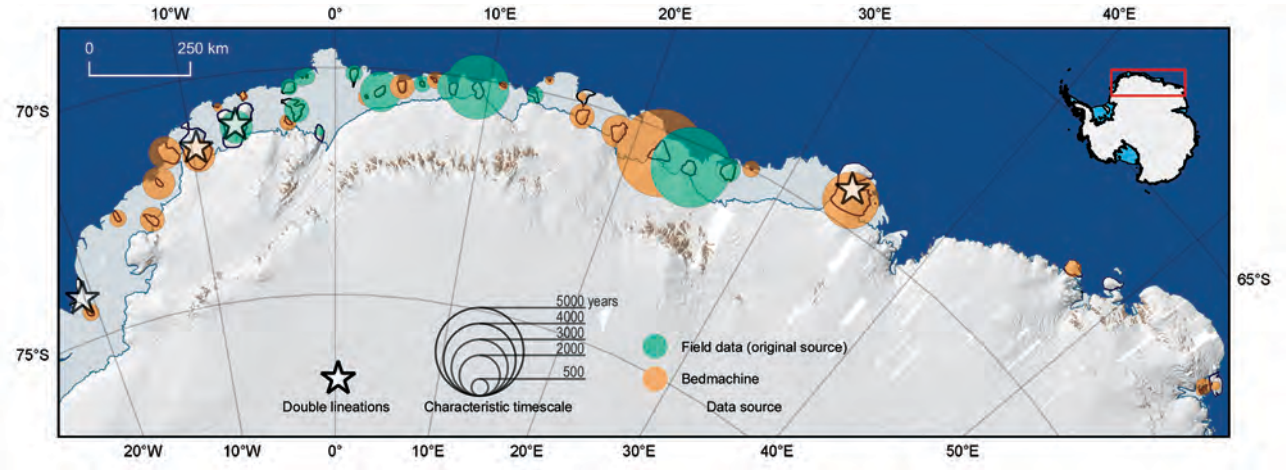


Fig. 4.2 Characteristic timescale *T* (a measure of the sensitivity of an ice rise to change) of ice rises in DML. A circle's area shows *T*, its colour shows the source of the ice thickness data. The stars indicate four ice rises with double lineations (an indicator of long-term stability) visible in MODIS imagery

from particle-bound organic carbon being potentially important contributors to the DOC pool.

4.1.5 Long-term monitoring of the Indian Ocean sector of Coastal Antarctica using XCTDs

The vertical structures of temperature and salinity obtained using expandable CTD's in the South West Indian Ocean sector showed a strong influence of the wind-driven, cyclonic Weddell Sea circulation, wherein the fresh and cold water is advected eastward to about 20-30°E. The vertical extent of the freshwater influx was about 300 m. Likewise, in the Prydz Bay, the up-sloping of isohalines, low temperature (-0.25°C) and densest water >27.7 kgm^{-3} at the surface are signatures of increased salt rejection during ice formation and entrainment of saltier, low-oxygen Circumpolar Deep Water (CDW) into the mixed layer during the winter convection **(Fig. 4.3).**

4.1.6 Polar Micropaleontology and Paleoclimate

Biogeochemistry of Antarctic Lakes

Dissolved major ions, Sr concentrations and $^{87}Sr/^{86}Sr$ ratios of ten coastal lakes from the Larsemann Hills, East Antarctica have been studied **(Fig. 4.4)** to constrain their solute sources, transport and glacial weathering patterns in their catchments. Sr isotope compositions of these lakes vary from 0.7110 to 0.7211, with an average value of 0.7145. Inverse model calculations provide first-order estimates of

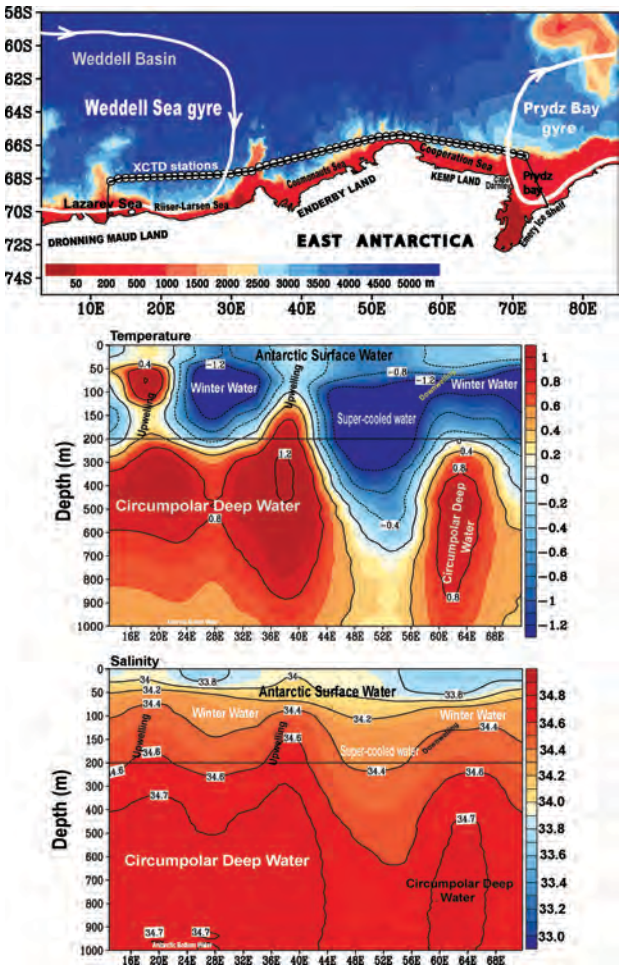


Fig. 4.3 The study area showing the schematics of surface circulation and the locations of the stations where expendable CTD were deployed during Indian Scientific Expedition to Antarctica 2019-2020 (top panel), vertical section of temperature (middle panel) and salinity (lower panel).

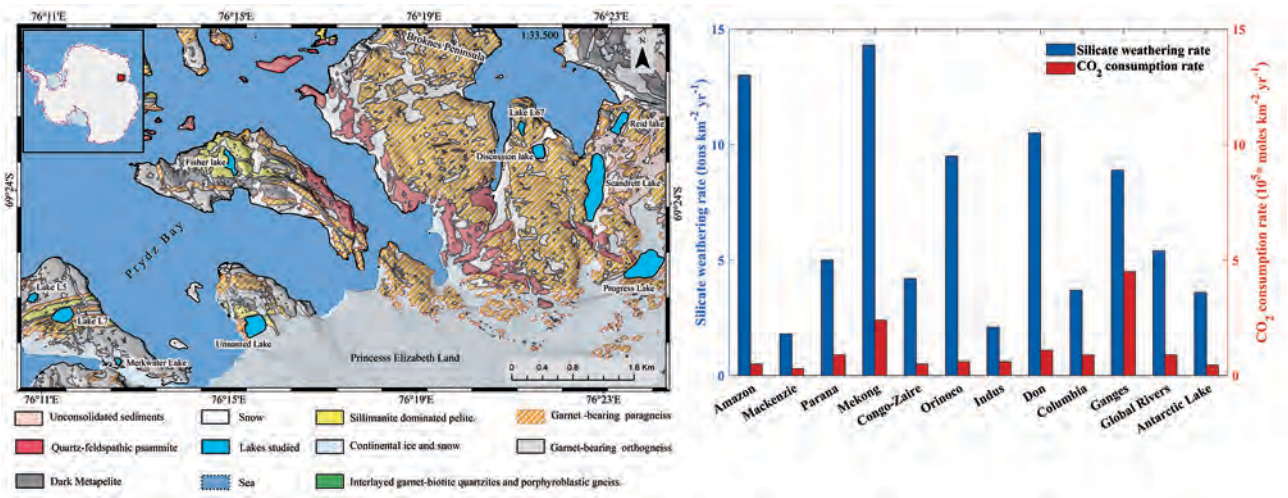


Fig. 4.4 Study map along with the plot showing silicate weathering rate and CO_2 consumption rate for different regimes across the globe

dissolved cations and Sr; they are mostly derived from oceanic (seawater + snow) sources (cations~76%) and Sr~92%)) with minimal supplies from weathering of silicates ((cations~15%); (Sr~2%) and Ca-rich minerals (cations~9%); Sr~7%). The silicate weathering rate and its corresponding atmospheric CO_2 consumption rate estimates for Scandrett lake catchment (3.6 ± 0.3 tons/km^2/yr and 0.5 x10^5 moles/km^2 /yr) are slightly lower than that of reported values for the average global river basins (5.4 tons/km 2/yr and 0.9 x 10^5 tons/km^2/yr) **(Fig. 4.4).**

The changes in Southern Ocean upwelling deciphered using two diatom species (Fragilariopsis kerguelensis and Thalassiosira lentiginosa) during the last 161,000 years

Valve sizes of *Fragilariopsis kerguelensis* and *Thalassiosira lentiginosa* was reconstructed from a sediment core (SK200/33) spanning the last 161 kyr retrieved from the Permanent Open Ocean Zone (POOZ) of the Indian Sector of Southern Ocean (SO) to understand their efficiency as silica vectors to the ocean bottom. A significant increase in the size and flux of the two diatom species was observed during glacial terminations possibly owing to intensified SO upwelling supplying high amount of macro-and micro-nutrient to the surface waters.

Antarctic sea-ice and palaeoproductivity variation over the last 156,000 years in the Indian sector of Southern Ocean

Diatom based quantitative record of winter sea ice concentration (WSIC) and duration (WSID), sea surface temperature (SST) and paleoproductivity from the sediment core SK 200/33 (55°01'S-45°09'E) from the Indian Sector of SO for 156kyr suggested ~1-2°C SST and WSID of ~2 months/year during each glacial period. It is evident that hydrological features migrated northward by a few degrees of latitude during each glacial period. It allows to place the SACCF at ~55°S, the WSI edge close to 49°S and the mean APF at 46°S. It is also evident that winter sea ice shows higher amplitude variation in the Atlantic sector in comparison to other sectors which is attributed to the presence of Weddell Gyre, which transports sea ice farther to the north.

4.1.7 Operations and management of Indian Antarctic stations

All scientific projects and logistics operations were successfully completed during the 39th Indian Antarctic Expedition. After resupplying stations of food and provisions, fuel, spares, etc., the expedition vessel MV Vasiliy Golovnin sailed for the return voyage on 26 March 2020 from India Bay with 28 Indian members and 8 helicopter crew on board on towards Cape Town. The vessel arrived in Cape Town on 10 April 2020. Due to COVID-19 pandemic lockdown, the 28 Indian Expedition members reached Delhi/ Mumbai on 22 May 2020 by special evacuation flight of South African Airways flight SA 2276.

4.1.8 BRICS Working Group meeting on Ocean and Polar Science and Technology

Third meeting of the BRICS Working Group on Ocean and Polar Science and Technology was organized online on 23 September 2020. About 50 delegates from Brazil, Russia, India, China, and South Africa joined the meeting and 21 scientific presentations were made. The current research programs and future activities of each BRICS country in the field of ocean and polar sciences as well as bilateral and multilateral cooperation initiatives between BRICS countries were discussed. Roadmap for the Working Group, priority research area/topics for next BRICS STI call, BRICS joint cruises, mutual cooperation and capacity building plans, and involvement in the United Nation's Decade of Ocean Sciences for Sustainable Development were discussed and actions were agreed in the meeting.

4.2 Scientific Studies in Arctic

The Arctic expeditions could not be conducted due to COVID-19 pandemic during the year. However, efforts were made to operationalize the Atmospheric Observatory, IndARC mooring and summer hydrographic time series observations with the help from scientists working at Svalbard.

4.2.1 Cloud and precipitation measurements at the Indian Arctic station (Ny Ålesund, Svalbard)

Clouds play a significant role in regulating the Arctic climate by impacting radiative balance through various complex feedback processes. Cloud, precipitation and other meteorological parameters measured at Ny Ålesund, Svalbard since 2013 indicated that the low clouds are dominant at the polar site, and there exists a link between cloud base heights (CBH) and heavy precipitation events.

4.2.2 Internal tidal mixing hotspots in Greenland Sea shelf region

Velocity observation from ADCP moorings (2016-2017 period) show the energetic internal tides in the continental shelf and slope of north Greenland Sea (~ 80 N) and moderate internal tides in the southern side (~70 N). The high-resolution (2 km) numerical model ROMS suggested that the internal tides are likely to play an important role in the vertical distribution of water mass in the Greenland Sea. In a warming Arctic scenario, changing water mass characteristics and stratification in the AO may significantly modify the internal tide induced mixing processes and its implications in the future.

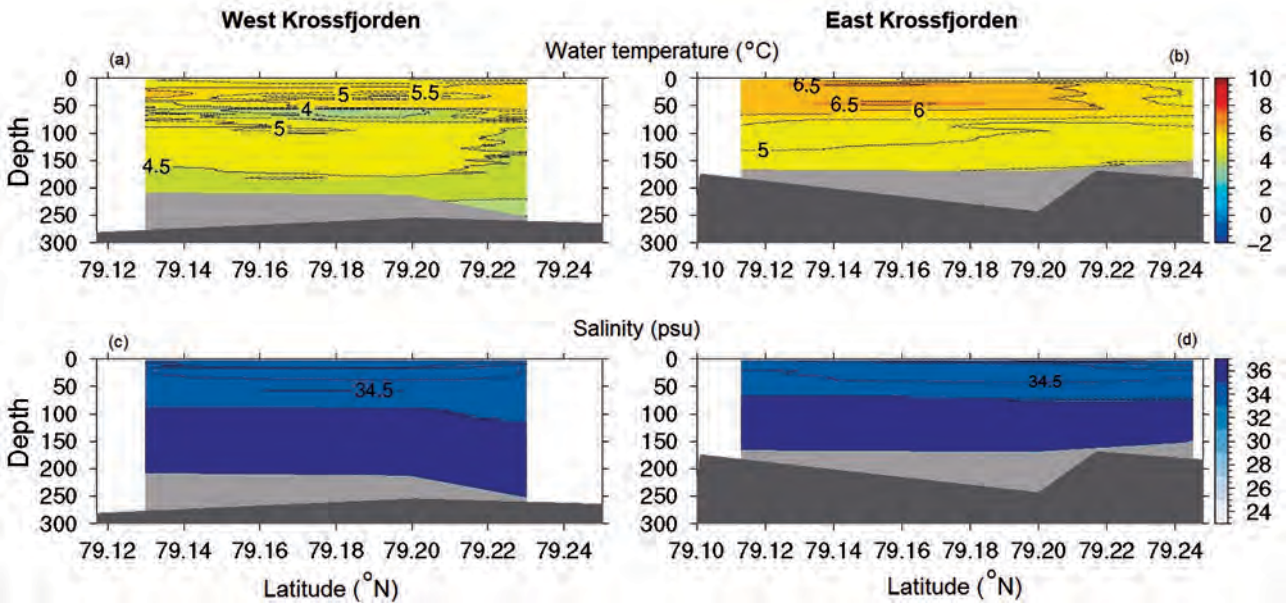


Fig. 4.5 Climatological August mean of water temperature (a) at the west and (b) east Krossfjorden, and salinity (a) at the west and (b) east Krossfjorden for the period 2013-2018.

4.2.3 Atlantic pathway in Krossfjorden

The spatial distribution of water temperature and salinity in Krossfgorden in summer **(Fig. 4.5)** showed that the eastern Krossfjorden was warmer-saline than its western side, indicating the possible pathway of Atlantic water entry to Krossfjorden through its eastern side. The cold fresher waters in the upper western Krossfjorden, coherent with large calving and freshwater discharge, indicated the glacial melt-induced freshwater outflow pathway through the western side. A comparison of Krossfjorden with Kongsfjorden showed that Kongsfjorden was always warm-saline due to more Atlantic Water volume in it. The estimated summer freshwater volume in Kongsfjorden was 0.11-1.45 km^3 that was 1.4-2.0 times higher than Krossfjorden.

4.2.4 Reduced Arctic sea ice extent during the mid-Pliocene Warm Period concurrent with increased Atlantic-climate regime

The semi-quantitative water mass exchange reconstruction was complemented with the estimates of spring sea ice concentration based on source-specific biomarkers. The estimated transport of warm waters into the Arctic Ocean suggest long-term secular changes from the lowest during the Marine Isotope Stage M2 glacial (3.312-3.264 Ma), to near-complete Atlantification of the Eurasian sector of the Arctic Ocean during the mPWP. Orbital forcing is found to be the dominant controlling factor for modulating northward volume transport of Atlantic-derived water masses, with an associated reduction in Arctic spring sea ice concentration of ~30-35%. The results provide input for validation of current-generation models aimed at improving the robustness of future climate modelling in the Arctic

4.2.5 Remote sensing studies

Spatio-temporal change and variability of Barents-Kara sea ice, in the Arctic

The analysis for the period 1979-2018 shows negative trends of the Arctic Sea Ice Extent (SIE) (-4.7 ± 0.3% $decade^{-1}$) with the largest decrease in the Barents Sea (-23 ± 2.5% $decade^{-1}$) and Kara Sea (-7.3 ± 0.9% $decade^{-1}$) **(Fig. 4.6).** The sea-ice decline in the Barents Sea was recorded very high during the winter (-17.6 ± 2.2% $decade^{-1}$) compared to the Kara Sea (-0.8 ± 0.2% $decade^{-1}$) due to increased heat absorption and higher sea surface temperature (SST) in the Barents Sea than in the Kara Sea. The Sea Ice Concentration (SIC) of BKS showed significant negative correlation analyses with SST (-0.75), sea air temperature (-0.84) and outgoing longwave radiation (-0.76). The study demonstrated the complex processes associated with Arctic warming and the declining sea-ice in the BKS region.

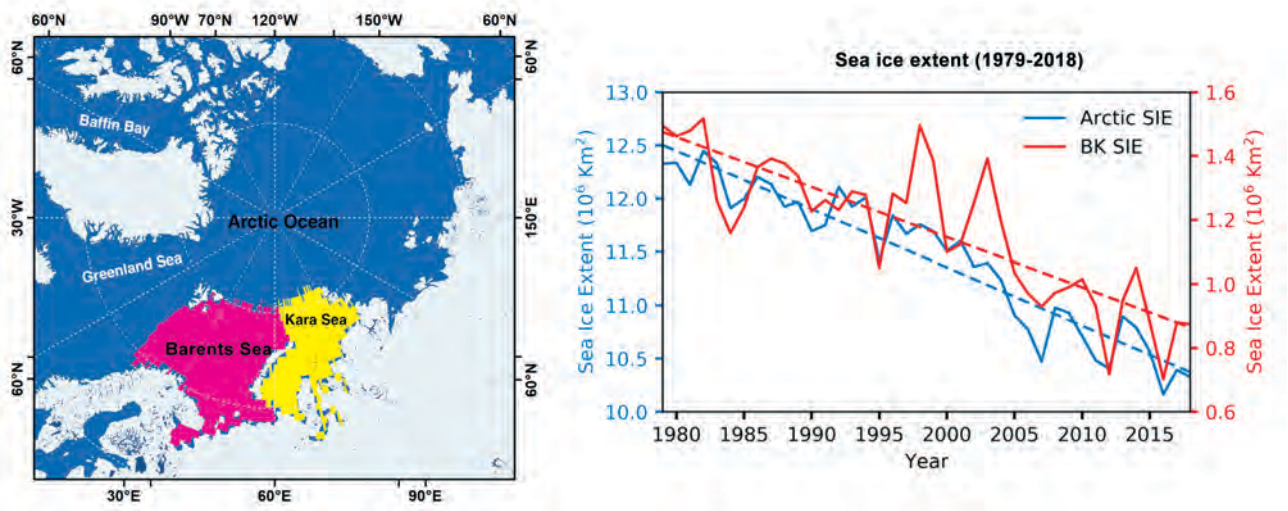


Fig. 4.6 Map showing the location of the Barents-Kara Seas (left), and timeseries plot representing annual SIE in total Arctic region and BKS for the year 1979-2018 (right).

Global warming leading to alarming recession of the Arctic sea-ice cover

The magnitude of Arctic sea-ice loss in the boreal summer (July-September), especially in September at different timescales (daily, monthly, annual and decadal) has been quantified by passive microwave satellite imagery and model reanalysis dataset **(Fig. 4.7).** The Arctic sea-ice declined rapidly in the boreal summer (-10.2 ± 0.8 % decade^{-1}) during 1979-2018, while, the highest decline in sea-ice extent (SIE) (i.e., 82,300 km^{2}yr^{-1}/-12.8 ± 1.1 % decade^{-1}) is reported in the month of September. Since late 1979, the SIE recorded the sixth-lowest decline during September 2018 (4.71 million km^2). Global and Arctic land-ocean temperatures have increased by ~0.78°C and ~3.1°C, respectively, over the past 40 years (1979-2018) while substantial warming rates have been identified in the Arctic Ocean (~3.5°C) relative to the Arctic land (~2.8°C). The prevailing ocean-atmospheric warming in the Arctic, the sea ice extent, concentration and thickness (SIE, SIC & SIT) have reduced, resulting in the decline of the sea-ice volume (SIV) at the rate of -3.0 ± 0.2 (1000 km^{3}decade^{-1}).

4.2.6 Microbiological Studies in Arctic

Cultivable Bacterial Diversity Across Three Arctic Fjords of Svalbard Archipelago

The culturable bacteria in the surface waters of three different fjords situated in the Svalbard Archipelago, Arctic recorded a total of 438 bacterial isolates by using four different bacterial mediums and two different temperatures (4°C and 15°C). Based on 16S rRNA gene sequence analysis, the isolates were categorized into 69different bacterial species belonging to phyla Actinobacteria (5%), Bacteroidetes (36%), and classes of Proteobacteria viz. α-proteobacteria (31%), β-proteobacteria (3%), and γ-proteobacteria (25%). The comparative data analysis between the three fjords revealed that the distribution of bacterial communities for each fjord was diverse.

4.3. Himalayan Studies

4.3.1 Glaciological studies in the Himalayas

Systematic long-term scientific investigations of six representative glaciers (Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Gepang Gath and Kunzam) of Chandra basin, western Himalaya have been carried out to understand the response of Himalayan Cryosphere to the changing climate and its hydrological impacts by integrated studies (mass balance and dynamics of benchmark glaciers, energy and water budget, isotope hydrology etc. An expedition to the Chandra basin was undertaken during September-October 2020 and various field activities like stake networking,

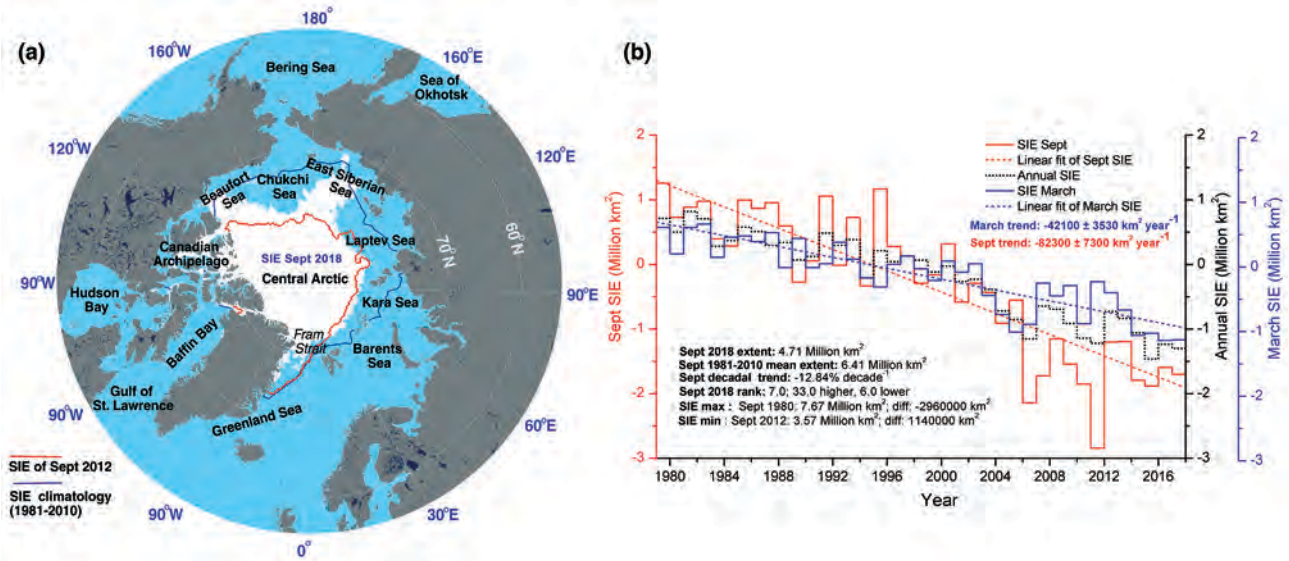


Fig. 4.7 (a) Multisensor analyzed sea ice extent (MASIE) of the Northern Hemisphere showing SIE of September 2018 and their regional seas. The red and dark blue lines delineating SIE of September 2012 and climatology (1979-2010). (b) The time series plot represents SIE anomaly (1979-2018) for the month of March and September with linear least-squares fit, and annual SIE.

snow pits measurements for snow/ice accumulation and ablation, discharge site maintenance, water level data collection, Automatic Weather Station (AWS) data collection and maintenance, observation of the debris cover influence on the glacier surface melting, GNSS survey for snout monitoring and glacier ice velocity were carried out. Four glaciers (Sutri Dhaka, Batal, Samudra Tapu and Gepang) were monitored for surface mass balance, and ablation stakes were installed. Two additional AWS and three aerosol instruments (Aethalometer, Nephelometer and APS) have also been installed.

4.3.2 Water Discharge and Suspended Sediment Dynamics in the Chandra River, Western Himalaya

River runoff and suspended sediments in the Chandra basin has been monitored to investigate water budget and its associated processes of the basin. The daily discharge of the Chandra River varies from 2 m^3s^{-1} to 459 m^3s^{-1}, and overall, annual water flux is about 4000 Million Cubic Meters (MCM). A significant positive correlation among temperature, discharge and suspended sediment shows an increase in mobilisation of stored sediment by the glacier during previous winter.

4.3.3 Glacier Area Changes and its Relation to Climatological Trends over the Western Himalaya Between 1971-2018

High-resolution satellite data sets are used to estimate the glacier area loss, snow cover variability, and climatic trends for four glacier basins (Chandra, Bhaga, Miyar, and Parvati) of the Upper Indus Basin in Western Himalaya. A total of 257 glaciers covering a glacierised area of 1306 km^2, having a mean altitude of 5200 m asl, and an average slope of 18°, were analysed using Corona (1971) and Sentinel (2018) satellite data **(Fig. 4.8).** These glaciers have experienced an area loss at a rate of 0.2 km^2a^{-1} and an increase in the number of glaciers due to fragmentation. The observed glacier fragmentation and glacier mass loss over the last five decades and enhanced rainfall (wet precipitation) revealed a significant influence of climatic changes over the glacierised region in Western Himalaya.

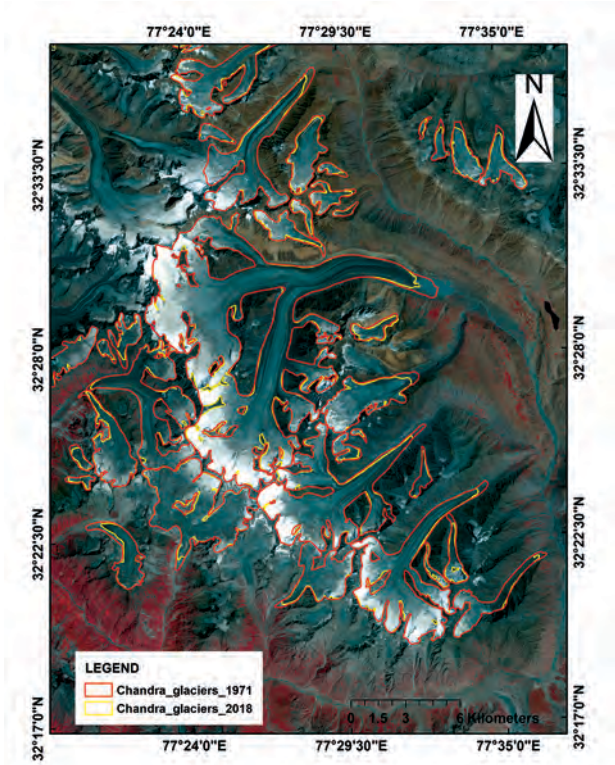


Fig. 4.8 Glacier changes between 1971 and 2018 for Chandra basin.

4.4 Southern Ocean Studies

4.4.1 Record loss of sea-ice in the Weddell Sea, Southern Ocean

The mean seasonal sea-ice extent (SIE) in the Weddell Sea, Southern Ocean dropped to its lowest value in austral summer 2016/17 in the satellite era (1.88×10^6 km^2, 56% of the long-term mean); a large negative seasonal anomaly that persisted in an unprecedented fashion for the following three summers. The ice loss started in late 2016 when the northern Weddell Sea experienced westerly winds of record strength that advected multi-year sea-ice from the region. The re-appearance of the Maud Rise polynya in 2017, high ocean temperatures and storms of record depth kept the summer SIE low.

4.4.2 Seasonal evolution of chlorophyll in the Indian sector of the Southern Ocean

The analysis of data collected using three Bio-Argo floats from the Sub-Tropical front, Sub-Antarctic Front and Polar Front of the ISSO shows that the seasonal evolution of Chl a is similar in all these frontal regions

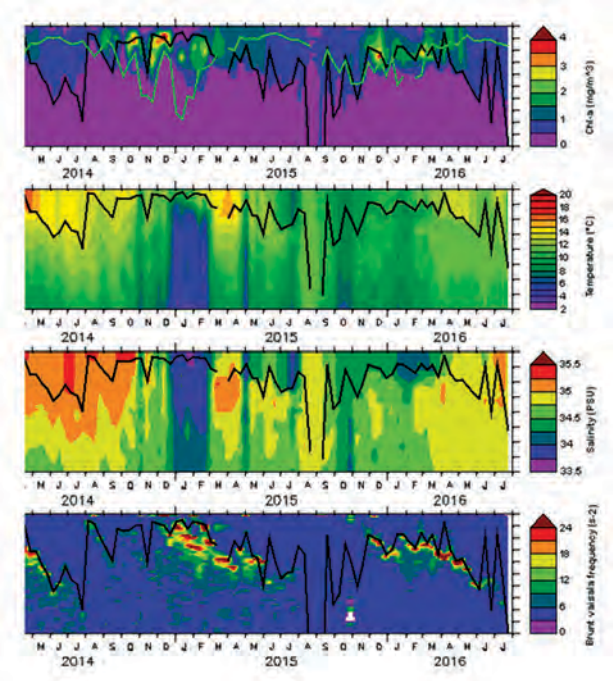


Fig. 4.9 Seasonal evolution of Bio-Physical parameters at the Southern Subtropical Front: Chlorophyll a (mg/m^3) (upper 250 m), temperature (°C), salinity (PSU) (upper 400 m), Brunt Vaisala frequency (s^{-2}) (upper 250 m) from top to bottom, respectively. The black line represents the MLD and the Green line in top panel represents critical depth

(Fig. 4.9). Shoaling of Mixed Layer Depth over the critical depth, owing to an increase in light exposure during spring; trigger the initiation of spring bloom.

4.4.3 Vertical profile of zooplankton community structure in Prydz Bay during the austral summer

Zooplankton samples collected from discrete depths throughout the water column to 500m from the neritic region of Prydz Bay during the austral summer indicated that Copepods were the numerically dominant zooplankton group. The Antarctic Surface Water (AASW) had a higher proportion of *Calanoides acutus, Calanus propinquus* and *Oithona similis,* while *Metridia gerlachei, Rhincalanus gigas* and *Paraeuchaeta antarctica* were mostly encountered in Shelf Water (SW). *Calanoides acutus* abundance was maximum in the 0 -100m layer but sharply decreased below this. *Calanus propinquus* showed a distribution pattern similar to *C. acutus,* with higher abundance in the epipelagic zones.

4.4.4 Nutrient dynamics and the influence of water masses at the Polar front in the Indian sector of Southern Ocean during austral summer

During Austral summer, a patch of high nutrients was observed between ~200-400 m **(Fig. 4.11)** in the Polar Front (PF) waters which may be possibly due to the intrusion of Circumpolar Deep Water (CDW) in this region. The CDW is a nutrient and carbon-rich water mass that often supplies nutrients and CO_2 to the region of intrusion. This intrusion and interaction of CDW may be the plausible reason for the prominent high nitrate and Phosphate later sandwiched between the dicothermal layer and CDW at PF-II **(Fig. 4.10)**, which weakened northwards and was at a greater depth with a smaller gradient at the PF-I.

4.4.5 Link established between past SST in the Southern Ocean and Indian Monsoon on a multi-millennial timescale

The first high-resolution sea surface temperature (SST) record for the last 40,000 years from the Indian

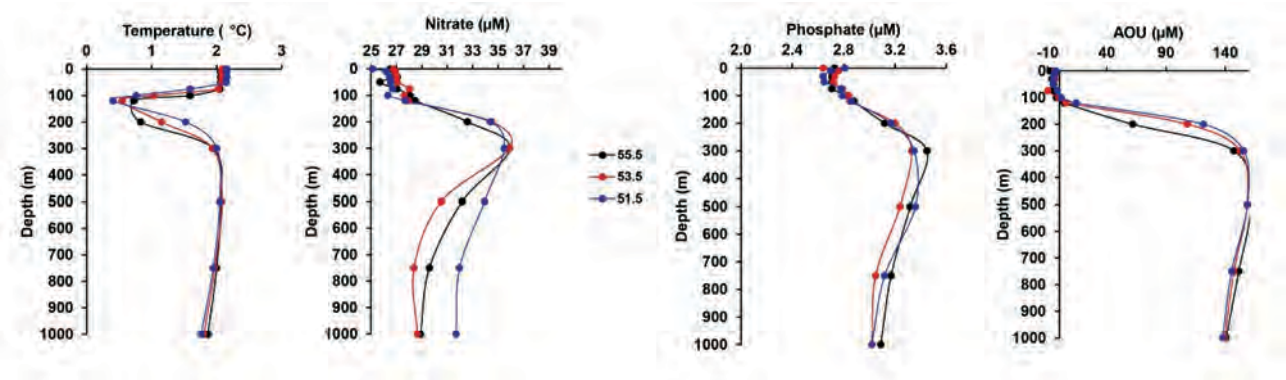


Fig. 4.10 Vertical distribution of Temperature, Nitrate, Phosphate and Apparent Oxygen Utilization at the Polar Front (PF-II).

sector of the Southern Ocean (approximate location: 40°S; 48.5°E) was reconstructed. The analysis indicated that Cold SSTs in the Indian Sector of the Southern Ocean are associated with intense monsoon intervals. Southern Ocean's mid-latitude climate appears to act as a control on the Indian monsoon circulation via oceanic propagation of temperature anomalies from the mid-latitude region into the tropical region. The SST record also reveals a cooling trend during the last 9,000 years (since early-Holocene) at the study site and a deglacial temperature rise before that following the Antarctic climate variability.

4.5 National Polar Data Center

National Polar Data Center is an authoritative platform for managing and sharing data of Indian Polar Research from a broad spectrum of disciplines, including oceanography, glaciology, resources and environmental science, biology & ecology, atmospheric science, etc. The Data Centre was strengthened by establishing Digital Current Weather Information System (DCWIS) to receive all data from Antarctica stations. Many datasets like Metadata of Antarctic expeditions and Southern Ocean Expedition metadata was integrated.

Chapter - 5 | SEISMOLOGY AND GEOSCIENCE RESEARCH (SAGE)

5.1 Observational Seismology, Earthquake Monitoring and Services

All the 115 seismological observatories **(Fig. 5.1)**, established under the National Seismological Network (NSN), have been functioning with more than 90 percent uptime. Data from the field observatories are flowing to Central Receiving Station (CRS) at New Delhi in real time through VSAT terminals. The incoming data are handled by state-of-the-art auto-location software, called 'SeisComP3', to estimate preliminary earthquake parameters, namely, time of occurrence, location (region), magnitude, and focal depth within a few minutes after the occurrence of an earthquake. The earthquake information is subsequently disseminated to the user agencies through various modes of communications, such as SMS, FAX, Email, Mobile-App (RISEQ), official website of NCS (http://www.seismo.gov.in) with value added products, social media platforms like WhatsApp, Twitter, and Facebook. To improve the operational capability to detect earthquake of M:3.0 or above anywhere in the country, National Centre for Seismology (NCS) is planning to strengthen the network this year by adding 35 new stations to fill the instrumental gap **(Fig. 5.1)**.

A total of 1527 earthquakes were located in and around the country during the period from January to November 2020 (Fig. 5.2). Out of these, 65 events were of magnitude M:5.0 and above, 277 events of micro nature, and remaining events fall within the category of small earthquakes. Monthly National Seismological Bulletins, containing the phase data and the processed information on focal parameters of all the earthquakes, located by the national network are being prepared regularly and has been updated till March 2020. These bulletins are regularly supplied to International Seismological Centre (ISC), UK for incorporation in their Monthly Seismological Bulletins.

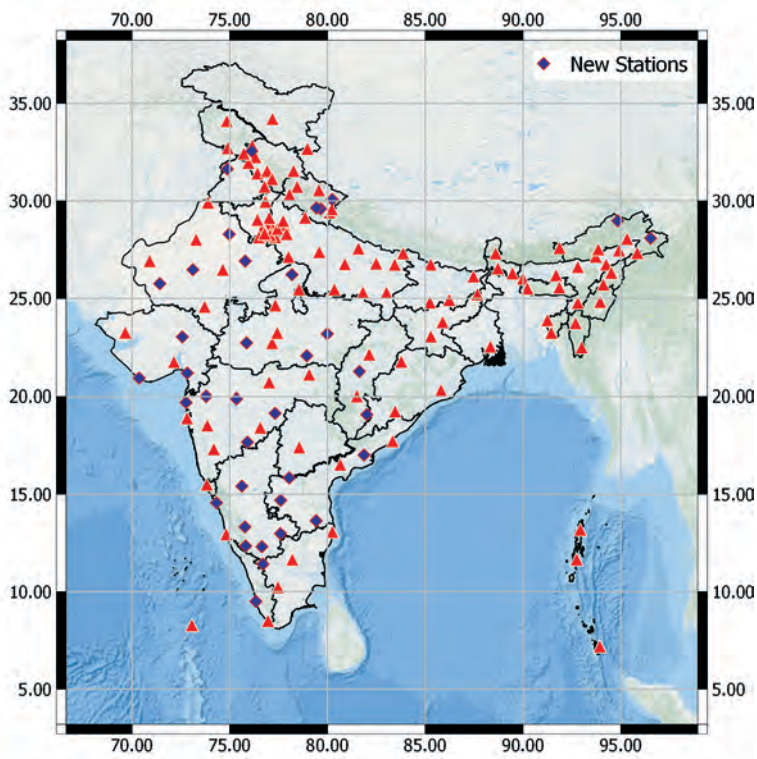


Fig. 5.1 National Seismological Network of India showing 115 existing stations (red triangle) and 35 new proposed stations to be installed (blue diamond)

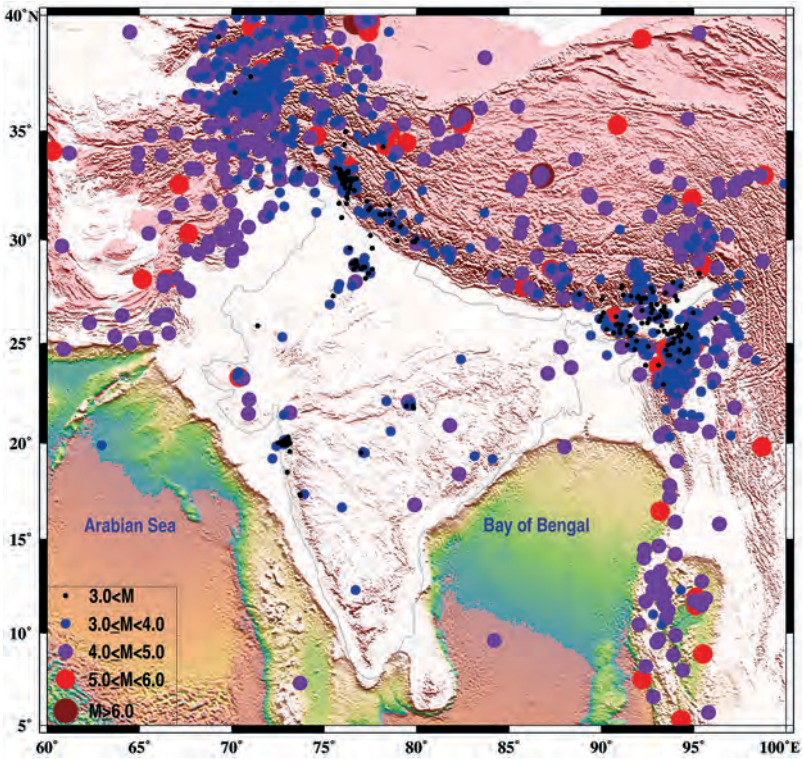


Fig. 5.2 Map showing the location of earthquakes in and around the country during the period from January to November 2020.

The calendar year has been quite challenging, as there have been several episodes of microearthquake/ swarm activity in different regions of the country, like Delhi; Palghar, Maharashtra and Idukki district of Kerala etc. A brief summary on these activities is given below:

Delhi region

On 12th April 2020, Delhi witnessed a small earthquake of magnitude M:3.5, which was felt locally with rumbling sound. The event was followed by four aftershocks (M<3.0) during 12-16 April 2020. Again, on 10th May 2020, an earthquake of magnitude M:3.4 occurred. This earthquake was located about 5.1 km northwest of the previous event of 12th April 2020. The activity continued in the region till July 2020 with two most significant events, occurred on 29th May 2020 (M:4.5) and 3rd July 2020 (M:4.7). However, there was no loss of life or damage to property reported due to these earthquakes. A total of 21 earthquakes with magnitude M:2.5 and above were recorded during the period from January to November 2020 **(Fig. 5.3)**.

A detailed analysis has also been carried out by considering earthquakes of magnitude 2.5 and more on past events in and around Delhi (in grid area from latitude 28° to 30° N and longitude 76° to 78° E) during the last two decades. The analysis showed that i) over Delhi, the earthquake activity has a seasonal cycle with maximum frequency of earthquakes during April-May-June and, on an average, 4-5 events of magnitude of 2.5 or more occur during this period and ii) there is no definite pattern in frequency of earthquake occurrence during the period of data analysis which could suggest any increase in earthquake activity. In the past years, at many times, Delhi region experienced similar earthquake activity. Also, in the annual frequency of earthquake activity, there is no sign of any increasing trend in year 2020. Thus, it is concluded that the activity during this year (since 12 April) is not unusual. However, for close monitoring of this activity, 11 temporary field stations were installed in Delhi region in July-August 2020. Additionally, two surveys viz., Magnetotelluric (MT) and Active fault Mapping based on Geological studies

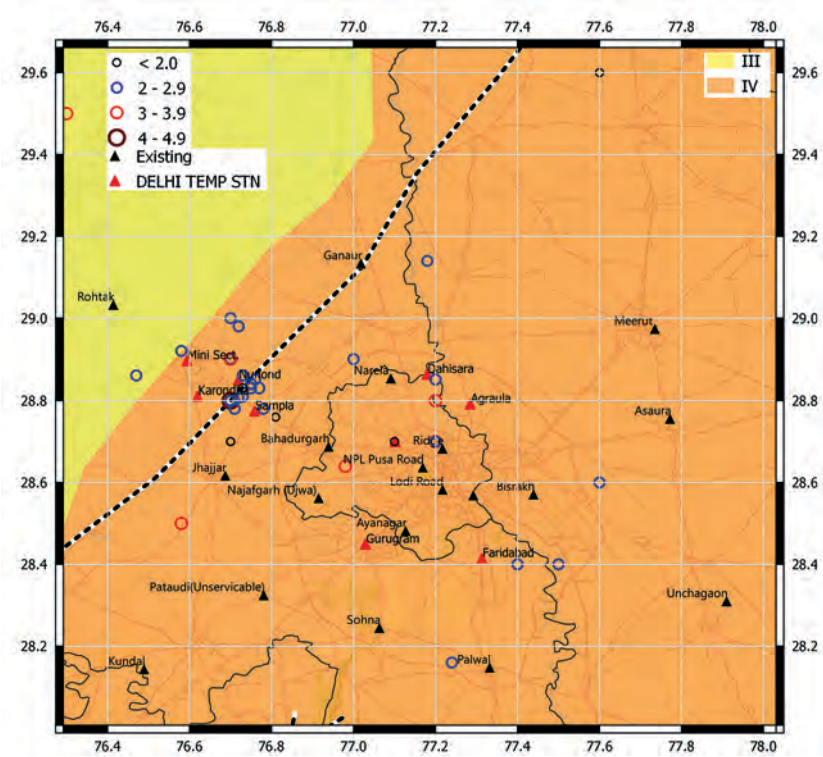


Fig. 5.3 Earthquake activity in Delhi region during the period of January to November 2020. Circles with difference colours indicate magnitude of the events and seismic stations in the region are denoted by triangles. The yellow and orange colour indicates Seismic Zone III and IV respectively.

have been initiated by NCS with an objective to delineate/ characterize the major faults in the region.

Idukki district of Kerala

Microearthquakes were reported and felt locally in Nedumkandam block of Idukki district, Kerala with a rumbling sound since 27th February 2020 and created panic among the local public. To monitor the activity closely, a temporary network of three digital portable seismographs were established in the region during March 2020. A total of 137 events of magnitude M:0.4 and above were recorded during the period from 12.03.2020 to 07.09.2020 including an event of maximum magnitude M:2.6. The analysis showed that activity is concentrated along NE-SW direction **(Fig. 5.4)**. The earthquake activity in the region, however, ceased after 07th September 2020.

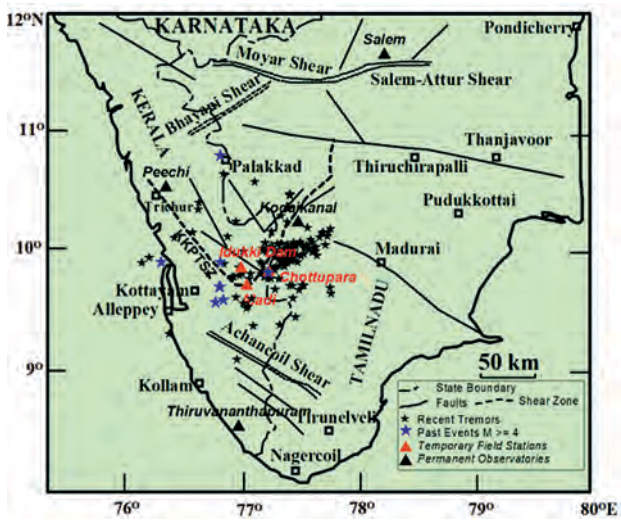


Fig. 5.4 Map showing the location of microearthquakes recorded from 12.03.2020 to 07.09.2020 in Idukki region. Tectonic features and past earthquakes are also depicted.

Palghar district of Maharashtra

A sequence of small magnitude earthquakes near Dhundhalwadi village in the Palghar district has been observed since 11 November 2018. About 710 earthquakes in the magnitude range 2.0 to 3.8 have been recorded by the temporary seismological

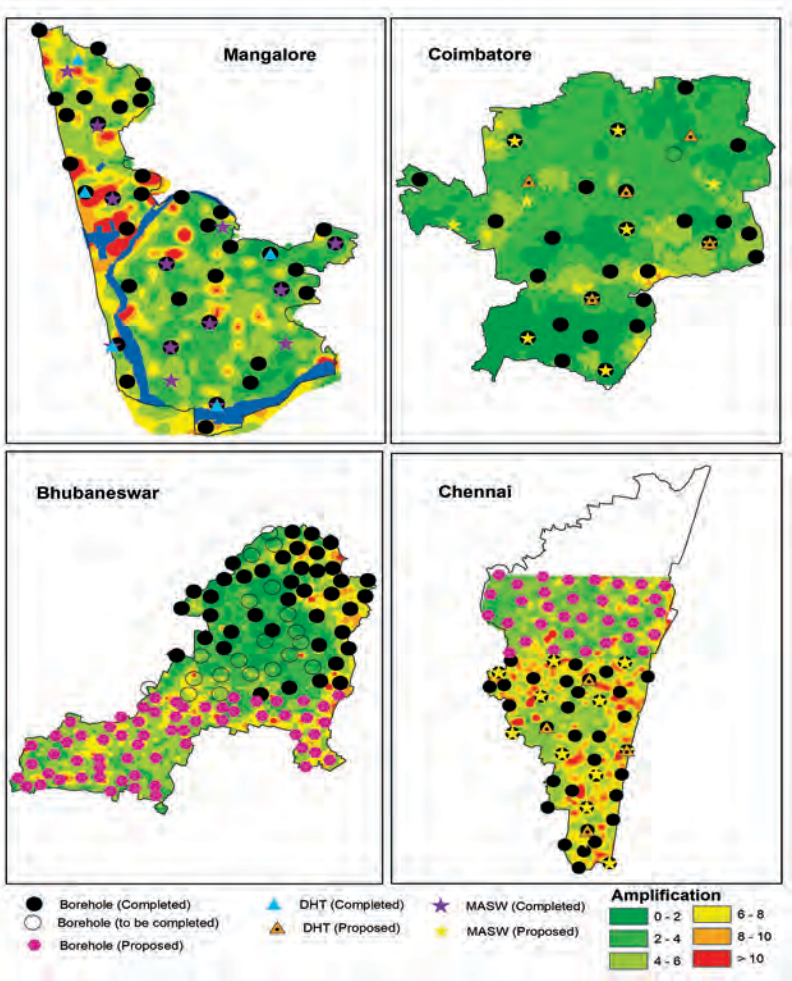


Fig. 5.5 A map showing the locations of the Boreholes (Completed & Proposed), MASW locations (Completed & Proposed) and DHT Locations (Proposed) along with the distribution of Site Amplification factor for the respective City (04).

network. Out of these, 238 earthquakes were of M ≥ 2.5 with a maximum M:3.8 event on 01 March 2019. Majority of the earthquakes (~ 90 %), however, found to be of magnitude less than 2.0 with shallow focal depth ranging between 4.0 to 6.0 km. Many of these events were reported accompanied by the blast like sounds with or without shaking. The analysis suggests that the earthquakes are clustered in a small area of ~ 6 x 15 km^2 to the south of Talasari village encompassing other villages like, Dapchari, Modgaon, Haladpada, Pandhartaragaon, Karanjvira, Osarvira, Ambesari, Dhundhalwadi, Shisne, and Deur.

5.1.2 Seismic Microzonation of selected cities

Microzonation is a site-specific study, which provides a realistic and reliable representation of ground motion characteristics. Microzonation and earthquake hazard assessment related studies are being undertaken in seismically vulnerable areas of the country in a phased manner. The study has potential societal benefits towards construction of earthquake resistant buildings, future land use planning, and retrofitting of existing lifeline structures, etc. The seismic microzonation work of four cities, namely, Bhubaneswar, Chennai, Coimbatore, and Mangalore, started about two years back, is in advanced stage of completion. **Fig. 5.5** shows locations of boreholes for Geotechnical investigations selected based on the mapped contrasts associated with predominant frequency and the corresponding peak amplification factor in corroboration with the existing geology of these four cities. Additionally, the

work related to eight more cities (Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad) has been initiated.

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

5.2.1 Integration of stress and fracture datasets yield new insights into RTS

Analyses of 3 km borehole image logs acquired in the Koyna seismogenic zone show that the majority of subsurface fractures strike parallel to sub-parallel with the orientation of maximum horizontal principal stress (S_{Hmax}) and fractures dip steeply in the range 40° to 75°, indicating ideal conditions for both strike-slip and normal faulting environment. Stress inversion of 50 well-determined earthquake focal mechanisms also reveals a transitional faulting environment. Additionally, hydraulic fracturing data indicate that the region is critically stressed. Integration of in-situ stress magnitude and orientation along with fracture data imply that the subsurface conditions in the Koyna region are favorable for failure and small changes in the fluid pressure and/or frictional strength of the fault may lead to recurrent reservoir triggered seismicity (RTS) in the region.

5.2.2 Strain budget estimation from GPS field velocities

Strain variations in the Koyna-Warna seismic zone has been estimated using GPS derived field velocities from five permanent stations. The average values of most extensional (e1) and most compressional (e2) strain component are estimated to be 8.654 and -11.237 Nano strain/year respectively and the direction of e2 strain component is found to be aligned in the NE-SW direction, consistent with the direction of Indian plate motion. The rate of strain accumulation in the Koyna seismic zone (KSZ) is ~11 times larger compared to the Warna seismic zone (WSZ). On the other hand, WSZ releases ~80% of the accumulated energy per year in the form of earthquakes whereas KSZ releases only ~20% of the accumulated energy per year. It may be inferred that the seismic activity in the WSZ would decay in near future, but the KSZ may remain active for a longer time.

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 endeavor that explores Earth's structure and history recorded in oceanic sediments and rocks beneath and monitors sub-seafloor environments. During the last two decades, more than 40 young Indian scientists have taken part in various IODP expeditions. This year, one Scientist from India participated in IODP-378 expedition in the far southern Pacific Ocean during 03 Jan - 06 Feb 2020. The expedition was aimed at investigating the record of Cenozoic climate and oceanography through a drilling transect. Apart from facilitating shipboard participation of Indian scientists, financial support has also been provided for the post-cruise research to the participating scientists. To commemorate the decade-long journey (2009-2019), a special Monograph by Springer Nature - Society of Earth Scientist Series on 'Dynamics of the Earth System: Evolution, Processes and Interactions: Contributions from scientific ocean drilling' was published by NCPOR. The book presents a glimpse of Indian scientific endeavors and contributions to the science of ocean drilling.

5.3.2 Exploring the largest geoid low in the world, the Indian Ocean Geoid Low (IOGL)

One way of describing Earth's irregular shape is the geoid, which is a hypothetical equipotential surface of Earth's gravity. The large geoid anomalies (either positive or negative) indicates a major change in mass distribution in the Earth's interior. The lowest geoid anomaly (~ -106 m) is observed in the Indian Ocean Geoid Low (IOGL) region. Due to lack of offshore seismological observations from this region, the reasons of this feature remain largely unknown. To collect the seismic data in the region of study, 17 OBS were deployed along a profile **(Fig. 5.6)**. These OBS have been successfully retrieved and a preliminary analysis of data has been undertaken. These data are being further analyzed to image the earth's mantle structure.

Fig. 5.6 (A) OBS recovery team during the SK-368 cruise onboard ORV Sagar Kanya, (B) SK-368 team retrieving an OBS system and (C) Gravity coring operation

NCPOR has also developed an efficient approach of Data Adaptive Polarization Filter (DAPF) to suppress random signals from the background seismic-noise significantly. The approach is successfully applied and demonstrated with the IOGL OBS data from the Indian Ocean. A self-contained software suite-DAPF-v1, supported by a MATLAB graphical user interface has been developed for extracting critical information from seafloor seismological stations

5.3.3 LA-ICP / MC-ICP - MS analysis of accessory minerals: Applications in understanding the evolution of Precambrian Granulite Terranes

In-situ analyses of rock/mineral samples to obtain precise data on trace element and isotope compositions is possible with the technological advancements in mass spectrometric techniques such as Laser Ablation - Inductively Coupled Plasma - Mass Spectrometry (LA-ICP-MS). NCESS established an Isotope Geochemistry Facility (IGF) that host a 213nm Nd: YAG Laser Ablation Microprobe (Teledyne CETAC) which can be coupled with a Quadrupole ICP-MS (Agilent 7800) and a Multi-Collector ICP-MS. By utilizing high resolution imaging techniques using SEM or EPMA, the internal structure of different accessory minerals such as zircon, monazite, rutile etc. can be understood. This powerful combination of technique is now being applied routinely in NCESS-IGF to resolve many outstanding geological problems in Indian shield specially to understand deep time evolution of Precambrian terranes such as the Southern Granulite Terrain (SGT) in South India.

5.3.4 Submarine Groundwater Discharge (SGD) zones

The national network project "SGD" envisages generating simultaneous and reliable data on quality and quantity of SGD occurring across coastal aquifers. During the first Phase of the program, nine zones with total shore length of 104 km have been demarcated out of 640km of pilot project area, as perennial fresh SGD zones. The SGD flux per unit length of shoreline calculated varies from 36 to 1213 m3/y/m, which indicates that 4 to 6% of rain fall is "lost" through the SGD. The cliff sections composed of Tertiary sedimentary formation typically discharges to the

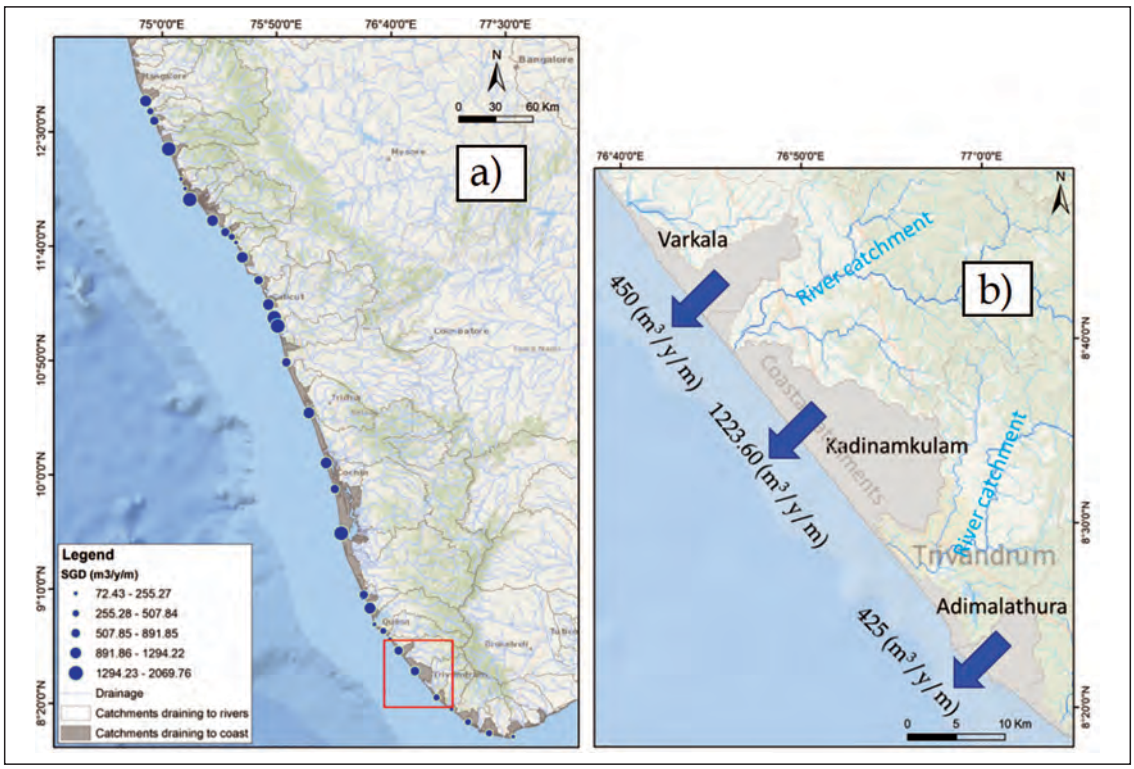


Fig. 5.7 Fresh submarine groundwater discharge along a) SW coast b) Thiruvananthapuram district.

tune of 700 m3/y/m as SGD and the fractured country rocks along with weathered material allow direct fresh water discharge to sea slightly at higher rate (< 900 m3/y/m). Neotectonism has favoured in generating conduits for SGD and to maintain higher hydraulic gradient, which in turn function as driving force for SGD. **Fig. 5.7** represents spatial and seasonal variability of SGD along the SW coastline. In general, coastal zone extending 358 km was identified as potential SGD zone based on physical parameters, with 367 km during monsoon and 349 km during post-monsoon. The areas where low EC levels have been maintained throughout the year are recorded as perennial SGD zone, which accounts for 104 km.

Samples were collected in the sea at various depths (maximum 30 m) up to 4 km offshore from the shoreline at a distance of ~1 km interval to compute nutrient flux. Eight transects were measured at 50 km interval and it was observed that DIN, DSi, and DIP fluxes between Thiruvananthapuram and Kozhikode were in the ranges of 7-57, 2.9-12.5 and 0.2-1.6 µM m^2/d, respectively. A Total of 42 electrical resistivity tomography (ERT) surveys were conducted to define the subsurface lithology and understand the relationship between groundwater and seawater along coastal zone (interface geometry) from Kanyakumari to Malappuram.

5.3.5 SK-362 cruise during 7th October - 5th November 2019 - Observations in and around Alleppey Terrace by NCESS

An exclusive cruise was arranged to study the open ocean interaction in the shelf sea along the west coast of India with particular reference to the Alleppey Terrace. The Alleppey Terrace is an anomalous lateral bathymetric protrusion in the southwest continental margin of India. High resolution CTD and suspended sediment profiling (262 stations) data were collected in and around the Alleppey Terrace **(Fig. 5.8)** region at depths ranging from 30 - 1000 m. Preliminary analyses of the CTD data reveals that the Alleppey Terrace plays a significant role in the dynamics of eastern Arabian Sea and its influence on the inner shelf region is clear from the observations. The study of the cross sectional (CS) plots of various parameters

Fig. 5.8 The SK-362 cruise track and alignment of Alleppey Terrace

like temperature, salinity, density, fluorescence, dissolved oxygen etc. along the 30 m and 50 m depth contours at 6 km (approx.) interval indicates significant variations in the mixed layer depth. A close examination of the CS plot along the 50 m contour reveals evidence of propagation of wave like features. This is observed in the inner shelf interface layer between the less dense, low salinity warm water and the denser, high saline cold water. Based on preliminary investigations of the measurements, the source for the low-density warm surface water can be attributed to the flow from the Bay of Bengal.

5.3.6 Wet and dry rainfall episodes and the modulations in monsoon Low Level Jet (LLJ) over southwest India

Understanding and predicting the wet and dry spells of monsoonal rainfall is crucial since it directly impacts agriculture, economy and hydrological cycle of a region. A study was taken up using station observations (1981-2015) and ancillary data to understand the wet and dry spells of rainfall in the southwest India, where the rainfall variability is different from the entire west coast of India. Though, average amount of rainfall received in a wet spell count 'one' is 43 mm and count 'two' and 'three' gives 38 mm, but the highest contributor to the total rainfall comes from wet spell count 'three' (35.80%) and 'four' (60%). Occurrence of wet and dry spells at the southern tip is a manifestation of oscillations in the monsoon Low Level Jet (LLJ). Dry spells are noted with an anti-cyclonic circulation with stronger westerlies around 25°N and easterlies covering from the Arabian Sea to east of 85°E. Apart from the large-scale control, wet and dry spells are also modulated by the local

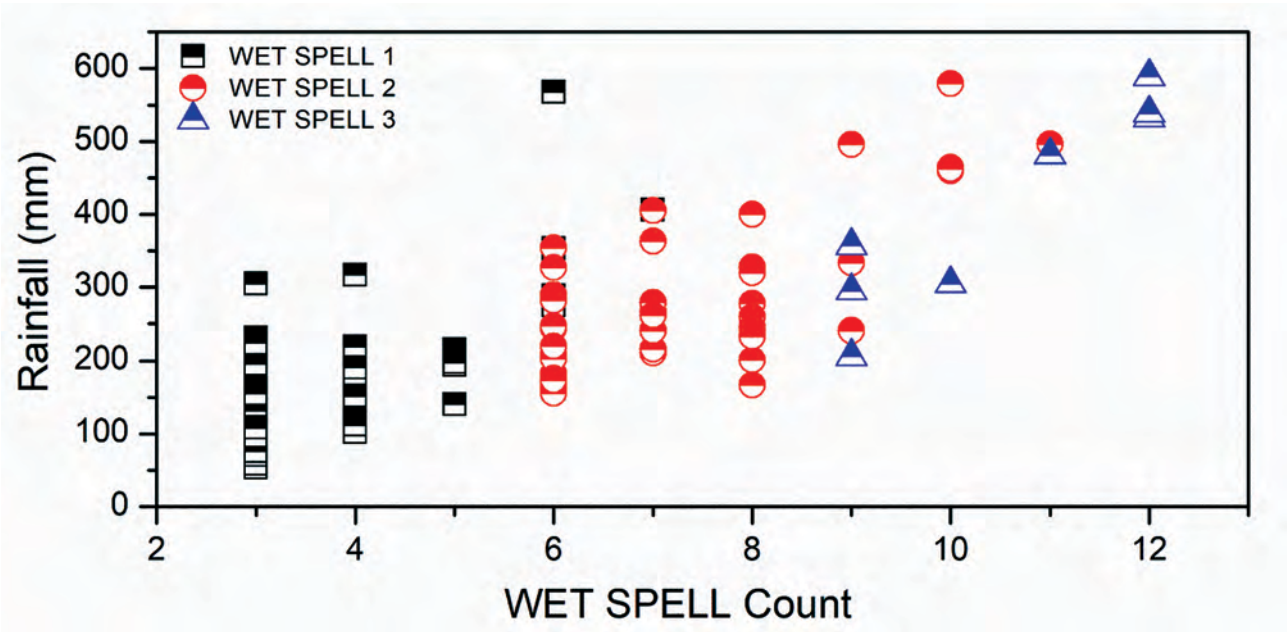


Fig. 5.9 Wet spell count versus rainfall (mm) for Trivandrum station comprised of five station rainfall data for the period 1981-2015.

conditions. On a regional scale, north-westerly winds dominate this region in the monsoon period with a stronger westerly component in wet spells. Distinctly different temperature peaks are observed between 2 to 4 km levels, with dry spells associated with warmer temperatures (0.5°C) than wet spells. The region 600E -85°E, 5°S-5°N delivers stronger precursor signals of westerly and easterly anomalies from d-2 days and also relative humidity at mid tropospheric levels (700 hPa) provides clear indications prior to the wet and dry spells.

5.3.7 Structure of convective systems from C-band Doppler Weather Radar measurements and rainfall estimation using Z-Rrelation

Understanding the 3-dimensional structure of convective systems is crucial in unravelling the processes associated with deep convection. Among different means to get information about the internal structure of such systems, the most sustainable one is measurement using a Doppler Weather Radar (DWR). A study has been undertaken to use data from a C-

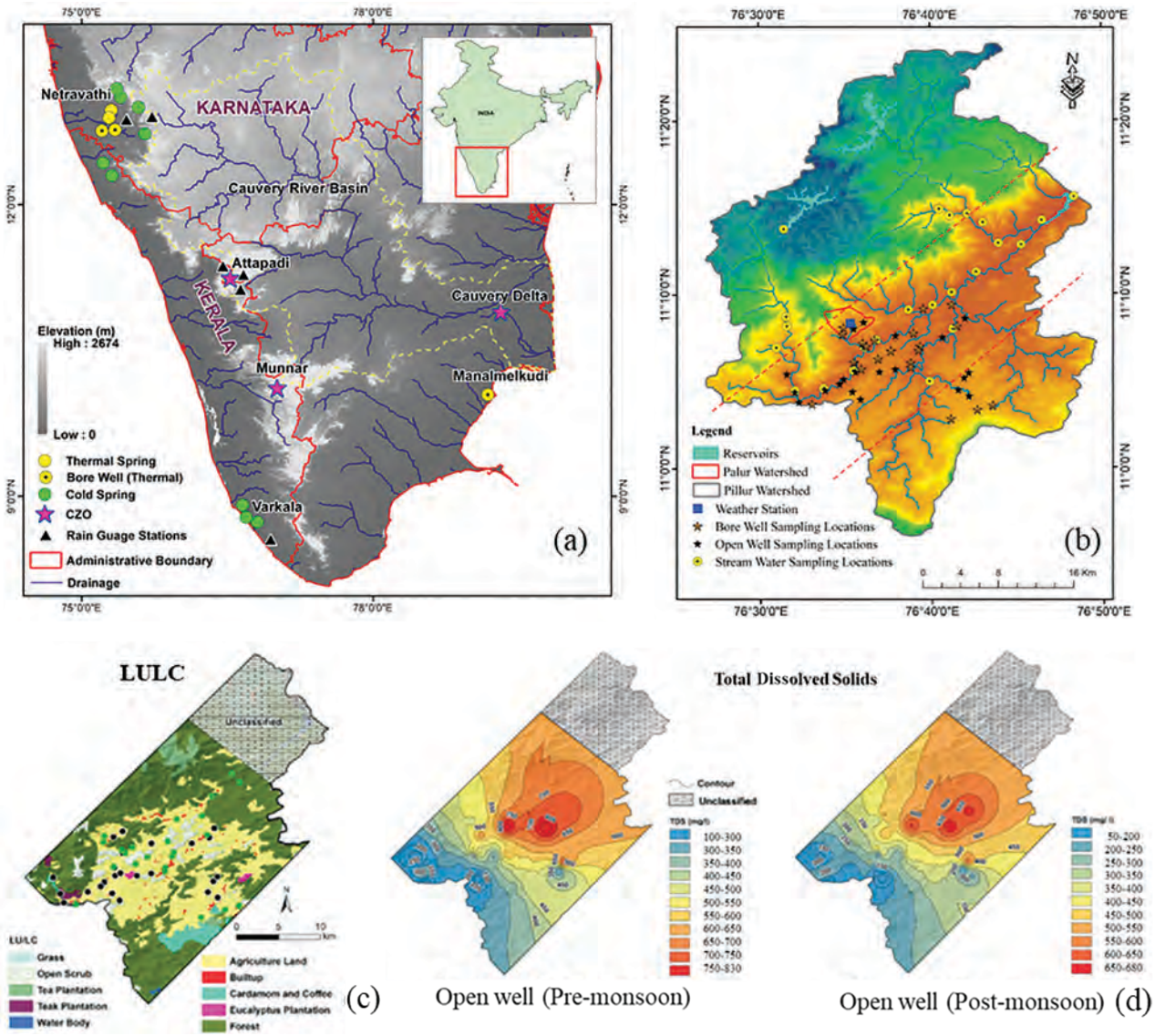


Fig. 5.10 The (a) Location of the three CZOs setup by NCESS, (b) Instrumentation in the Attappadi CZO, (c) Landuse/landcover and (d) Spatio-temporal variation of total dissolved solids in the groundwaters of Attappadi CZO.

band DWR installed at the Space Physics Laboratory (8.52 N, 76.89 E), Trivandrum (south western tip of India). 12 prominent convective events were identified having reflectivity greater than 40 dBZ persistent for at least an hour over a 60 X 60 km region during pre-monsoon (March-May) of 2018. An algorithm was applied to identify the convective and stratiform regions. The study shows that, the mean vertical profile of radar reflectivity for convective pixels peaks near 2 km altitude and then gradually decreases towards higher altitudes. At the same time, the profile in case of stratiform pixels peak near 5 km altitude due to the presence of bright band near that level over stratiform pixels. Further, frequency distribution of reflectivity at 3 km altitude shows peak near 33 dBZ (≡ 5.86 mm h^{-1}) for convective pixels and for stratiform pixels the peak is around 20 dBZ (≡ 0.69 mm h^{-1}). Certain overlap between the two distributions is also seen.

5.3.8 Tropical Ecosystem Research Observations in Peninsular India

The narrow near-surface terrestrial environment, extending from the top of the canopies to the lower limits of the groundwater aquifers, that sustains life is the critical zone. Abundant in resources, this zone nourishes conditions most conducive to life on our planet. In this background, NCESS has set up Critical Zone Observatories (CZO) in Munnar (tropical humid) and Attappadi (sub-humid - semi-arid transition). The observatories in these locations, equipped with state-of-the-art instruments, will generate data that will lend insight into the controls of resilience, response and recovery that function in critical zones with consequent perturbations in climate, land-use and anthropogenic interference. Data collected, and analysis so far has showed that the solute loading in the shallow unconfined aquifers in Attappadi CZO is dependent largely on climatic gradient-controlled chemical weathering and this in turn have a strong bearing on river water chemistry of the watershed.

Chapter - 6 | RESEARCH, EDUCATION, TRAINING AND OUTREACH (REACHOUT)

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

I. R&D in Earth System Science (RDESS)
II. Outreach and Awareness
III. BIMSTEC Centre for Weather and Climate (BCWC)
IV. International Training Centre for Operational Oceanography (ITCOOcean)
V. Program for Development of Skilled manpower in Earth System Sciences (DESK)
VI. MoES-Knowledge Resource 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. Due to the limited availability of grants during the current financial year, funds were provided only to the ongoing projects and no new proposals were considered for support.

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

6.1.1 Atmospheric Sciences including Climate Change

A School of Earth System Sciences and Man Power Development has been established at the University of Hyderabad-completed.

The main objective of the project was to create laboratory facilities and state of art training modules for students to generate skilled/ trained manpower in the field of ocean and atmospheric science. Under this project infrastructural facilities such as remote sensing lab, oceanography and atmospheric science labs. have been established.

Using field and modeling studies to investigate noise propagation in urban traffic corridor by Indian Institute of Technology Guwahati-completed.

The main goal of the project was to investigate environmental noise propagation in an urban traffic corridor using field and modelling studies.

6.1.2 Geosciences

Luminescence Chronology of Palaeflood and Aeolian Dunes deposit in Kaveri Basin: Implications to Holocene Climate Reconstruction by IISER Kolkata- completed

Under this project, paleoflood studies were carried out in upper Kaveri basin to understand the current pattern and its relation with climate or role of human impact in terms of global warming. Fluvial archives having flood units including levees, slackwater deposit and their luminescence chronology were combined with current records and precipitation data.

Rockfall hazard assessment along the Road Cut Slopes on NH-44A between Aizwal City and Leingpui airport, Aizwal, Mizoram, India by IIT-ISM Dhanbad- Completed

Rockfall and the instability in the road cut slopes are the most critical and common problem in the Northeast region of India. Rockmass characterization of thirteen slopes from three regions namely Lengpui, Phunchawng and Aizawl zoo areas near the Aizawl city have been carried out on the basis of rock mass rating *(RMR)*, geological strength index *(GSI)*, kinematic analysis, and various slope mass rating techniques.

6.1.3 Hydrology & Cryosphere

A scoping proposal to build a two-dimensional ice-flow model for basin- scale glacier simulation in the Himalaya by IISER Pune- Completed

The objective of the project was to develop a numerically efficient glacier flow model for basin-scale simulation of glacier dynamics in the Himalaya. The model has been implemented, tested and is freely accessible from https://doi.org/10.5281/zenodo.4050370. This model can potentially be useful in studying recent and future glacier changes and paleoglaciation in the Himalaya, glacier volume estimation, and simulating changes in runoff from high Himalayan glacierised catchments.

6.1.4 Seismology

Paleoseismology, Active Tectonic and Seismic Hazard of Active Faults of Andaman with an emphasis on Jarawa Thrust" by Pondicherry University, Andaman. Paleoseismic investigations were carried out across various faulted landforms and scarps at multiple places in the North, Middle and South Andaman and the active fault sites were carefully chosen after geomorphic mapping and rigorous field investigations.

Seismic vulnerability assessment of selected heritage structures in the state of Himachal Pradesh adopting output only vibration testing and fragility curves" by NIT, Puducherry. Ambient vibration test and operational modal analysis was performed for KalkaShimla railways bridge no. 493 and 541 and an initial finite element model was prepared. Non-linear dynamic analysis showed that the major damage in both the bridges to be near the bottom piers.

6.1.5 Ocean sciences

Effect of Human interventions in the fragile ecosystem along Gulf of Cambay, Mainland Gujarat by Prof. Rolee Kanchan, Maharaja Sayajirao University of Baroda Vadodara- Completed.

This project analysed the level of contamination and identify the vulnerability zones. It is imperative to observe the land use and land cover changes and study the effect of human interventions on environment. The study adopts a methodology on vulnerability assessment and anthropogenic stresses in the coastal area. The study identifies the indicators of vulnerability in various dimensions such as physical, hydrological and environmental. Under this project two papers were published.

Establishment of Coastal Ocean Observatory at the innovation center for climate change (IC3) and capacity building at School of Earth, Ocean and Climate Sciences, Dr. Sandeep Pattanaik, IIT Bhubaneswar - Completed.

This project was a multidisciplinary research projects (total 9) to address various challenging scientific issues specifically related to Bay of Bengal and increase the capacity building of School of Earth Ocean and Climate Sciences. About 20 peer reviewed publications were made possible under this project and one day national brain storming workshop was organized. Coastal currents near Paradip, Odisha are quantified with shallow water meter and its variability has been studied.

Potential impact of climate change on extreme waves, IIT, Mumbai-Completed.

Coastal structures are generally designed on the basis of significant wave height, Hs, corresponding to a return period of 100 years. This design wave height is derived by fitting an appropriate statistical distribution to a set of long duration Hs data either observed or simulated using historical wind conditions. This study investigates what might happen if wind conditions projected on the basis of regional climate models (RCMs), reflecting the impact of climate change, are instead used.

6.1.6 Earth System Science and Technology Cells (ESTC)

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

- ESTC on Satellite Meteorology (SM) at SRM Institute of Science & Technology, Kuttankulathur (Tamil Nadu) comprising of projects entitled (i) Studies of Atmospheric Boundary layer using space-borne and ground based techniques, and (ii) Studies on Tropospheric Warming and Stratospheric Cooling using GPSRO'.
- ESTC on Coastal and Ocean Technology (COT) with project entitled "Hydrodynamic performance characteristics of Caisson type Breakwater"
- ESTC on Marine Biotechnological Studies (MBS), comprising the projects - (i)Studies on the implications of engineered nanoparticles and bio-nanocomposites in aquatic animal health, (ii) Surface modification nanotechnological approach for antifouling and anticorrosion applications, (iii) Enhancement of marine microbial by-products for biomedical applications, (iv) Biofunctionalization nanoparticles for anticancer applications using marine bio-sources, and(v) Isolation and identification of bioactive compounds from marine sponges for white spot syndrome virus (WSSV) control.

Five papers are published in referred journals and seven are under review. Five students completed their M.Tech. dissertation under the ESTCs. Nine number of Ph.D. are ongoing under the ESTC projects. Two month online certificate course was conducted on 'Marine Nanobiotechnology'.

6.1.7 Human Resource development & Capacity Building

- MoES continued to support the User-oriented M.Tech. programme on Ocean technology at IIT Madras. One scientist from NIOT have joined the M. Tech Programme.
- MoU was renewed for continuation 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). Shri. Anirudha V. Mahagaonkar, recruited as PhD fellow (Glaciology) already initiated his PhD work entitled "Assessment Of Changing Ice Sheet Dynamical Features Along The Margins Of Dronning Maud Land, East Antarctica" at the University of Oslo.

6.1.8 Economic Benefits of the Monsoon Mission and HPC

Under the National Monsoon Mission(NMM), MoES has established the state of the art dynamical models for weather and climate forecasts. MoES also augmented the High Performance Computing (HPC) facility to around 10.0 petaflops. Based on these weather forecasts, India Meteorological Department (IMD) in collaboration with Indian Council for Agricultural Research (ICAR) provides agrometeorological advisories twice in a week to around 43 million farmers. The Indian National Centre for Ocean Information Services (INCOIS) provides Potential Fishing Zone (PFZ) Advisories and Ocean State Forecasts(OSF) and warnings to around 7 lakh fishermen going out to sea for fishing on daily basis.

MoES engaged the National Centre for Applied Economic Research (NCAER), Delhi to study the economic benefits of the Monsoon Mission and HPC acquired by the Ministry through estimating the income gain to the farmers in rain-fed areas, livestock owners and fishermen by adopting the weather and ocean state forecast respectively. The report also examined the economic benefits from gender perspective. The report is available on the MoES website.

The report highlights that India's investment of nearly 1,000 crores in the NMM and HPC facilities would provide benefits worth rupees 50 thousand crores to nearly 10.7 million below poverty line (BPL) agricultural households and 0.53 million BPL

fisherfolk households in the country over a 5 year period. About 26.6% of this benefit is attributed to women folk. The report is available on the MoES website.

Some of the salient aspects of the report are:

- A face-to-face survey of 6098 respondents (including 3,965 farmers, 757 marine fishermen and 1,376 livestock owners) was conducted in 173 districts spread across 16 states of India to gauge the economic benefits; and an Interactive Voice Response Survey (IVRS) of around 2 lakh respondents was conducted to validate the findings of face-to-face survey.
- 98% farmers made modifications to at least one of the nine critical agricultural practices based on the weather advisories and 94% of these could either avoid loss or saw an increase in income.
- 76% of the livestock owners are using weather information for taking decisions on modification of shed/shelter; vaccination against seasonal disease; and fodder management.
- 82% of fishermen reported using PFZ and OSF advisories every time before venturing into sea and 95% of them reported to have avoided empty trips by following these advisories.
- The total annual economic benefits to the 10.7 million Below Poverty Line (BPL) agricultural households (farmers and livestock owners taken together) works out to be Rs. 13,331 crores and incremental benefit over the next five years is estimated to be about Rs. 48,056 crores for the farming community.
- Annual income gained by 0.53 million BPL fisher households is estimated to be Rs. 663 crore and the present value of benefits accruing to fisher-folk works out to be Rs. 2391 crore over a period of 5 years.
- Hence, a total of Rs. 50,447 crore is the present value of economic benefit accruing to agricultural households and fisherfolk, realised over the 5-year period.
- Derived estimated benefits realized by the women works out to be Rs. 13,447 crore, which is 26.6 percent of the total benefit.

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

Release of NCAER report by Hon'ble Minister Dr. Harsh Vardhan

MoES Foundation Day Function on 27 July

International exhibitions, sponsoring seminars, symposia, workshop in the area relevant to the programme of the Ministry. In addition "Earth Day" and "Ozone Day" are celebrated with the participation of School, College and University students.

6.2.1 MoES Foundation Day

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27 July 2020 at the Prithvi 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 Margarat Leinen, Director of Scripps Institute of Oceanography, San Diego, USA. The new mobile app of India Meteorological Department, "MAUSAM" and MoES Knowledge Resource Network (KRCNet) Portal were launched by the Honourable Minister.

This year the Life Time Excellence Award was awarded to Professor Ashok Sahni for his significant contribution in the field of Geology, Vertebrate Paleontology and Biostratigraphy. The National Award for Ocean Science & technology was awarded to Dr. V. V. S. S. Sarma, CSIR-National Institute of Oceanography, Vishakapatnam and Dr. M. Ravichandran, National Centre for Polar and Ocean Research, Goa. The National Award for Atmospheric Science & technology was awarded to Dr. S. Suresh Babu, VSSC, Thiruvananthapuram. The National award for Geoscience & technology was awarded to N. V. Chalapathi Rao Department of Geology, Banaras Hindu University, Varanasi. The National Award for Ocean Technology was awarded to Dr. M. A. Atmanand, National Institute of Ocean Technology, Chennai. Dr. Lidita D. S. Khandeparker, CSIR-National Institute of Oceanography, Goa received the Anna Mani award for woman scientist. The Young Researcher Awards were awarded to Dr. Indra Sekhar Sen, Indian Institute of Technology Kanpur and Dr. Arvind Singh Physical Research Laboratory (PRL), Ahmedabad for their outstanding work in Earth System Science.

6.2.2 India International Science Festival (IISF) 2020

India International Science Festival (IISF) is an annual event organized jointly by DST, DBT, MoES, MHWF,

and CSIR from the Government of India and Vijnana Bharati (VIBHA). IISF is perhaps the biggest platform in the country to bring together students, researchers, innovators, artists, and the general public. The sixth edition of India International Science Festival (IISF)-2020 was organized during 22-25 December 2020 at New Delhi in Virtual Mode. The theme for this year's festival is **Science for Atmanirbhar Bharat and Global Welfare.** MoES hosted two events on the themes of "Water" and "Clean Air "during the IISF 2020. NIOT, Chennai coordinated the event on "Water" with a focus on water science for societal development, nation building and AtmaNirbhar Bharat. IITM, Pune coordinated the event on " Clean Air".

6.3 BIMSTEC - CENTRE FOR WEATHER AND CLIMATE (BCWC)

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

6.4 INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANOGRAPHY (ITCOocean)

The ITCOocean continued its operations using the state-of-the art facilities of INCOIS, Hyderabad. The Governing Body approved by MoES for Category 2 Center had their first Governing Body meeting on 8th January 2020 at NIOT, Chennai.During January 2020 - December 2020, **1731** persons were trained of which **1150 (Male: 642, Female: 508)** are from India and **581 (Male: 345, Female: 236)** are from **73** other countries. Internal furnishings were completed in the newly constructed ITOoocean building along with facilities for faculty, PhD students. Both faculty and students started to operate from the ITCOOcean campus from October, 2020. The first batch of students expected for the certificate course in "Operational Oceanography" starting from August, 2020 was postponed owing to Covid-19. ITCOOcean submitted application for Regional Training Centre (RTC) and Specialized Training Centre (STC) to Ocean Teacher Global Academy project under International Oceanography Data Exchange (IODE). ITCOOcean was successfully recognized as RTC for a period of 3 years from 2020 - 2023.

6.5 Development of Skilled manpower in Earth System Sciences (DESK)

During the current year, applications were invited and screened for the Second Batch of MRFP. THE INTERVIEW IS PLANNED IN DEC-2020. DESK organized the MoES Webinars - a series of Live Talks on "Earth Sciences Popular Lectures", in coordination with MoES & its Institution since May 2020. **As of now, 38 Live talks have been delivered and archived on IITM YouTube channel.** DESK organized 9 sessions of virtual lecture series on **'Introduction to OpenMP'** was organized from 17 August 2020 onwards. This series was led by Mr. Mandar Gurav from IIT Mumbai. DESK organized the following International Workshops/Conferences conducted by DESK in collaboration with other International agencies :

- Workshop of Weather and Climate Science and Service Partnership (WCSSP): First WCSSP India Annual Science Meeting, IITM, Pune, 5-7 February 2020.
- 6th International Conference on Climate Services (ICCS 6): IITM & MoES hosted ICCS-6 at IITM, Pune, 11-13 February 2020. Organized jointly by the Global Framework for Climate Service, coordinated by the World Meteorological Organization (WMO), and the Climate Services Partnership.
- South Asia Heat Health Summit (SAHHS), IITM, Pune, 14 February 2020. Organized by the Global Heat Health Information Network & IITM.

DESK also organized seminars and other activities on the occasion of World Water Day, World Environment Day, World Ozone Day and National Pollution Control Day.

6.6 MoES-Knowledge Resource Centre Network (KRCNet)

The Knowledge Resources Centre Network (KRCNet) is a unique initiative of the MoES which aims to integrate all knowledge and intellectual resources of MoES and its institutes on a single, dynamic, web portal. Under the Digital India Initiative of the Government of India, the portal is a one-of-its-kind digital system to collect, collate, catalogue, store and retrieve the knowledge products of MoES and its institutes 24X7 from around the globe.

The KRCNet portal was launched by the Hon'ble Minister of Earth Sciences, Dr Harsh Vardhan on the MoES foundation day on July 27, 2020. It is possibly the only ISO 9001:2015 certified digital knowledge resources portal in the government system. The KRCNet portal is fully functional and accessible at https://krcnet.moes.gov.in/ The portal is bilingual (English and Hindi), user friendly, and enables submission of feedback and keyword-based search.

KRCNet portal was recognized amongst the 35 path-breaking e-governance projects of the Government of India, by independent research done by Coeus Age, supported by Microsoft in 2019. It was awarded the Governance Now GCloud and Data Center Award of 2020 by Governance Now, a popular publication on public policy and governance in India *(Fig. 3: the Governance Now GCloud and Data Center Award of 2020 conferred to MoES-KRCNet portal).*

6.6.1 Subscription to e-resources under DERCON (Digital Earth Sciences Consortium): To keep scientists of MoES institutes abreast with the latest developments in their respective research areas, MoES established the Digital Earth Sciences Consortium (DERCON) in 2010. As part of DERCON, subscription to a variety of journals is available at discounted rates for the entire organisation, which reduces the expenditure incurred by individual MoES institutes on their procurement of resources. Members are able to refer to resources round the clock from everywhere around the globe through their individual user IDs and password.

6.7 Vaishvik Bhartiya Vaigyanik (VAIBHAV) Summit

The Vaishwik Bharatiya Vaigyanik (VAIBHAV) Summit, a global virtual summit of overseas and resident Indian researchers and Academicians was held during 02-31 October 2020. About 3200 panelists and about 22,500 academicians and scientists from India and overseas participated in this month-long series of webinars. The Summit had 18 verticals (areas) and 70 horizontals(subjects).

MoES led the discussions on the Earth Sciences vertical. IITM, Pune, INCOIS, Hyderabad, NIOT, Chennai and NCPOR, Goa were the Champion Institutes for Atmospheric Science, Ocean Science, Ocean Technology and Polar Sciences respectively. Director IITM presented the outcome of Vaibhav Summit for the Earth Science Vertical before the review committee during the Advisory Council meeting of VAIBHAV.

Chapter - 7 | INTERNATIONAL COOPERATION

In its constant endeavour to provide the best possible weather, climate and ocean service, Ministry of Earth Sciences (MoES) regularly partners with national and international institutes for scientific collaboration in all fields related to earth sciences to broaden the scope of research through trans-national joint projects and joint developmental work. The international collaborations not only help in delivery of high-end research for societal benefits 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 and the agreement formally came into force in 2010 after the exchange of diplomatic note and had a duration of ten years. The MoU was renewed on 23 October 2020 in a virtual event. The Indian ambassador to the United States Mr Taranjeet Singh Sandhu signed the MoU on behalf of the Ministry. Although 10 joint research and development activities as Implementation Agreements (IA) have been undertaken in the field of monsoon, ocean observations, tropical cyclone, Tsunami, INSAT 3D, Harmful Algal blooms, ocean wave modeling and assimilation, presently only 3 of these are active. Some of the significant outcomes from these projects are mentioned below:

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

The field work and the research conducted under the RAMA have greatly contributed to our understanding of the importance of the Indian Ocean in the regional and global climate system. The data derived from the array have also provided essential support in the development of operational climate forecast models, weather and climate prediction, ocean data assimilation, ocean state forecasts, reanalysis efforts and satellite validation. Under the RAMA IA, NIOT, Chennai coordinates with Pacific Marine Environmental Laboratory (PMEL), NOAA to maintain 25 moored buoys in the Indian Ocean. During this reporting period, one RAMA cruise of 26 days covering 10 deployments, 10 retrievals and CTD operation were completed.

- Technical cooperation for the study of dynamical short range, extended range and seasonal prediction for Indian summer monsoon rainfall.

The collaboration activities under this IA, have greatly contributed in setting up a seasonal, extended-range and short range dynamical predictions with specific emphasis on monsoon variability. A modified version of the same modelling system is also used for developing an Earth System Model for climate change studies and enabled India to contribute to the CMIP6 inter-comparison exercise. NCMRWF shared IMD-GFS near-real time 00z cycle data with NCEP's Environmental Modeling Center and their daily statistics added into NCEP's multi-model forecast verification. During this period the Global Forecast System (GFS) was upgraded to GFS v14. The Global Ensemble Forecasting System (GEFS) products are made available to European Centre for Medium-Range Weather Forecasts (ECMWF) TIGGE portal from 01 July 2020 onwards.

- 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 HWRF with both the HYbrid Coordinate *Ocean Model* (HYCOM) and Princeton Ocean Model (POM) are now operational. The regional GSI data assimilation scheme was upgraded to assimilate radiance data from different satellites in collaboration with NCMRWF. The processing of ocean state data from INCOIS has been done in collaboration for efficient

real-time utilization as initial conditions to HYCOM ocean model during cyclone at its depression stage.

7.2 Cooperation with United States Geological Survey (USGS)

Under the Memorandum of Understanding (MoU), signed between MoES and USGS on 01 November 2018, a list of probable topics/projects for joint cooperation were shared with USGS in June 2019 in accordance to the activities outlined in the MoU. A joint collaborative work with USGS on development of Earthquake Early warning System for India as a pilot project is being considered. A Virtual meeting with USGS was organized on Sep. 01, 2020 to discuss " Development of Earthquake Early warning System for India" which was attended by representatives of USGS, US Embassy in Delhi, Director, NCS and senior scientists.

7.3 Cooperation with University Corporation for Atmospheric Research (UCAR)

The tenure of the MoU, signed in September 2014 for a period of 5 years, expired in September 2019. However activities under the collaborative project with the National Center for Atmospheric Research (NCAR), a lab funded by UCAR on "Early Warning System for Air Quality in Delhi" is continuing. On 25 September 2020, Hon'ble Minister for Earth Sciences Dr Harshvardhan launched an **Advanced high-resolution Air quality early warning system for Delhi and India through virtual mode.** This system considers the NCAR atmospheric chemistry transport model (WRF-Chem) which takes into account the latest land use land cover (LULC) change information over Delhi, background aerosols and pollutants, long range transport of dust from dust storms and particulate matter from stubble burning. This system provides Air Quality predictions with 72 hours lead time at 400 m resolution and 10 days in advance at 10 km resolution for the Delhi region. This integrated modeling framework also provides short range forecast at 10 km resolution for entire south Asia region, and at 2 km resolution for major cities such as Pune, Mumbai, Hyderabad, Kolkata, Patna, Bangalore, Lucknow and Varanasi.

7.4 Cooperation with UK Met Office (UKMO)

7.4.1 Consortium Agreement with UM Partners

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 Partnership Board meeting was held twice, which was attended by other Board members from Met Office, UK, BoM, Australia, NIWA, New Zealand, KMA, South Korea and US Air Force. Global Coupled Programme Board (GCPB) meeting was held twice. India (MoES/NCMRWF) was representing all the UM partners in this GCPB for a period of two years. NCMRWF developed and implemented a regional land data assimilation system for soil moisture assimilation for the 4-km Regional NCUM-R model. Severe Weather Warning products from NCUM-R like maximum wind gust, lightning flash counts and mean surface dust concentration were developed and operationalized. DM-Chem 330 mts Delhi winter fog model was further developed and operationally run for winter period of 2019-20 to demonstrate the impact of interactive aerosol on the fog and visibility prediction. NCMRWF organized a conference, Ensemble Methods in Modelling and Data Assimilation **(EMMDA)**" during 24-26 February 2020. Seven scientists from NCMRWF participated and delivered lectures in EMMDA. The UM partnership sponsored 6 scientists from UK, South Korea, Australia, South Africa to participate in the workshop. New Zealand joined via web.

7.4.2 MoU with UK Met Office

Under the Implementation Agreement on WEATHER AND CLIMATE SCIENCE FOR SERVICE PARTNERSHIP INDIA (WCSSP India) between MoES and UK Met Office on 7 February 2019, work is being done through three work packages as per the agreed science plan with a focus on enhancing our capabilities in modeling high impact weather and inform services. The work packages are focused on specific topics as follows:

(i) Work Package 1: Seamless Coupled System Development across Scales

(ii) Work Package 2: Model & Observation Evaluation of Monsoon Processes and Hazards

(iii) Work Package 3 : **Risk-based forecasting & high-impact weather/seasonal events**

Implementation Agreement on WCSSP India was extended for 1 year till 31 March 2021 on mutual consent. Dr Kamal Puri, BoM, Australia was appointed as Chair of WCSSP India Science Review Panel (SRP) and Prof. Ravi Nanjundiah, Dir, IITM Pune was nominated as an Observer in SRP of WCSSP India programme. Annual Science workshop of WCSSP India program was hosted by IITM Pune during 5-7 February 2020 and all the Indian and UK scientists involved in the programme participated in the workshop. During the workshop, progress of all the three work-packages under the programme was reviewed by the 4-member Science Review Panel. NCMRWF is collaborating with UK partners on WP1 on Regional Coupled Model for Indian Region and coupled data Assimilation System. IITM has compared the skill of the seasonal hindcast runs shared by UKMO with that of the GFS based seasonal runs at IITM. In addition, IITM also shared the daily hind-cast data with UKMO to carry out analysis of synoptic scale systems in the seasonal hind-casts.

7.5 Cooperation with Natural Environment Research Council (NERC)

The MoU on Cooperation in Earth Sciences signed in February 2013 between MoES and NERC has been extended by a further period of five years. The progress on the ongoing three IA's 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. The observational campaign involved 3 field campaigns in Delhi during November 2017-February 2018, May-June 2018 and November 2018-January 2019. Three science meetings have been organized and 2 more are scheduled online during December 2020 to March 2021. An international workshop with various stakeholders was planned in March 2020 but could not be held due to COVID-19. The APHH so far published 31 peer-reviewed papers in reputed journals including 1 in Nature Geoscience, 2 chapters in book, 24 conference papers. APHH contributed in capacity building in the area, delivered skillful products with significant potential for sustainable societal needs and its outcome is expected to yield an integrated framework of air quality.

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 jointly funded by MoES and NERC-UK has been completed. A virtual final review meeting of MoES, NERC, PIs and Co-PIs was organised on 24th November 2020 to review the highlights and outputs from these projects. A webinar was also organised on 25th November 2020 to showcase the research, successes and lessons learned from the SWR programme. The webinar was attended by more than 100 participants.

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

India-UK Virtual Joint Centre on Water Security, set-up jointly by MoES and NERC-UK organised a webinar series (total nine webinars) on a variety of topics to showcase the Indo-UK water research/practice and its impacts, as well as outputs and learning's from IUKWC activities. The centre also held a virtual User Engagement Initiative consisting of pre-recorded interviews with scientists who had developed or were piloting scientific tools, models and technologies through Indo-UK projects that could be of use to real-world water managers, and decision and policy makers. A meeting with Prof Alan Jenkins, UK Centre for Ecology & Hydrology was organized to discuss the future of the India-UK Virtual Water Centre.

Since its inception in 2016, the Centre convened six science workshops (3 in India, 3 in UK), three Grassroots Field Exposure Initiatives, three User

Engagement Initiatives and funded three Pump Priming projects. Water policy briefs and reports were produced and published as a result of these activities. The Centre also produced two promotional videos to demonstrate the approach of the Centre and future research opportunities - and made available online via YouTube. IUKWC has built an active community of over 1000 water scientists and stakeholders from both countries through its Open Network, and has engaged directly with water resource managers across India to promote Indo-UK freshwater research. Due to changes in funding policies of NERC, this collaborative project was discontinued at the end of September 2020.

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 an MoU in February 2013 to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. An Amendment to the MoU consisting of amendment in terminologies, open data policy has been accepted by the Belmont Forum members in the Annual Plenary meeting held virtually during 13-15 October 2020. MoES is participating in the Belmont Forum, Future Earth and JPI Oceans co-branded CRA on "Transdisciplinary Research for Ocean Sustainability" proposed by FORMAS, Sweden. Two projects with Indian PIs were recommended for funding by Panel of experts. One of the recommended projects titled "Coastal Ocean Assessment for Sustainability and Transformation (COAST Card)" with Indian PI, Dr. Dattesh Desai, CSIR-NIO, is funded by MoES during 2020-21.

7.6.1 Belmont Forum Secretariat

Belmont Forum Secretariat has been established to coordinate the activities and to maintain a certain degree of continuity in the operations of the Forum. After a tenure of 3 years at ANR France, the Belmont Forum Secretariat is being hosted by Inter-American Institute for Global Change Research (IAI), Uruguay since July 2018 till 2021. Accordingly, as per the Cabinet approval, an annual contribution of 20,000 Euros equivalent of INR from India was transferred to IAI for the period 2019-20.

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

BIMSTEC Secretary General His Excellency M. Shahidul Islam, visited BIMSTEC Center for Weather and Climate (BCWC) being hosted by NCMRWF on 13 February 2020. He visited the facilities of BCWC which are being supported by NCMRWF. The first BIMSTEC-Intergovernmental Expert Group Meeting on Disaster Management was organized by the National Disaster Management Authority during 14 February 2020 at Puri, Odisha. An approach paper highlighting the activities of the BIMSTEC center for Weather and Climate (BCWC), infrastructure available at the BCWC center at NCMRWF NOIDA, the training facilities and the capacity building that can be offered by NCMRWF was shared with Joint Secretary (BIMSTEC), MEA for further sharing with the Ambassadors of the BIMSTEC nations. The Himalayan Science Council (HSC) meeting was held during 4-5 Dec 2019 at NCPOR, Goa where the BIMSTEC nations discussed about the Terms and Conditions and the white paper prepared by India for establishment of the HSC.

BCWC, NCMRWF has started sharing EPSgram and Meteogram (10-days forecasts) for 20 locations over Bhutan with Bhutan Met Department in real-time under BIMSTEC activity. BCWC has also shared medium range forecasts plots and data of total precipitation, maximum & minimum temperature for whole Bhutan region from NCUM Global and NEPS ensemble model on daily basis up to next ten days from 17 July 2020 onwards.

7.8 Cooperation with Norway

MoU with Research Council of Norway (RCN)

Following a joint call in Feb 2015, 5 projects under Climate System in Polar regions and 3 projects under Geohazard theme were supported in October 2015. One of the projects OCTEL between NCPOR and

Norwegian Polar Institute (NPI) has been completed while others are in various stages of implementation. The MoU was extended for further 5 years with effect from 14 October, 2019.

7.9 Horizon 2020

Ministry of Earth Sciences (MoES) and the European Union (EU) have established a co-funding mechanism (CFM) to support the successful Indian participants in certain projects selected under European Research & Innovation Framework Program 'Horizon 2020' related to **climate change and polar research.**

7.10 Cooperation with UNESCO/IOC

The ITCOocean continued its operations using the state-of-the art facilities of INCOIS, Hyderabad. Owing to Covid-19 the face to face training were shifted to online mode which enabled more participation from IOR countries. During January 2020 - November 2020, **2908** persons were trained of which **2064 (Male: 1310, Female:754)** are from India and **844 (Male:536, Female:308)** from **85** other countries. Internal furnishing in the newly constructed ITOoocean building with state of the art facilities is fully functional with research students and faculty. In total two online training courses and one Webinar was conducted during the COVID-19 pandemic period, which covered various topics like "Discovery and Use of Operational Ocean Data Products and Services - Aug 31 - Sep 04, 2020" and "Understanding Sea Level: data analysis and applications - October 12 - 14, 2020" and Webinar on "Fishery Oceanography for Future Professionals - November 16-20, 2020", Hyderabad, India.

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

The IIOE-2 Joint Project Office (JPO) India continued its outreach activities by publishing monthly newsletter and semi-annual "The Indian Ocean Bubble-2". Till November 2020, 46 issues of monthly newsletter and 13 issues of "Indian Ocean Bubble -2" have been published. These outreach activities have been widely appreciated and has become a strong and valuable medium to spread not only awareness on the activities being carried out in the Indian Ocean but also become a forum to stimulate new ideas and addressing the outstanding issues of the region. Till November 2020, a total of 42 research projects from 46 different countries have been endorsed which spreads over different facets of the Indian Ocean ranging from physical, biological, chemical and geological oceanography.

7.12 Contract with ISA on extraction of Polymetallic Nodule (PMN)

Under the contract with International Seabed Authority (ISBA), MoES carried out Survey & Exploration, Environmental Impact Assessment, Technology Development (Mining), and Technology Development (Extractive Metallurgy) for polymetallic nodules through various national institutes. Survey and exploration at the grid size of 12 km x 12 km has been carried out and an estimate on the abundance, and grade of target metals have been made. The estimates have been updated to about 365 Million metric Tonnes of polymetallic nodules with around 2.3% of Copper, Nickel and Cobalt. Efforts are continuing to refine these estimates. Regarding development of mining system, in-situ soil tester has been developed and deployment was successfully undertaken in the contract area of CIOB at depths of 5400 m. Soft soil seabed locomotion trials with the mining machine were undertaken in Feb 2020 at depths of 3420 m.

Environmental baseline data has been collected in the Area and Environment Impact Statement has been prepared for the proposed test of locomotion trials proposed to be carried out at 5500 m water depth in the allocated area in 2021.

7.13 Contract with ISA on extraction of Polymetallic Sulfides

The present efforts are concentrated on obtaining hydrothermal plume signatures, to locate new hydrothermal plumes and to generate environmental baseline data. Samples collected from the identified turbid layers were analysed for confirmation of hydrothermal plumes. This provides the evidence for high temperature hydrothermal venting in CIR.

Further, baseline environmental data about the flora and fauna are being collected. India has been submitting Annual Reports regularly to the Authority indicating the progress of work pertaining to both the contracts. Ministry of Earth Sciences is also providing data to the International Seabed Authority as a part of these 2 Annual Reports. India is also contributing to the work of the Authority through its active participation in various organs of the Authority viz. Legal and Technical Commission, Council, Finance Committee and Assembly.

7.14 Cooperation with Japan

Under the Memorandum of Cooperation signed between Ministry of Earth Sciences and Japan Agency for Marine Earth Science and Technology (JAMSTEC), Japan collaborative projects of mutual interests were taken up 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. IITM scientists together with the JAMSTEC scientists compared the coupled model results of both centers to understand model biases in CFS model of IITM and SINTEX-F model of JAMSTEC. New collaborative projects involving (i) JAMSTEC, MoES institutes and IIT Kharagpur to evaluate the internal wave energy potential to generate electrical power on the east coast of India and (ii) JAMSTEC, MoES and CDAC to develop city scale information systems including climate forecasts are under discussion. MoES presented the progress of the ongoing collaboration on coupled models between MoES and JAMSTEC and on Polar Research between NCPOR and National Institute of Polar Research, Japan during the 10th Indo -Japan Joint Committee Meeting on Science and Technology Cooperation held virtually at DST on 10 November 2020. MoEs presented the possible areas of collaboration on Coastal Vulnerability and Marine Litter and once again reiterated India's keenness to collaborate on Deep Ocean technology aspects like Manned Submersibles, Ocean Mining etc.

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

An MoU on the Membership of the ICDP between MoES and the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, for a period of five years was signed on 30th August 2016. As per MoU, MoES is paying annual contribution of US$ 200,000 to GFZ. The MoU is facilitating engagement of internationally renowned experts from ICDP to accomplish scientific deep drilling and associated investigations in the Koyna region. As a part of the membership agreement, ICDP also provides technical/ operational support, facilitate capacity building in terms of manpower training in key scientific areas. India is also represented on two panels of ICDP, viz, Assembly of Governors and Executive Committee. During the current year, in-situ hydrofrac test data acquired in the Koyna Pilot Borehole up to depth of 3 km with technical support of ICDP has been analyzed and a joint research publication on the implications for seismicity in the Koyna region is under finalization.

7.16 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 and the sane 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. As per MoU, MoES is paying annual contribution of US$ 1M to NSF. During the last two decades, more than 40 young Indian scientists have taken part in various IODP expeditions. During the current year, one scientist from India participated in IODP-378 expedition in the far southern Pacific Ocean during 03 Jan - 06 Feb 2020. The expedition was aimed at investigating the record of Cenozoic climate and oceanography through a drilling transect.

7.17 Cooperation with Argentina

A Memorandum of Understanding (MoU) on Antarctic co-operation between Ministry of Earth

Sciences of the Republic of India 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 delegation of Argentina during the Antarctic Treaty Consultative Meeting in Prague, Czech Republic.

7.18 Collaboration with Sweden

NCPOR and Swedish Institute of Space Physics (IRF) have been collaborating in Antarctica on Atmospheric Research under an Letter of Intent (LoI) signed in 2015 and a Movable Atmospheric Radar for Antarctica 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. A MoU on Polar Science between MoES and the Ministry of Education & Research, Sweden was signed on 2nd December 2019. Discussion meeting with the Swedish Embassy was held to plan the activities to be undertaken as part of the MoU.

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

RIMES is an international and intergovernmental institution, owned and managed by its Member States, for building capacities in the generation and application of user-relevant early warning information. Currently, 48 countries collaborate under RIMES. The 11th RIMES Council Meeting was held at Bangkok, Thailand during 20-22 January 2020. The 12th RIMES Council Meeting was held in a virtual mode during 25-26 November 2020. Despite the many restrictions associated with the Covid pandemic, RIMES was able to continue to provide uninterrupted services to its Member and Collaborating States. RIMES facilitated the Establishment of an institutional mechanism within the National Meteorological and Hydrological Services (NMHS) of Bangladesh, Bhutan, India, Papua New Guinea, and Sri Lanka to interface with users for integrating weather and climate information into decision-making processes. IMD and RIMES are working in collaboration with State Governments and SDMA to develop a multi-hazard potential impact assessment and management system, to support disaster risk management decisions.

7.20 Collaboration with Norwegian Ministry of Climate and Environment

As a follow-up to the Joint Task Force on Blue Economy for Sustainable Development taken up under the Memorandum of Understanding signed between India and Norway in January 2019, a letter of Intent (LoI) was signed on 18 Feb 2020 between MoES and Norwegian Ministry of Climate and Environment and Norwegian Ministry of Foreign Affairs on "Integrated Ocean Management & Research Initiative". Prior to this a bilateral meeting between Dr Harsh Vardhan, Honble Minister of Earth Sciences and Mr. Sveinung Rotevatn, Norwegian Minister for Climate and Environment was held at at Prithvi Bhavan, Ministry of Earth Sciences to discuss avenues of collaboration especially in the field of ocean sciences and health sector. Under the LOI, The Norwegian Environment Agency through the Norwegian Ministry of Foreign Affairs (MFA) and MoES have developed a draft framework for the Integrated Ocean Initiative with a focus on **Marine spatial planning (MSP)**. A background paper on MSP has been prepared with inputs from both sides and this was discussed in details on 9th October 2020 by the two sides. A Project Steering Committee with members from all line Ministries has been constituted on 18th November 2020 to steer the Integrated Ocean Management and Research Initiative.

7.21 Cooperation with United Arab Emirates (UAE)

A Memorandum of Understanding (MoU) for Scientific and Technical cooperation between Ministry of Earth Sciences of the Republic of India and National Center of Meteorology, Ministry of Presidential Affairs UAE was signed on 23rd November 2020. Under this MoU both the countries will support promotion and extension of cooperation in Scientific Research and Technology Development in the field of mutual interest.

Chapter - 8 | Publications, Patents, Awards and Honours

A total number of 527 research papers were published in 2020 by MoES centers under its various programs, the details of which are given below. The number of research papers published in 2020 (527) and the total impact factor (1413.2) are comparatively higher as compared to the previous years as seen in Chapter 1. Seven patents were also granted during the current year.

	ACROSS	OSMART	PACER	SAGE	TOTAL
Total no. of Publications	252	154	78	43	**527**
Cumulative Impact Factor	**726.9**	**324.0**	**257.6**	**104.6**	**1413.2**

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Patents Granted

Patents granted to NIOT

Sl. No.	Innovators	Title	Country	Grant Reference
1.	P. Muthuvel, T. Sasikala, A.A. Gnanaraj, C.R.Deepak, M.A. Atmanand	Portable In-Situ Soil Testing Device	India	319005, 2019
2.	J. Mary LeemaThilakam, D. Magesh Peter, T. S. Kumar, K. Thirupathi, G. Dharani, R. Kirubagaran, M.A. Atmanand	Process for the Production of Lutein.	Europe	EP 3 246 311 A1, 2020
3.	Kirubagaran R, Josephine A, Kumar T.S., Vijaya Raghavan R, Dharani G, Vinithkumar N.V., Mary Leema Thilagam J Magesh Peter D	Pharmacoactive nutrient & a process of production there of from Marine Algae.	Europe	EP3403662 29.01.2020
4.	R.Srinivasan, ShijoZacharia, V.Gowthaman,Tata Sudhakar, Atmanand M.A.	Intelligent Buoy Tracking System	India	343277, 2020
5.	M.A.Atmanand, C.R.Deepak, K.Thirumurugan, N.R.Ramesh, B.O.Vishwanath V.Sundaramoorthi	Depth Independent Sub-sea Loadcell	India	343659, 2020

Sl. No.	Innovators	Title	Country	Grant Reference
6.	Shijo Zacharia, Dhilsha Rajapan C. Kannan, P.M. Rajeshwari Shibu Jacob, M.A.Atmanand	Hydrophone array design-High sensitive broadband sonar receiver array with motion sensor for underwater imaging applications	India	341200, 2020
7.	C.R.Deepak,K.Thirumurugan, B.O.Vishwanath, V.Sundaramoorthi, N.R.Ramesh, M.A. Atmanand	Crushing System	India	346494, 2020

Awards and Honours

Mr. B. Rohith, INCOIS, was selected for the WMO Research Award- 2020 for Young Scientists for the paper entitled "Basin-wide sea level coherency in the tropical Indian Ocean driven by Madden-Julian Oscillation" published in Nature Communications, 2019, 10(1), 1257.

Dr. Thamban Meloth, Scientist-G and Group Director (Polar Sciences) has been elected as a **Fellow of the National Academy of Sciences India for 2020** for his contributions on polar cryosphere and climate change.

Dr. Kunal Chakraborty, INCOIS has been selected as an Associate of the Indian Academy of Sciences (IAS) in 2020

Dr. R Venkatesan Scientist-G, NIOT has been nominated as a Vice Chair at a newly restructured WMO Study Group on Ocean Observations and Infrastructure Systems (SG OOIS).

The term of Dr. J. Sanjay, Sc-F, IITM, as a Member, World Climate Research Program (WCRP) Coordinated Regional climate Downscaling Experiment (CORDEX) Science Advisory Team (SAT) was extended for two years up to 31 December 2021. He is also a Member of the Expert Network of the new WMO Technical Commissions: INFCOM and SERCOM.

Dr. Devendraa Siingh, Sc-E, IITM became a Member of COSPAR-URSI-SCOSTEP- Nat. committee for Int. Science Council-INSA New Delhi.

Dr. Swapna Panickal, Sc-E, IITM is selected as a Member, SPARC Science Task Team, World Climate Research Program (WCRP) for the period 2020-2025.

Dr. Roxy Mathew Koll, Sc-E, IITM became a Member, recent Research Foci group on Tropical Basin Interactions (TBI), announced by CLIVAR.

Dr. Yogesh K. Tiwari, Sc-E, IITM became a Member for the Integrated Global Greenhouse Gas Information System **(IG3IS) Steering Committee by WMO - Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC-SSC).**

Ms. Shikha Singh, Sc-C, IITM was awarded with the Outstanding Student Presentation Award in the **AGU Fall Meeting 2019** in San Francisco on 9-13 December 2019.

Ms. Aditi Modi, Sc-C, IITM became a Core Committee Member, International Indian Ocean Expedition (IIOE-2) Early Career Scientist Network.

Dr. Kunal Chakraborty has been selected for the membership of the National Academy of Sciences, India (NASI)

Dr. Avinash Kumar, Scientist D, NCPOR Goa has been awarded the prestigious National Award "ATAL VAGYAANIKA SHIKHAR SAMMAN - 2020". In the 7th Atal Award Ceremony on December 24, 2020, organized at Vigyan Bhawan, New Delhi.

Mr. Vineet Kumar Singh, Ph.D student, IITM received the Augmenting Writing Skills for

Articulating Research (AWSAR) Award by Department of Science and Technology, Govt. of India for Best Popular Science Stories entitled "Cyclones in the North Indian Ocean in a Changing Climate", under PhD Category on 28 February 2020.

Dr. Purnima Jalihal, Scientist-G, Group Head, Energy and Fresh Water, NIOT has been selected as Mission Innovation (MI) Champion for India for the year 2020 and was recognized by MI in a virtual award ceremony on June 12, 2020.

Dr. R Venkatesan, Scientist-G and Head OOS, NIOT is honored with NACE Fellow award by National Association of Corrosion Engineers (NACE) International USA.

Film on IITM (released on MoES Foundation day-2019) nominated by Vigyan Prasar for **10th National Science Film Festival 2020** under film by Govt. Category "ÏNTERFACE"., March 2020. Event was postponed due to Covid 19 in March 2020. 10th NSFFI2020 was conducted online during 24-27 November 2020. IITM film was screened through online mode on 24th Nov 2020 @ Vigyan Prasar Facebook.

The Telangana Academy of Sciences has recognised the contributions of **Dr. Abhisek Chatterjee,** Sc-D, INCOIS in its recent fellowship election and awards and has selected him as Associate Fellow.

Dr. Mrutyunjay Mohapatra, Director General of Meteorology conferred with the Doctor of Science (D. Sc. - Honoris Causa) by Fakir Mohan University, Odisha during its 10th Convocation on 4th March, 2020 for his outstanding & distinguished contributions in the field of Atmospheric Sciences and Meteorology and by Kalinga Institute of Industrial Technology (KIIT) for his services to the Society through cyclone warning.

Chapter - 9 | ADMINISTRATIVE SUPPORT

9.1. CITIZEN'S CHARTER

Vision

To excel as knowledge and technology enterprise in the earth system science realm towards socio-economic benefit of the society.

Mission

To provide services for weather, climate, ocean and coastal state, hydrology, seismology, and natural hazards; to explore and harness marine living and non-living resources in a sustainable way and to explore the three poles (Arctic, Antarctic and Himalayas).

Our Commitments			
S. No.	**Services/Transactions**	**Success Indicators**	**Service Standard**
1	Weather Forecasts and warnings and warning to General Public and Meteorological support for Pilgrimage, tourism, mountain expedition, sports etc.	Timely release of weather forecast	6 Hrs.
2	Providing Agro - Meteorological advisories at district Level	Agro-meteorological advisories at district Level	5 Days
3	Meteorological support for Civil Aviation purpose	Meteorological support for Civil Aviation purpose	30 Minutes
4	Rainfall Monitoring	Rainfall Monitoring	1 Day
5	Ocean Forecast	Timely release of (a) Fishing advisory	24 Hrs.
		Ocean State Forecast (i) General Public	6 Hrs.
		(ii) Fishing	6 Hrs.
		(iii) Industry	6 Hrs.
		(iv) Defense/Security/Researchers	6 Hrs.
6	Early warning of natural hazards.	Timely release of (a) Tsunamis Bulletin	10 Minutes
		Earthquake Bulletin (after)	10 Minutes
		Cyclone Warning Bulletin	3 Hrs.
7	Processing of proposals of holding of Seminars/Symposia on the matters relating to Earth Sciences	Approval of Seminars/Symposia proposals	2 Months
8	Processing of extra-mural proposals in the field of Earth Sciences	Timely processing of proposals from scientists/scientific institutions	6 Months

Our Commitments			
S. No.	**Services/Transactions**	**Success Indicators**	**Service Standard**
9	Payment to vendors	Timely payment to vendors on submission of bills	4 Weeks
10	Processing of requests for filling of scientific positions received from various centres	Timely processing of proposals received from various centres	2 Months
11	Grievance redressal	Timely redressal of grievance (a) Acknowledgement	7 Days
		(b) Final response	60 Days
12	Release of funds to the responsibility Centers under the control of MoES	Timely processing of proposals received	30 Days
13	Disposal of applications/appeals under RTI Act 2005.	Timely disposal of applications/ appeals under RTI Act 2005	
		Acknowledgement	1 Day
		Disposal of RTI applications	30 Days
		Disposal of RTI Appeals	

9.2 Implementation of the 15 Point Programme on Minority Welfare

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

9.3 BUDGET AND ACCOUNTS

(Rs. In crore)

S. No.	Major Head of Accounts	2018-19 Actuals			2019-20 Budget Estimates			2019-20 Actuals		
		Revenue	Capital	Total	Revenue	Capital	Total	Revenue	Capital	Total
REVENUE SECTION										
1.	3403- Oceanographic Research	692.34	0.00	692.34	703.00	0.00	703.00	655.44	0.00	655.44
2.	3425- Other Scientific Research	102.04	0.00	102.04	100.50	0.00	100. 50	72.66	0.00	72.66
3.	3451- Secretariat Economic Services	36.58	0.00	36.58	43.00	0.00	43.00	36.75	0.00	36.75
4.	3455- Meteorology	830.14	0.00	830.14	918.55	0.00	918.55	854.35	0.00	854.35
	Total (Revenue)	**1661.10**	**0.00**	**1661.10**	**1765.05**	**0.00**	**1765.05**	**1619.20**	**0.00**	**1619.20**
CAPITAL SECTION										
1.	5403- Capital Outlay on Oceanographic Research	0.00	13.16	13.16	0.00	18.00	18.00	0.00	11.23	11.23
2.	5455- Capital Outlay on Meteorology	0.00	73.07	73.07	0.00	123.00	123.00	0.00	93.98	93.98
	Total (Capital)	**0.00**	**86.23**	**86.23**	**0.00**	**141.00**	**141.00**	**0.00**	**105.21**	**105.21**
	Grand Total	**1661.10**	**86.23**	**1747.33**	**1765.05**	**141.00**	**1906.05**	**1619.20**	**105.21**	**1724.41**

9.4 Report of the Comptroller and Auditor General of India

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:-						
S. No.	Year	No. of Paras/PAC reports on which ATNs have been submitted to Monitoring Cell after vetting by Audit	Details of the C&AG/PAC reports on which ATNs are pending			No. of ATNs with Audit
			No. of ATNs not sent by the Ministry even for the first time	No. of ATNs sent but returned with observations and audit is awaiting their resubmission by the Ministry	No. of ATNs which have been finally vetted by Audit but have not been submitted by the Ministry to PAC	
1	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	One (Para No. 5.1 of Report No. 27 of 2014 on National Data Buoy Project").	NIL	NIL	One (Para No. 5.2 of Report No. 27 of 2014 on "Irregular Payment of Gratuity NIOT, Chennai").	NIL
3	2015	Two (Para No. 6.1 of Report No. 30 of 2015- "Unfruitful Expenditure due to non-functional website" and Para No. 6.2 of Report No. 30 of 2015- "Installation and upkeep of meteorological observatories by Regional Meteorological...").	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	Two (Para No. 7.1 of Report No. 17 of 2017 on "Non-recovery of fuel charges due to improper contract management" and Para No. 7.2 of Report No. 17 of 2017 -"Irregular Implementation of promotion scheme").	NIL	NIL	NIL	NIL
6	2018	One (Para No.8.1 of Report No. 2 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
7	2020	NIL	One (Para No.6.1 of Report No. 6 of 2020 on "Grant of financial benefits with out approval of co mpetent authority").	NIL	NIL	NIL

9.5 STAFF STRENGTH

Strength of all groups of Ministry of Earth Sciences including the constituent institutions are as below:-

Sr. 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 = NATIONAL CENTRE FOR MEDIUM RANGE WEATHER FORECASTING
CMLRE = CENTRE FOR MARINE LIVING RESOURCES AND ECOLOGY
NCCR = NATIONAL CENTRE FOR COASTAL REASEARCH
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

The sanctioned strength of the Ministry of Earth Sciences including attached offices is 329. The detailed break up is given below:

Ministry/ Attached Offices	Scientific/ Technical Posts	Non-Technical Posts	Grand Total
Ministry (Proper) including NCS+Koyna 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 15nos. 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 1.1.2021				Number of appointments made during the calendar year 2020											
					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

The Hindi Section of this Ministry is working under the supervision of Joint Secretary and to assist him there is One Joint Director (OL), One Assistant Director (OL) and two Senior Translation officer and one Junior Translation officer along with 2 Data Entry Operators. Hindi Section is responsible for the entire translation work and Implementation of Official Language Policy of the Government of India in the Ministry and its attached and subordinate offices and their field organizations. The important activities undertaken during the year are as under:-

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

REVIEW

i) The annual programme for the year 2020-2021 for implementation of the Official Language Policy of the Union, issued by the Ministry of Official Language as well as the 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.

INCENTIVE SCHEMES

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

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

iii) The Ministry observed Hindi fortnight from 14.09.2020 to 30.9.2020. Due to Covid-19 pandemic during this year various competitions were organized online. Officers and employees from the Ministry and Subordinate offices participated in these online competitions and the response was tremendous.

OTHER ACTIVITIES

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

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

iii) In this year, Committee of Parliament on Official Language has inspected IMD, RMC, Delhi and NCMRWF.

iv) Two Hindi Web-Series were organised on the 150th Birth Anniversary of Mahatma Gandhi. In these Series, first Webinar was organised on 16 September, 2020.

v) Online Essay Writing Competition on the themes of Gandhian Philosophy was organised on 26 September 2020.

vi) In Hindi Webinar Series on "Jan-Jan-ke Liye Vigyan", Secretary, Department Official Language delivered a Lecture in MOES on the topic Bhasha Vigyan Banam Rajbhasha: Dasha or Disha.

vii) Webinar on Gandhi Philosophy was organized on 1st October, 2020 to Commemorate the 150 Birth anniversary of the Father of Nation. The Webinar was given by none other than Prof. (Dr.) Girishwar Mishra, a Scholar, Writer, Gandhian, Thinker and former Vice-Chancellor of Mahatma Gandhi Anterashtriya Hindi Vishwa Vidhyalaya, Vardha.

viii) During the year, Ministry has been awarded with second Rajbhasha Kirti Award for doing the excellent work in progressive use of Hindi in year 2018-2019.

ix) Circulars regarding checkpoints and Vayaktisha Aadesh were issued.

9.7 Capacity Building and Human Resources development

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

9.8 Implementation of the judgments / orders of the CAT

All the 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. Kamaljit Ray, Scientist 'G' has been appointed as Chief Vigilance Officer (CVO) of the Ministry w.e.f 01.01.2020. 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(VOs) of various institutes & Departments under MoES. Dr. S. K. Sarkar, IAS (Retd.) & Shri Rakesh Goyal, IRSE (Retd.) have been appointed as Independent External Monitors by the Ministry with the approval of Central Vigilance Commission(CVC) for monitoring the contracts exceeding Rs.5crores, in accordance with the guidelines of CVC. Vigilance Awareness Week was observed from 27th October to 2nd November, 2020 with the theme "Vigilance India, Prosperous India" (सतर्क भारत, समृद्ध भारत). During Vigilance Awareness Week, two webinars were conducted by inviting guest speaker from other organisations. An essay competition was also conducted for the officers/officials of this Ministry under two categories and prizes and commendation certificates were awarded to the winners.

9.10 Parliament Matters

The Parliament Section which caters to the correspondence with Parliament Secretariats, replied Lok Sabha (36 Questions) and Rajya Sabha (13 questions) last year.

9.11 Significant Audit Points Printed in audit Reports of 2020

One audit point has appeared in the Audit Report of 2020.

Chapter - 10 | **ACKNOWLEDGEMENTS**

During the year, many scientists and academicians from India and abroad have contributed as external experts in the various committees in the ongoing activities and programmes of MoES. The Ministry extends its gratitude to all those who have provided their enormous support in both administrative and scientific matters. The Ministry is further immensely grateful and expresses its gratitude to the Parliamentary Standing Committee on Environment and Forests, Science and Technology and also the Parliamentary Committee on Rajbhasha for their constant support, guidance and encouragement.

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

1. Program Advisory and Monitoring Committee (PAMC) on Atmospheric Sciences chaired by Prof. J. Srinivasan, IISc, Bengaluru.
2. PAMC on Ocean Science and Resources chaired by Dr. Satish Shetye, Former Director, NIO, Goa
3. PAMC on Hydrology and Cryosphere chaired by Dr. R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO, Bengaluru
4. PAMC on Geosciences, chaired by Prof. Ashok Singhvi, PRL, Ahmedabad.
5. PAMC on Seismicity and Earthquake Precursors chaired by Dr. M. Ravi Kumar, DG, Institute of Seismological Research, Gandhinagar
6. Re-constituted PAMC on Atmospheric Sciences chaired by Prof G.S. Bhat, IISc, Bengaluru.
7. Re-constituted PAMC on Ocean Sciences Sciences chaired by Dr. S. S. C. Shenoi, Former Director, INCOIS
8. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
9. Research Advisory Committee of IITM chaired by Prof. J. Srinivasan, IISc, Bengaluru
10. Research Advisory Committee of NCMRWF chaired by Prof. J. Srinivasan, IISc, Bengaluru
11. Research Advisory Committee of INCOIS chaired by Prof. G. S. Bhat, IISc, Bengaluru
12. Reconstituted Research Advisory Committee of INCOIS chaired by Dr. Satish Shetye, Former Director, NIO, Goa
13. Scientific Advisory Council of NIOT chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
14. Research Advisory Committee of NCCR chaired by Dr. Shailesh Nayak, Director, NIAS.
15. Research Advisory Committee of CMLRE chaired by Prof. T. Balasubramanian, Vice Chancellor, Chettinad Academy of Research and Science, Chennai.
16. Research Advisory Council of NCPOR, chaired by Dr. Shailesh Nayak, Director, NIAS.
17. Research Advisory Council of NCESS chaired by Dr. S.K. Tandon Professor Emeritus, University of Delhi
18. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof. Sulochana Gadgil
19. Committee to draft new byelaws of the autonomous institutions of Ministry- Dr L.S.Rathore, Former Director General of IMD.
20. Various subject experts who have participated in the MFCS and Recruitment Board interviews as members.

सत्यमेव जयते

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