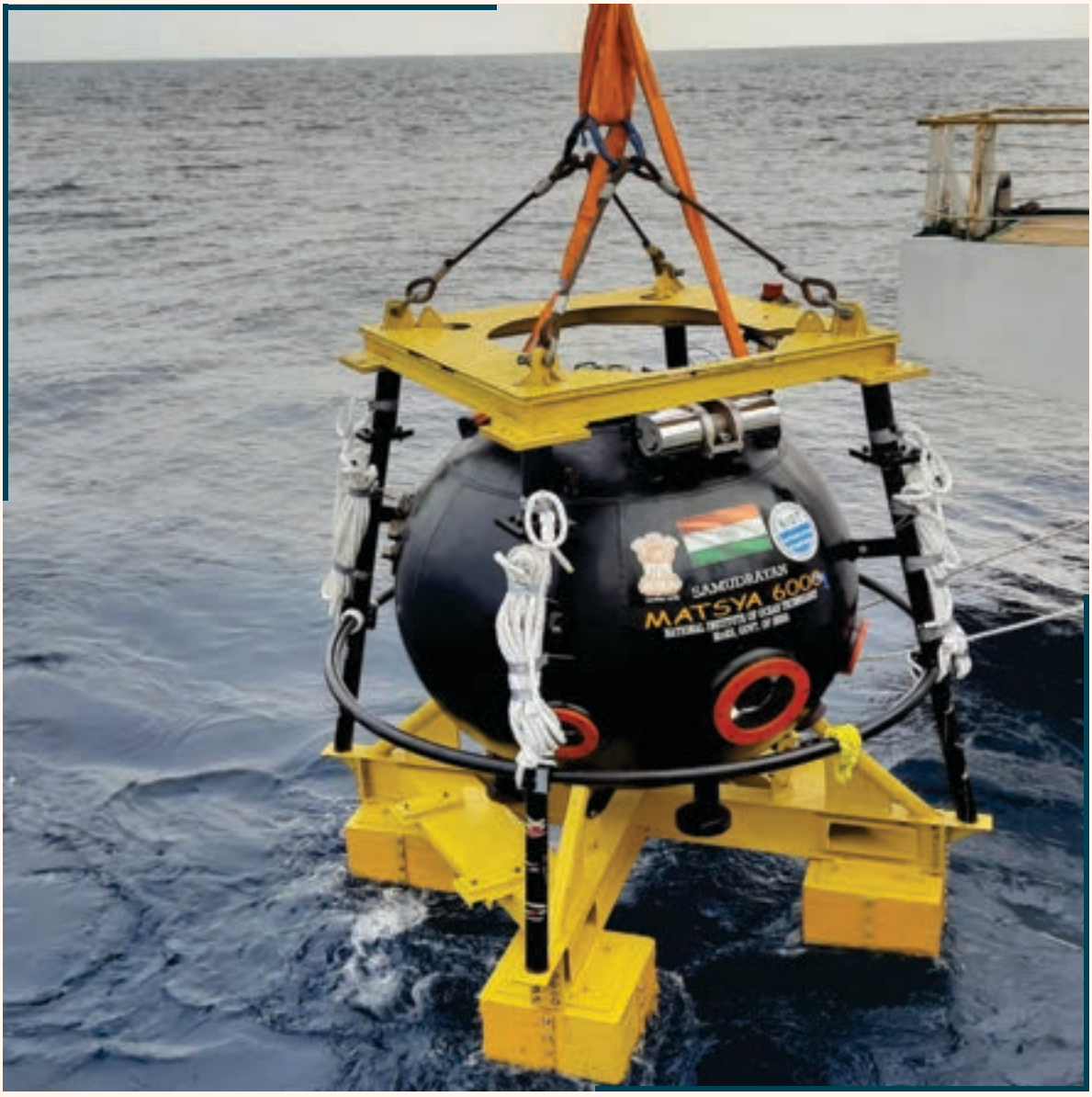
सत्यमेव जयते

Government of India
Ministry of Earth Sciences



ANNUAL REPORT
2021-2022

FRONT COVER

Government of India
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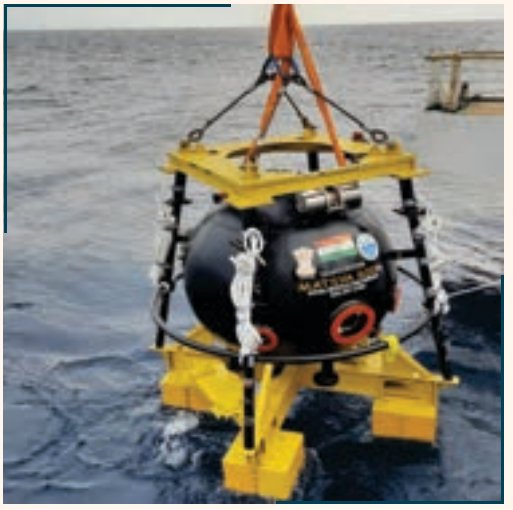

ANNUAL REPORT
2021-2022

Sea trial of Shallow water Personnel Sphere for human occupancy at 610 m water depth in Bay of Bengal

BACK COVER

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Ministry of Earth Sciences

NCESS Critical Zone Observatory (CZO) at Attappadi, Kerala for generating continuous data on key Critical Zone variables using automatic weather station, profile soil moisture sensors, digital pan evaporimeters etc.

ANNUAL REPORT

2021-2022

Government of India
Ministry of Earth Sciences

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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; alerts for Tsunamis and monitoring of 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 the Renewable Energy sector. Several major milestones have been accomplished under the five major programs of the MoES during the last year, which are illustrated below:

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

- Accurate and timely prediction of tropical cyclones Tautkae, Yaas, Gulab and Shaheen by India Meteorological Department (IMD), combined with fieldwork by disaster management agencies, that helped save thousands of precious lives of countrymen.
- Seven Doppler Weather Radars were commissioned at Mukteshwar, Kufri, Jammu, New Delhi, Mumbai, Chennai and Leh.
- Eleven new District Agro-Meteorological Units (DAMUs) were established during the year taking the total of DAMUs to 199.
- India Meteorological Department (IMD) released Climate Data Service Portal, 21 Standard Operation Procedure Manuals on various forecasting services of IMD and a series of brochures/templates highlighting the services rendered by various divisions and offices of IMD on 23rd March 2021.
- A Pune Live Weather Mobile App was launched on 27 July 2021 with data of more than 80 weather stations including rainfall data every 15 minutes live to its Users. The app provides data from different resources under one umbrella.
- IMD launched its crowd-sourcing mechanism through web interface to collect all observed weather phenomena like rain, thunderstorm, squall etc., from public.
- Atmospheric Research Testbed is an open field observatory spread in 100 acres of land (50 km northwest of Bhopal in Sehore District of Madhya Pradesh) being established for better understanding on the processes governing monsoon convection and land-atmosphere interactions over the core monsoon region using the state-of-the-art observational systems such as Radars, Wind Profilers, UAVs etc. This Atmospheric Research Testbed will be a unique facility in the Tropical region. A Dual-polarimetric C-band Doppler Weather Radar was commissioned in the above facility recently for detailed precipitation process studies in the core monsoon zone.
- New sensors for the Lightning Location network have been installed at remote locations Aizawl, Leh and Port Blair and integrated with central processor at Indian Institute of Tropical Meteorology (IITM). With these installations, sensors have been placed in all the States and Union territories except Lakshadweep Islands.
- Under Lightning Location Network, Indian Institute of Tropical Meteorology (IITM) has established a total of 83 sensors across the country.
- IITM has successfully developed indigenous Decision Support System (https://ews.tropmet.res.in/dss/) for advanced air quality management for Delhi NCR region. It was

inaugurated by the Hon'ble Minister of Earth Sciences, Dr. Jitendra Singh, on 18 October 2021.

- An ice parameterization scheme has been developed using Ice nuclei and aerosol measurements carried out over High-Altitude Physics Laboratory at Mahabaleshwar.
- National Centre for Medium Range Weather Forecasting (NCMRWF) has started receiving many new observations.
- NCMRWF data assimilation systems were upgraded to include these observations during 2021. The new observational datasets mainly include atmospheric motion vectors from Korea Meteorological Administration(KMA: GK-2), China Meteorological Administration (CMA: FY-2G & FY-2H) and EUMETSAT DUAL-METOP AMVs and vertical wind profiles from the Aeolus satellite, through EUMETCAST Terrestrial Reception System.
- A High-Resolution Rapid Refresh (HRRR) system was also implemented to support nowcasting activities of IMD.
- A Virtual Centre on Artificial Intelligence (AI) / Machine Learning (ML)/ Deep Learning (DL) has been is established at IITM Pune in order to expand the domain through multidisciplinary programs in the field of Earth System Sciences.

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

- Indian National Centre for Ocean Information Services (INCOIS) continued to provide its flagship service of advisories on the Potential Fishing Zones (PFZ), which were disseminated in smart map and text form on daily basis, except during fishing-ban period and during adverse sea-state conditions. During January to December 2021, multilingual PFZ advisories and Yellowfin Tuna advisories were provided for 326 and 254 days, respectively.
- An Earth System Science Data Portal (ESSDP) of MoES (https://incois.gov.in/essdp) was launched on 27 July 2021. The ESSDP hosts about 1050 metadata records of data collected and maintained under different programs implemented by MoES over the years and link them to the respective data centres. It facilitates ease of search and discovery of various data-sets by different search criteria. ESSDP will serve the increasing data-discovery needs of a wide range of users including research institutions, operational agencies, strategic users, academic community, industry, policy makers and the public.
- The underwater mining system was deployed from ORV Sagar Nidhi and Seabed locomotion trials of the experimental undercarriage system of underwater mining system (Varaha-I and II) was successfully undertaken over a distance of 120m on water-saturated soft soil at 5270 m depth in the Central Indian Ocean (CIO) during March – April 2021.
- Two gliders were deployed in the Bay of Bengal to monitor the deep ocean physical and biogeochemical parameters with special emphasis to understand the temporal and spatial variability of the Oxygen Minimum Zone (OMZ). Both the gliders, after covering 5000 km distance, are recovered and collected data was retrieved.
- The Joint OMNI-RAMA Indian Ocean Data Portal developed by INCOIS jointly with NIOT and PMEL-NOAA was launched on 9 August 2021.
- An Indian patent has been granted for the invention titled 'REAL TIME TSUNAMI MONITORING SYSTEM', patent No. 369964 on 22nd June 2021. Six Indigenous Ocean observation technologies developed and has been successfully transferred to M/s L&T for commercialisation.
- A water quality buoy deployed by National Centre for Coastal Research (NCCR) in the coastal water off Puducherry at 10m depth (~1.5 km from the coast) was dedicated to the nation on 28.07.2021 by the Chief Minister of Puducherry. This is an automated water quality buoy fitted with sensors to monitor the variations in the water quality and productivity of the coastal waters. The real time water quality data will be disseminated through web-based forecasting system and a mobile app "clean coast" at every 20 minutes interval.

- As a shoreline monitoring program, long term shoreline change maps have been prepared at 1:25000 scale for dissemination to different stake holders of the state for management of coastal resources. The Shoreline change mapping for some of the Islands has been prepared on long term scale (1990-2018).
- Under the Resource Exploration and Inventorization System (REIS) programme taxonomic studies of samples collected on-board FORV Sagar Sampada within the Indian Exclusive Economic Zone (EEZ) yielded six new species of decapod crustaceans, one new species of polycheate and two species of deep sea eels.

1.3 Polar and Cryosphere Research (PACER)

- The 40th Indian Scientific Expedition to Antarctica (40-ISEA) was launched from Murmugao, Goa in January 2021 with 43 Indian members on board expedition vessel MV Vasiliy Golovnin.
- The 41st Indian Scientific Expedition to Antarctica was successfully launched in November 2021 from National Centre for Polar and Ocean Research (NCPOR), Goa.
- The 41st expedition has two major programs. The first program encompasses geological exploration of the Amery ice shelf at Bharati station. This will help explore the link between India and Antarctica in the past. The second program involves reconnaissance surveys and preparatory work for drilling of 500 meters of ice core near Maitri in collaboration with the British Antarctic Survey and the Norwegian Polar Institute. It will help in improving the understanding of Antarctic climate, westerly winds, sea-ice and greenhouse gases from a single climate archive for past 10,000 years.
- Glaciological field campaigns have been carried out for six glaciers during May 2021 to October 2021 covering total glacierized area of ~300 km^2.
- India is developing POLarAERosolNETwork (POLAERNET) for long-term and continuous observations of aerosols over the polar (Arctic,Antarctic and Himalayan) regions.

1.4 Seismology and Geoscience Research (SAGE)

- The Existing National Seismological Network has now been strengthened to 150 stations with the addition of 35 new seismic observatories to improve the operational capability to detect any earthquake of M:3.0 or above in most parts of the country.
- During the period January- December 2021, a total of 1398 earthquakes were located and reported. Out of these earthquakes, 58 events are of magnitude M:5.0 and above.
- The seismic microzonation work of four cities, Bhubaneswar, Chennai, Coimbatore and Mangalore, is at advanced stage of completion and work related to eight more cities (Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad) has been started and various Geophysical & Geotechnical surveys are in progress.
- Under the Scientific Deep Drilling project in the Koyna Intraplate Seismic Zone, Maharashtra, the evidence of deep-water percolation in the Koyna Seismogenic Zone has been established with several damage zones being delineated between 2 and 3 km in the Koyna pilot borehole based on the physical and mechanical properties of the rock formations.
- Under the national network project, Submarine Ground Water Discharge (SGD), National Centre for Earth Science Studies (NCESS) has estimated SGD flux from three coastal catchments of southwest coastal zone of India through aquifer modelling technique. There are nine critical zones with a total shore length of 106.5 km, out of 640km surveyed, in the SW coastal zone having SGD signatures.
- NCESS developed a MATLAB-based inversion program, b-spline polynomial approximation using the differential evolution algorithm (SPODEA), to recover the concealed basement geometry under heterogeneous sedimentary basins.

1.5 REACHOUT

- During the current financial year, a total number of 27 research proposals from various academic/ research organizations and universities have been sanctioned.
- The International Training Centre for Operational Oceanography (ITCOocean) established at INCOIS, Hyderabad a UNESCO Category 2 Centre, had trainees from 95 countries uptill now. The online training mode due to the pandemic has enabled increased participation from Indian Ocean Rim countries in the training programmes. During January 2021 - December 2021, 16 training courses were conducted. A total of 1713 persons were trained of which 1021 are from India and 692 from other countries.
- An online workshop cum training programme on 'Use of Ensemble Model Forecast by NCMRWF Products for Weather/Climate' was conducted during 24-26 March 2021. There were about 50 participants from the NHMS of Bangladesh, Bhutan, Nepal, Myanmar, Thailand and Sri Lanka who are the Member Countries of BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation).
- Five days Online training Program named 'Online training in AI/ML for atmosphere-ocean applications for beginners' was conducted under the Development of Skilled Manpower in Earth System Sciences (DESK).
- E-resources subscribed under DERCON (Digital Earth Sciences Consortium) in 2021 were made available to scientists and employees of MoES institutes through KRCNET.
- "Azadi Ka Amrit Mahotsav" is an initiative of the Government of India to celebrate and commemorate 75 years of progressive India and the glorious history of its people, culture, and achievements. This event is an embodiment of all that is progressive about India's socio-cultural, political, and economic identity. The MoES iconic week celebrations began on October 18, 2021 and ended on October 24, 2021. To commemorate the monumental occasion, MoES and all its institutes hosted a set of activities for a resurgent, AtmaNirbhar Bharat.
- The seventh edition of the India International Science Festival (IISF 2021) organized by the Ministry of Earth Sciences, Ministry of Science and Technology and Vijnana Bharati along with Government of Goa was held in Goa during 10-13, December 2021. The National Centre for Polar and Ocean Research (NCPOR), MoES was the nodal agency for organizing the IISF 2021. The theme of IISF 2021 was 'Celebrating Creativity in Science'. The festival had 12 programmes including the mega science and technology expo.

1.6 Deep Ocean Mission

- The Deep Ocean Mission, India's ambitious plan to explore and harness deep-oceanic resources and support the Blue Economy Initiatives of the Government of India with a budget of Rs 4077 crores was approved by the Cabinet Committee on Economic Affairs on June 16, 2021. Ministry of Earth Sciences (MoES) will be the nodal Ministry implementing this multi-institutional ambitious mission.
- Dr. Jitendra Singh, Hon'ble Minister of State (Independent Charge) of the Ministry of Earth Sciences and Ministry of Science & Technology (HMoES) launched the SAMUDRAYAAN Indian Manned Ocean Mission under Deep Ocean Mission on 05th November 2021.

1.7 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.
- The Implementation Agreement on "Technical Cooperation in Development of the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA) and the Ocean Moored buoy Network in the northern Indian ocean (OMNI) for Improving Weather and

Monsoon Forecasts" was signed on 09 August 2021 in a virtual event. The Joint RAMA-OMNI Indian Ocean Data Portal was also launched by Secretary, MoES during the virtual event. The OMNI-RAMA portal will showcase the large inventory of meteorological and oceanographic data sets with direct access for data display and delivery.

- Consequent upon extension of the Implementation Agreement on Weather and Climate Science for Service Partnership India (**WCSSP India**) between MoES and UK Met Office by a year till March 2021, both sides mutually agreed for an additional extension till March 2022. The annual Science meeting of WCSSP India program was organized virtually during 1-4 Feb 2021 with participation of over 100 scientists from India and UK.
- 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. The Belmont Forum annual preliminary 2021 was held in a virtual mode during 26-28 October 2021. Members from over 31 countries participated in the meeting.
- The First Meeting of the BIMSTEC Expert Group on Himalayan Science Council was held virtually in New Delhi, India on 12 October 2021 with an aim to finalize the Concept Paper on 'Proposal for the Himalayan Science Council (HSC) under the BIMSTEC'.
- A joint Indo-Norwegian meeting was conducted on 23rd March 2021 to review the progress of projects sanctioned jointly under the MoU between MoES and Research council of Norway (RCN).
- A webinar on "Marine Plastic Pollution Prevention and Management" was held on 16 February, 2021 with the aim to highlight the specific efforts of institutions in Japan and India on Marine plastic waste related issues and collaborate to address the marine waste problem.
- Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) continued its efforts to provide uninterrupted services to its member and collaborating States in 2021. RIMES along with the Regional Climate Centre, Pune of India Meteorological Department, UK Met Office, and World Meteorological Organization participated in the South Asian Outlook Forum (SASCOF) during 26-28th April 2021 in a virtual mode. About 100 meteorologists from National Meteorological and Hydrological Services offices and climate experts prepared the seasonal and regional climate outlook of monsoon. The SASCOF-20 and Climate Services User Forum (CSUF) was held in September 2021 for producing a seasonal outlook for winter monsoon or Northeast monsoon season.
- Ministry of Earth Sciences and UK Research and Innovation (UKRI) jointly organized a COP26 partnership virtual event on Sustainable and Inclusive Climate Adaptation and Resilience: local leadership for a global goal on 29 September 2021 as a contribution towards the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow in November 2021,
- India and Vietnam signed a Memorandum of Understanding (MoU) towards promoting scientific and technical cooperation in marine science and ecology on 17th December 2021.

1.8 Scientific Publications

A total number of 622 research papers were published during 2021 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 (2099) are comparatively much higher as compared to the previous years. The average impact factor of research papers was 3.37.

1.9 Budget Expenditure:

The total outlay for the Ministry for the year 2021-22 was Rs.1897.13 crores which was increased to Rs. 2369.54 crores at the RE stage. However, the RE

includes an amount of Rs 521.01 crores to be paid to Department of Space as a lease rental for the Oceansat-3 satellite. The expenditure profile for the last 14 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	1285.76
2021-22	**1897.13**	**2369.54***	**1379.98****

* It includes Rs 521.01 crores to be paid to DoS as lease rental for Oceansat-3 Satellite **As on 31/01/2022

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

2.1. Observing Systems and Field Campaigns

The following observational systems have been installed during the period by IMD and IITM:

- **Doppler Weather Radar (DWR):** Seven Doppler Weather Radars were commissioned at Mukteshwar, Kufri, Jammu, New Delhi, Mumbai, Chennai and Leh.
- **Lightning Location network:** New sensors for the Lightning Location network have been installed at remote locations Aizawl, Leh and Port Blair and integrated with central processor at IITM, Pune.
- A total number of 71 Automatic Weather Stations (AWS) and 36 Automatic Rain Gauges (ARG) and 179 Agro-AWS were installed in the country.
- Eleven new District Agro-Meteorological Units (DAMUs) were established taking the total of DAMUs to 199.
- Digital Current Weather Instrument System (DCWIS) were installed at 10 airports.
- High Wind Speed Recorder (HWSR) were installed at Ratnagiri, Maharashtra, Thondi, Tamil Nadu, Puducherry, Puducherry, Nagapattninam, Tamil Nadu, Thotthukudi, Tamil Nadu, Mormugoa, Goa, Pamban, Tamil Nadu and Kanyakumari, Tamil Nadu.
- IMD launched its crowd-sourcing mechanism through web interface to collect all observed weather phenomena like rain, thunderstorm, squall etc., from public.
- In-house built portable sensor 'Visible Sky Imager' for cloud detection is successfully tested and is being operated at IITM, Pune for continuous measurements of sky cover during day hours.
- For the first time, two test flights were conducted successfully using a quad-copter at Police Grounds in Pune for testing the in-house designed ground equipment for operating a meteorological sensor on Unmanned Aerial Vehicle (UAV) for temperature, relative humidity and wind measurements.

2.1.1 Atmospheric Research Testbed (ART) facility in central India

The ART program 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. Work has been initiated for establishing the ART facility on the ~100 acres of land at Silkheda village in Sehore District of Madhya Pradesh. This is a unique facility of international standards. The civil and electrical infrastructure at the ART site is being developed by CPWD which includes construction of boundary wall and main entrance gate, electrical sub-station (HT), solar lighting, etc. A dual-polarimetric C-band

Doppler Weather Radar was commissioned at the site in June 2021 (Fig. 2.1) and the first observational campaign was conducted during monsoon (01 June - 30 September 2021) to collect the vertically-resolved polarimetric data on 3-D structures of convective and microphysical properties in the monsoon core zone. For conducting Beyond Visual Line of Sight (BVLOS) experiments for atmospheric research up to 9000ft using Unmanned aerial System (UAS) facility, necessary approvals and clearances have been obtained from various agencies.

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, for collecting high-quality aircraft observations of cloud and precipitation related processes in natural and seeded clouds over the rain shadow region. These 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 resulted in 267 randomized cloud seeding samples, which have been evaluated and a report was submitted to MoES. The 18th International Conference on Clouds and Precipitation (ICCP 2021) was organized by the International Commission on Clouds and Precipitation (ICCP) and hosted by CAIPEEX- IITM in virtual mode during 2-6 August 2021. The conference hosted 639 authors and 120 participants contributing to the conference from 32 countries.

Fig. 2.1 : Dual-polarimetric C-band Doppler Weather Radar commissioned at the ART site.

2.1.3. Satellite products for weather forecasting services

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 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 the 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.

The satellite and lightning merged products are also operationalized at IMD website. The merged lightning & satellite cloud top temperature operational product is a joint collaboration of IMD, IITM & IAF. Work is going on merged (all 3 types of instrument data) Satellite, RADAR and Lightning data for the weather forecast.

The processed Satellite data (Digital, image, products) are being used by the operational weather forecasters, IAF, Indian Navy, Indian Coast Guard, Disaster management authorities, international meteorological agencies in a near real time basis for issuing the weather forecasts on a routine basis.

2.2. Modelling work at NCMRWF

2.2.1. Global observations and Data Assimilation

The NCMRWF data assimilation (DA) system was upgraded in 2021 to include atmospheric motion vectors from Korea Meteorological Administration, China Meteorological Administration and EUMETSAT DUAL-METOP Atmospheric Motion Vectors (AMV). The global coverage of these data sets on a typical day received at NCMRWF is shown in Fig. 2.2. Assimilation of these observations in the atmospheric DA system has resulted in improvement of forecasts, especially over the northern hemisphere.

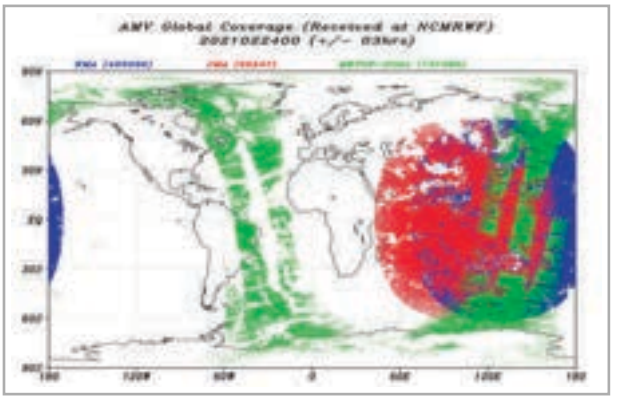

Fig. 2.2 : Global coverage of AMVs from KMA, CMA and METOP - Dual on 00UTC 24th Feb 2021 .

In addition, *vertical wind profiles* from the Aeolus satellite were also received, through EUMETCAST Terrestrial Reception System. The main product from Aeolus is the horizontally projected Line of Sight (HLOS) wind component. Since June 2021, these observations along with the cloud-affected microwave humidity sounder (MHS) observations of Advanced TIROS Operational Sounder (ATOVS) are being assimilated into the NCUM global (NCUM-G) DA system, which is based on the "Hybrid 4D-Var" method. A Forecast Sensitivity to Observation Impact (FSOI) study clearly shows (Fig.2.3) that HLOS wind observations have a significant beneficial impact on the model forecast especially over conventional data sparse regions like tropics and Southern Hemisphere extra-tropics. The Observing System Experiment (OSE) study of Aeolus HLOS in NCUM-G forecast system during tropical cyclone "Nisarga" showed that Aeolus observations help to reduce the position error of the tropical cyclone. This data is now included in the operational NCUM-G system since June 2021.

The NCUM regional model (NCUM-R, 4km) was also updated with the capability to assimilate Indian Doppler Weather Radar (DWR) observed reflectivity in addition to other in-situ and remote sensing observations. A High-Resolution Rapid Refresh (HRRR) system based on WRF (3 km resolution) model with GSI based assimilation system to support nowcasting activities has been developed. The system which uses high-frequency observations such as

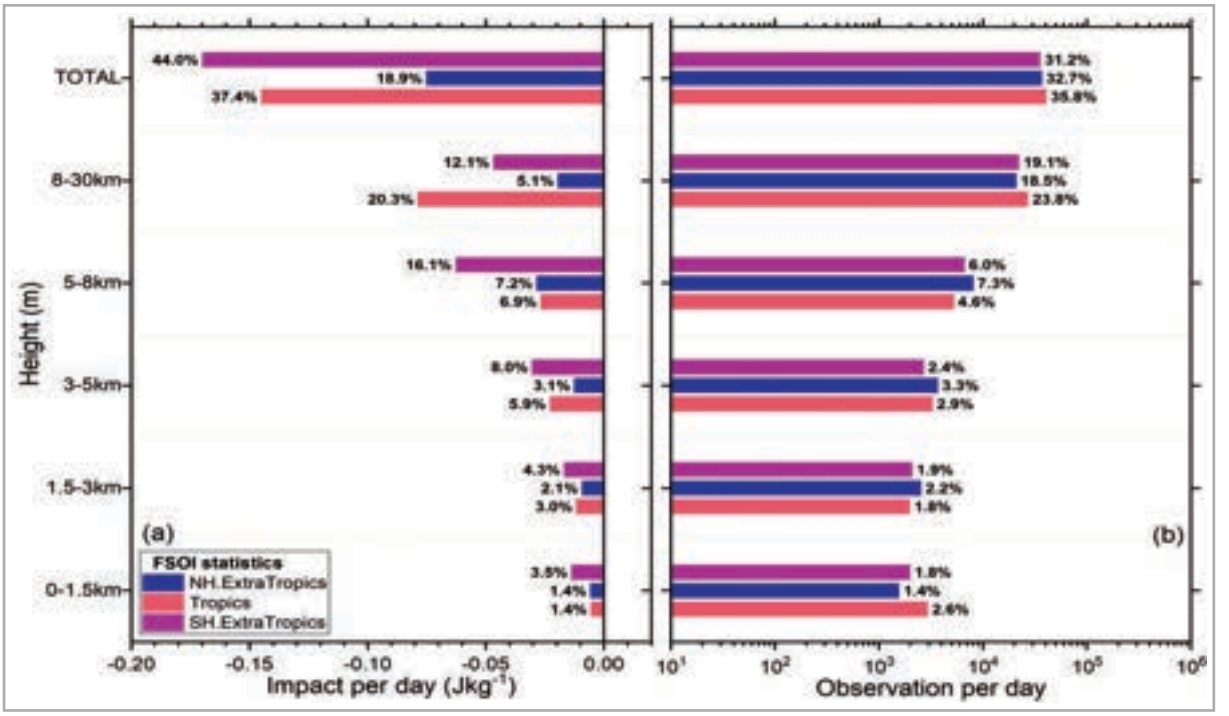

Fig 2.3: (a) Relative observation (AEOLUS-HLOS) impact on NCUM global forecast (b) Number of observations assimilated for various altitudes and the total of all levels at Northern extra-tropics (blue), Tropics (brown) and Southern extra-tropics (pink) average for 21 May to 22 June 2020.

Radar Reflectivity and Radial wind from the Indian DWR network, lightning flash count, along with all other observations was tested during monsoon 2021 and forecasts up to 16 hours are found useful. The 4D-VAR based HRRR-DA system was also tested in the NCUM-R at 1.5 km horizontal resolution. The impact of the DWR reflectivity data in the HRRR-DA system on the forecast of a heavy rainfall event that occurred during 5-7 August 2020 over Mumbai region indicates that the prediction of rainfall amount is improved in the 1.5 km model with HRRR DA when radar reflectivity is assimilated (Fig-2.4 f) as compared to the operational 4 km (Fig-2.4d) and 1.5 km model (HRRR without reflectivity assimilation: Fig 2.4e).

2.2.2 Global/Regional Atmospheric Model

As part of urban modelling studies, a two-tile urban energy budget parameterization scheme Urban Surface Exchange Scheme (MORUSES), was implemented in the NCUM high resolution (330 m) model over the Delhi domain. Input data was generated from detailed urban morphology of Delhi in collaboration with the Indian Institute of Remote Sensing (IIRS), Dehradun.

Delhi Fog Model (DM) was further upgraded with the revised visibility parametrization incorporating EDGAR (1.5km) and SAFAR (330m) emission inventories, and daily biomass emission from Global Fire Assimilation System (GFAS). From winter 2020-2021, this model has been operational providing an improved high-resolution fog/visibility forecast for Delhi and the adjoining regions. "The 330 m DM-Chem model with hourly scaling of emission, implemented during 2021-22 winter season compares better with the current metar visibility observations of IGI Airport than those generated from the runs with daily emissions (Fig. 2.5)."

2.2.3. Global/Regional Ensemble Prediction Systems:

Tropical cyclone tracks are now being operationally generated using the unified model based global ensemble prediction system of NCMRWF (NEPS-G) at

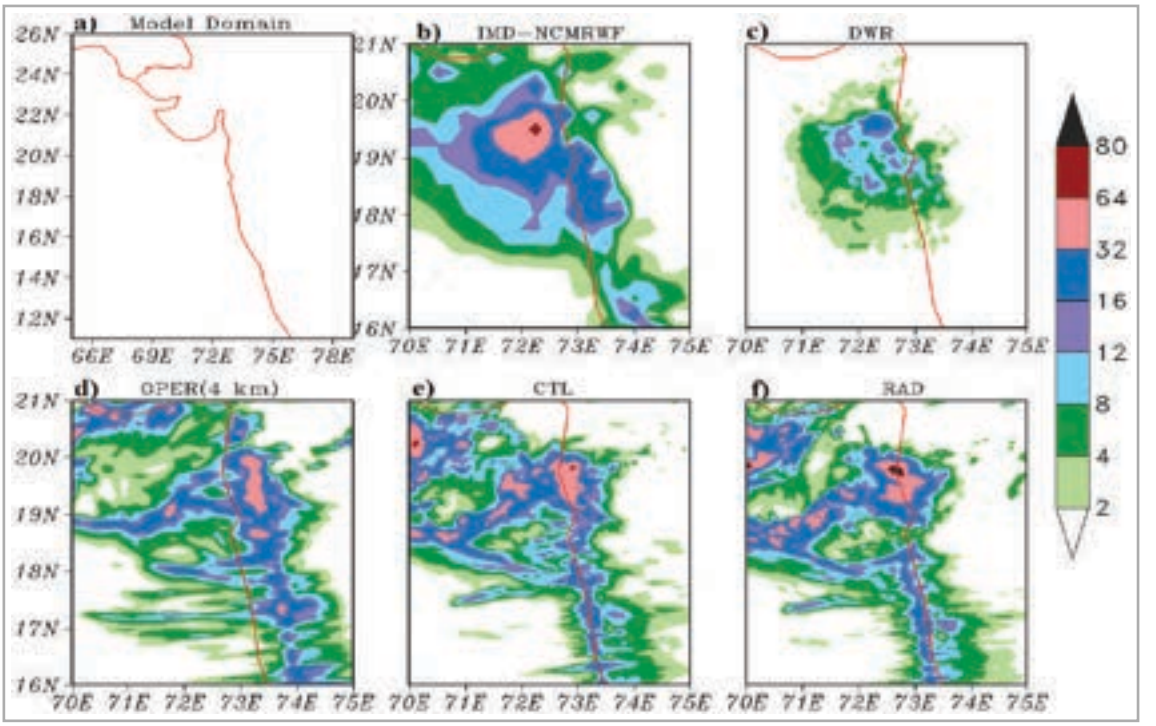

Fig 2.4: a) Model domain with height (shaded; m); b) IMD-NCMRWF merged rainfall analysis (cm); c) DWR derived rainfall; d) Operational 4 km model 24 hrs forecast; e) 1.5 km model 24 hrs forecast (HRRR without radar reflectivity) and f) HRRR (with reflectivity) 24 hrs forecast valid on 00 UTC 06 August 2020 (all are 24 hrs accumulated rainfall).

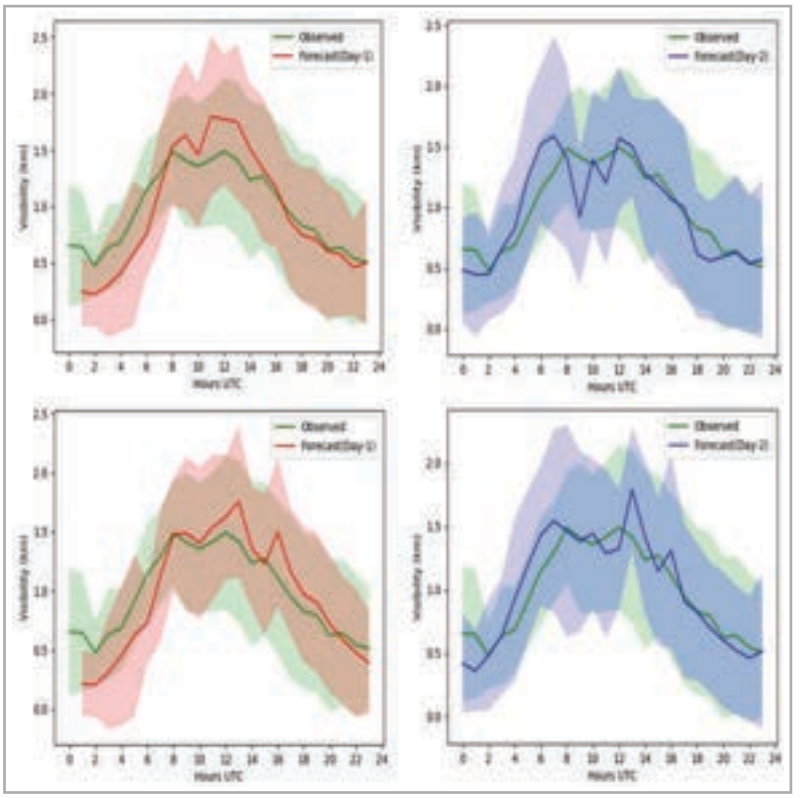

Fig. 2.5 : Visibility (km) observed at IGI Airport and predicted by DM-Chem (~330m) model at day-1 (a and c) and day-2 (b and d) lead times. Top panels are with daily mean emissions and bottom panels with hourly varying emissions for January 2021. The solid curves denote monthly mean values and the shading denotes the standard deviation.

12 km resolution. Fig. 2.6 shows the probabilistic forecasts of tropical cyclone 'Gulab' provided by NEPS-G depicting strike probability, tracks and storm following Meteograms which are based on 23 members from 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. NCMRWF has started sharing the verification scores for the NEPS-G forecasts for the Northern and Southern Hemisphere and the Tropics (NH, SH & TR) with the Lead Centre since last year. Fig. 2.7 shows the reliability diagram and ROC curves of 850 hPa forecasts over the tropics (TR) for July 2021. It is seen from the figure that the reliability curve is aligned along the diagonal line of perfect reliability. However, for lower (*higher*) probabilities there is a slight under (*over*) forecasting. The ROC curve shows Hit Rate vs False Alarm Rate and measures the ability of the forecast system to discriminate between events and non-events.

The verification statistics of the NEPS with other centres (UKMO, ECMWF, JMA) is being compared to assess the relative performance of the models. It can be seen from Fig. 2.8 that the reliability of temperature

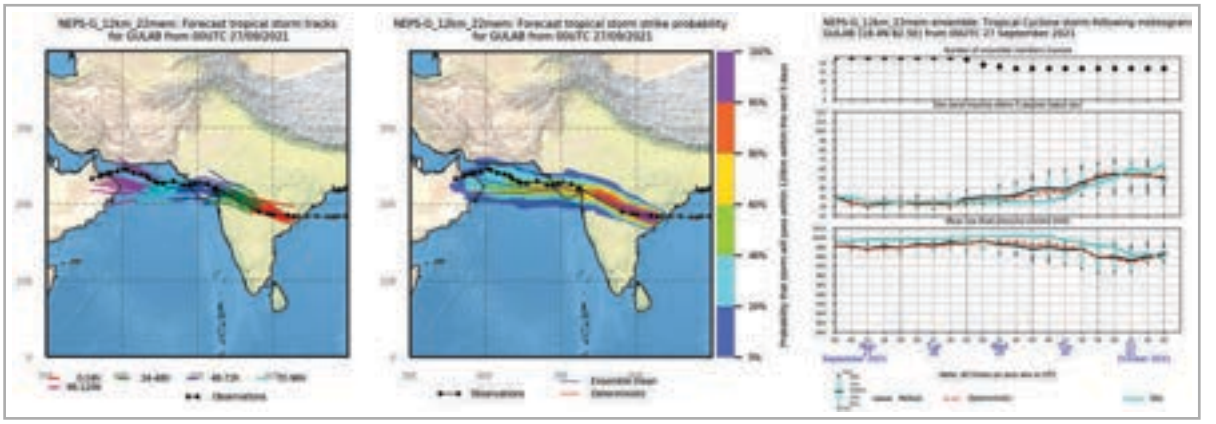

Fig.2.6 : (a) Ensemble members tracks, Strike Probability and Storm Following Meteogram of 23 ensemble members from NEPS-G for tropical cyclone Gulab based on initial condition of 00 UTC 27th Sep 2021.

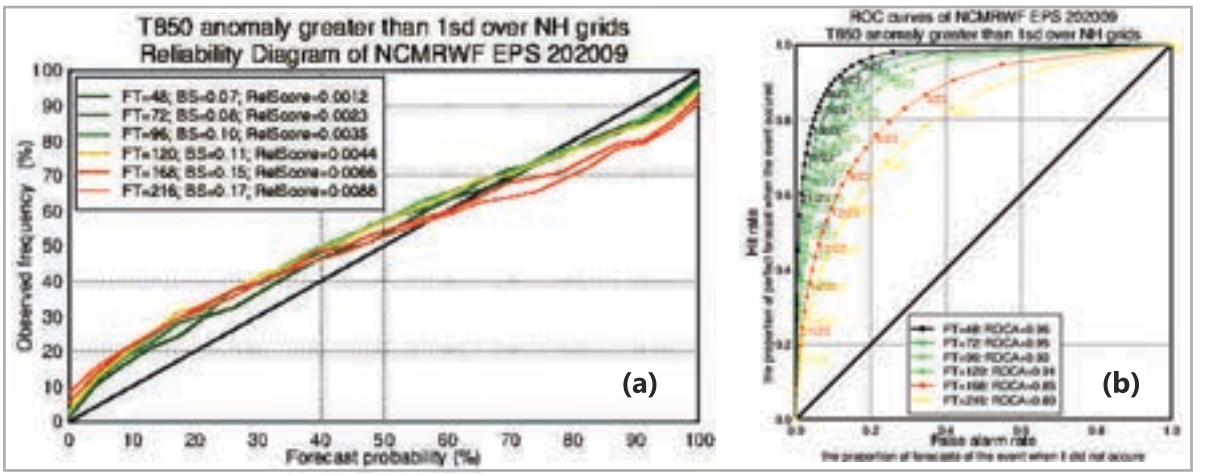

Fig. 2.7 : (a) Reliability Diagram (b) the ROC diagram for T850 forecasts over the tropics (TR) from NEPS for July 2021.

forecasts (48 hour lead time) at 850 hPa level (T850) from NEPS-G is at par with other global meteorological centres. The reliability was computed for 6 thresholds i.e., T850 > climatology+1sd, climatology+1.5sd and climatology+2sd and T850<climatology-1sd, climatology-1.5sd and climatology-2sd.

2.2.5 Ocean Data Assimilation and NCMRWF Coupled Model (C-NCUM):

Nucleus for European Modelling of the Ocean (NEMO) is a modelling framework for ocean state monitoring and its forecast, research activity, and climate studies. The NEMO-based global high-resolution eddy-resolving ocean model (ORCA12 configuration) with 75 vertical layers is operational at 1/12th degree resolution (approximately 9 Km grid point distance). It has been observed that the NEMO ocean model is able to capture mesoscale eddies and meanders reasonably well. Fig 2.9 shows the eddy formations, as depicted by the NEMO ocean model, during cyclones 'Mekunu' and 'Vayu' over the Arabian Sea (AS) and 'Amphan' and 'Fani' over Bay of Bengal (BoB). HF Radar derived coastal surface ocean currents were used by NCMRWF to validate ocean model simulations of a Very Severe Cyclonic Storm "Vardah" that originated from the low-pressure area near the Malay Peninsula on 3rd December 2016 and intensified into a severe cyclonic storm on December 9th and made landfall on December 12th near Chennai. Both HF radar and NEMO analysis show strong surface current that increased from 10th December to 12th December along the Tamil Nadu coast (Fig. 2.10).

2.2.6 Polar Sea-Ice Forecasts

NCMRWF coupled model also has sea-ice

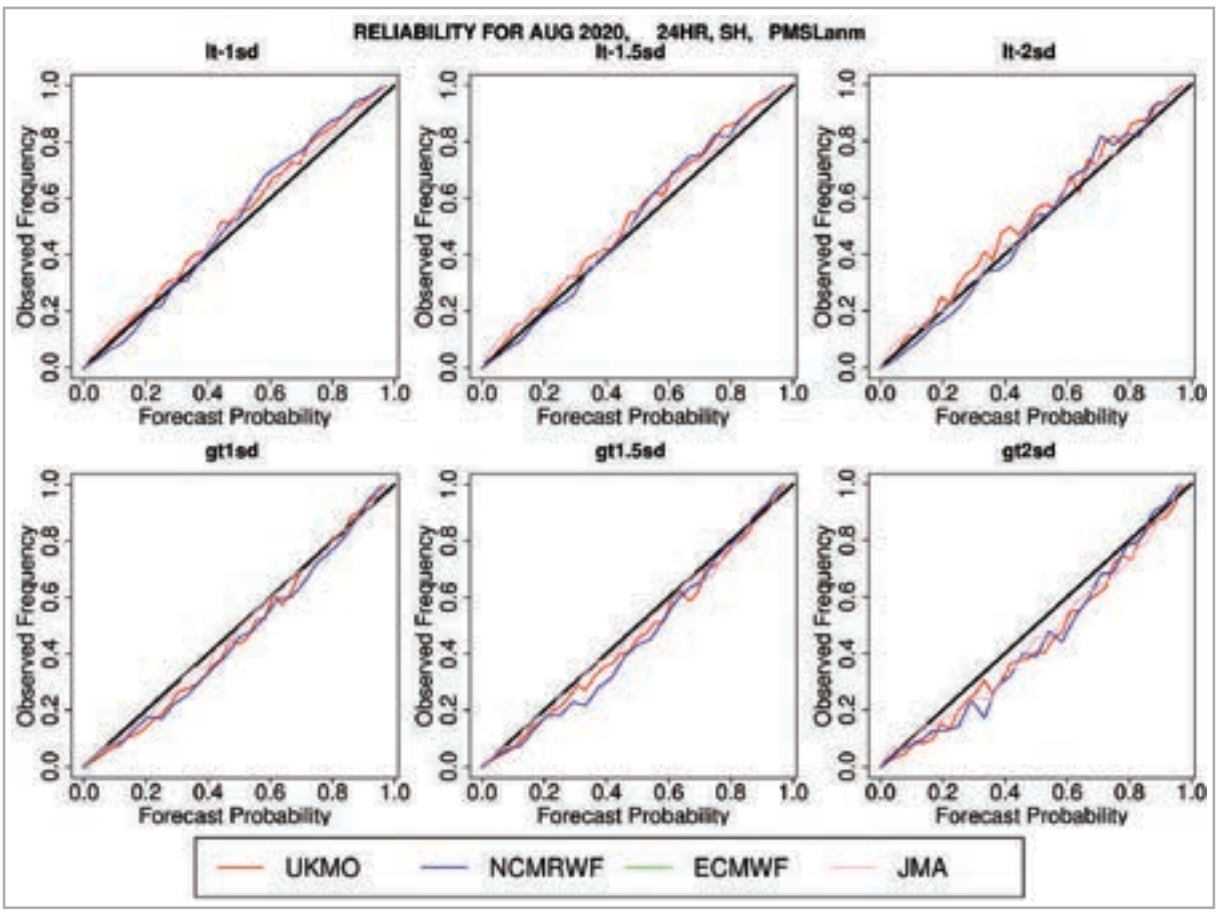

Fig 2.8 : Comparison of reliability from NCMWRF, ECMWF, UKMO and JMA for T850 in the tropics (TR) for July 2021.

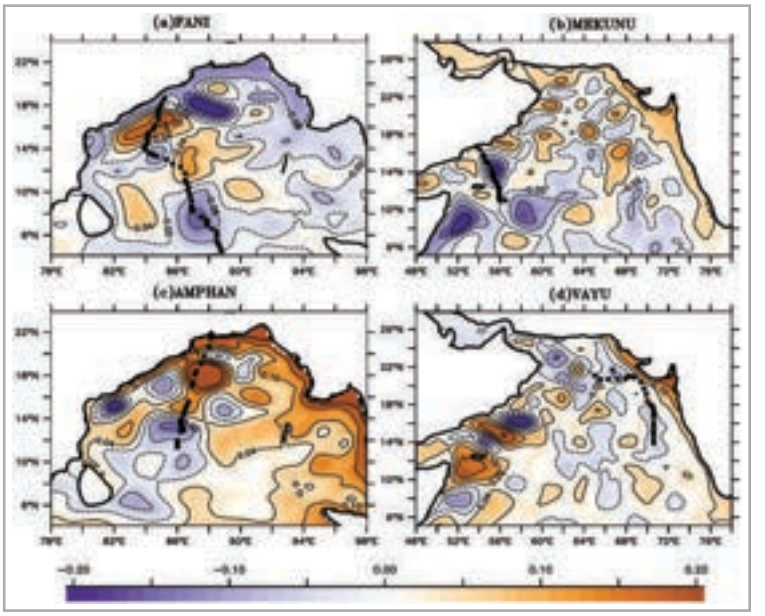

Fig. 2.9 : Sea level anomaly (SLA; m) from the NEMO analysis in AS and BoB regions during the TCs.

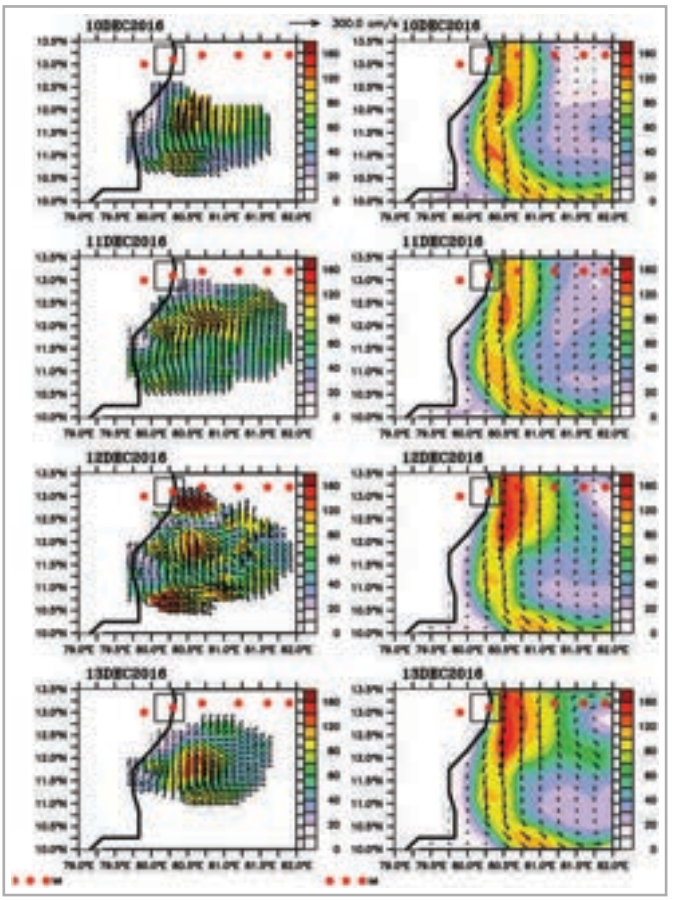

Fig. 2.10 : Comparison of Surface Current from NCMRWF NEMO analysis with HF radar-derived coastal ocean surface currents during the TC Vardah (10-13th December 2016).

initialization and forecast modules integrated into the analysis-forecast system producing 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. The sea-ice concentration simulated for the Arctic in extended range prediction (ERP) system (up to 4 weeks ERP issued every week) of NCMRWF coupled model is shown in Fig 2.11 for September month representing the peak sea-ice melting season. The sea-ice simulation quality is very good, and from week-1 to week-4 the bias grows very marginally.

2.3 Operational Global and Regional model runs at India Meteorological Department (IMD)

2.3.1. Global Forecasting System

Global Forecasting System (GFS T1534L64) model developed by IITM is run operationally at India

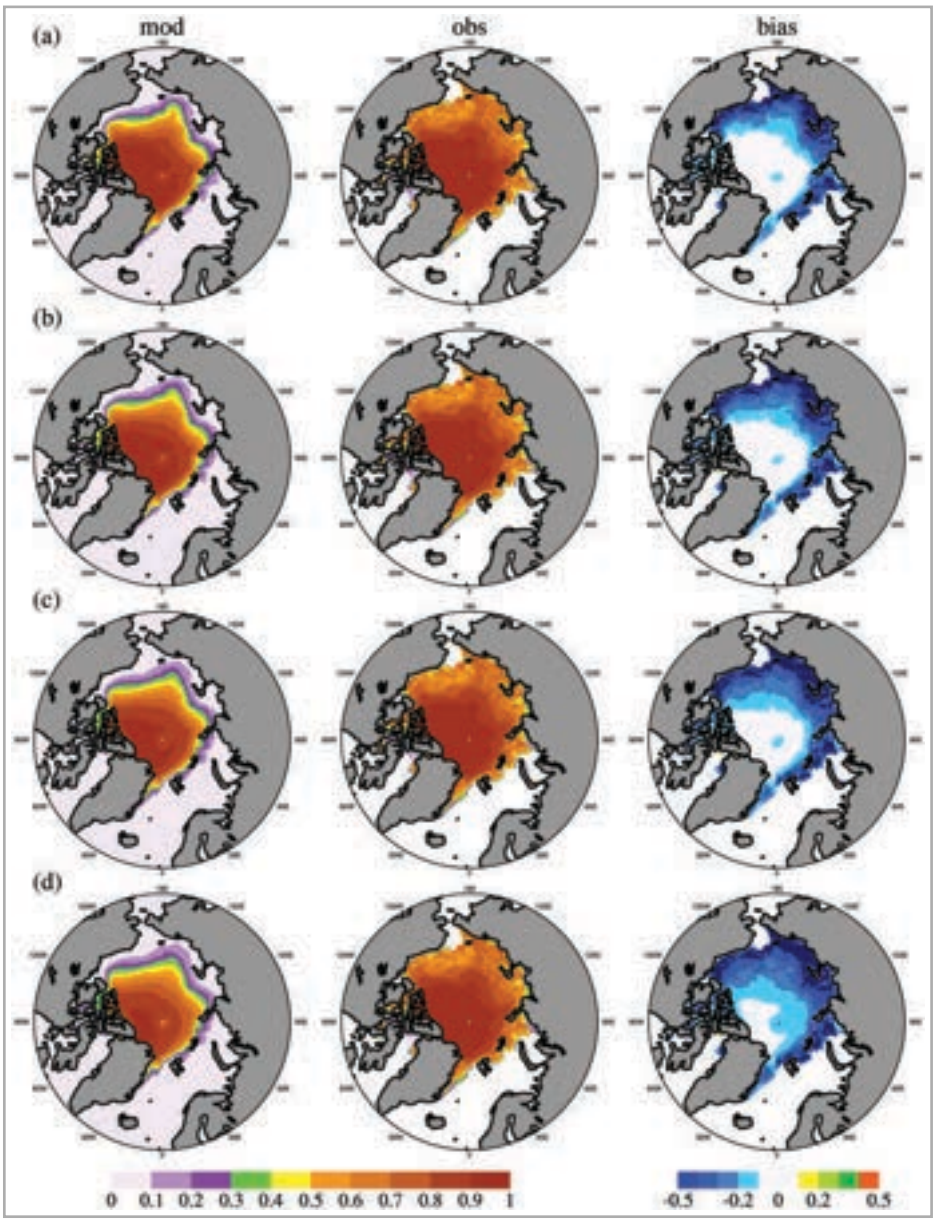

Figure 2.11 : Arctic Sea-Ice concentration for September (peak melting season) from 23 years mean (1993-2015) ERP hindcast. (a) shows the model, observation & bias for week 1 and Panel (b), (c) & (d) shows the same for week 2, 3 & 4, respectively.

Meteorological Department (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 forecast model has a resolution of approximately 12 km in horizontal and has 64 levels in the vertical. The initial conditions for this GFS model is generated from the four-dimensional (4D) ensemble–variational data assimilation (DA) system (4DEnsVar) built upon the grid point statistical interpolation (GSI)-based hybrid Global Data Assimilation System (GDAS) developed and run by National Centre for Medium Range Weather Forecasting (NCMRWF). The real-time GFS(T1534L64) model outputs are used 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 2021, the WRF model (ARW) delivered three days forecasts at 3 km horizontal resolution four times daily at 0000, 0600, 1200 and 1800 UTC with hourly interval. The data assimilation component, regional GSI (Global Statistical Interpolation) developed by NCMRWF takes global GFS analysis and all other conventional quality controlled observations 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 2021, 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 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC for tropical cyclones formed over north Indian Ocean (NIO). The data assimilation component of HWRF, regional GSI Data Assimilation system developed by NCMRWF, generates 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 performance of the model with 3 days lead time is satisfying operational requirements.

2.3.4 High Resolution Rapid Refresh (HRRR) MODEL

The HRRR model is based on Weather Research and Forecasting (WRF) Model's ARW core and takes the initial and boundary condition from the IMD-GFS global model. Utilising the WRF Data Assimilation system (WRF-DA), the RADAR data is assimilated in HRRR model every 10-15 min over a 1-h period. The HRRR is hourly updated, cloud-resolving, convection-allowing atmospheric model, with horizontal resolution of 2km and provides reflectivity and rainfall forecast for next 12 hours. The HRRR model is run in cyclic mode every hour for three domains covering entire mainland of India viz. North-West Domain, East & North-East Domain and South Peninsular India domain and forecast products are updated on the NWP website after every two hours. The forecast product from HRRR model is shown in Fig. 2.12.

2.3.5 Extended Range Forecasts

A coupled model with a suite of models from CFSv2 coupled model developed and implemented by IITM and operationalized in IMD in 2017 for generating operational Extended Range Forecast products for different users. This suite of models are (i) CFSv2 at T382 (≈ 38 km) (ii) CFSv2 at T126 (≈100 km) (iii) GFSbc (bias corrected SST from CFSv2) at T382 and (iv) GFSbc at T126. The Multi-model ensemble (MME) of the above suite is run operationally for 32 days based on every Wednesday initial condition with 4 ensemble members to give forecast for 4 weeks for days 2-8 (week1; Friday to Thursday), days 09-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday). The observed weekly rainfall over India

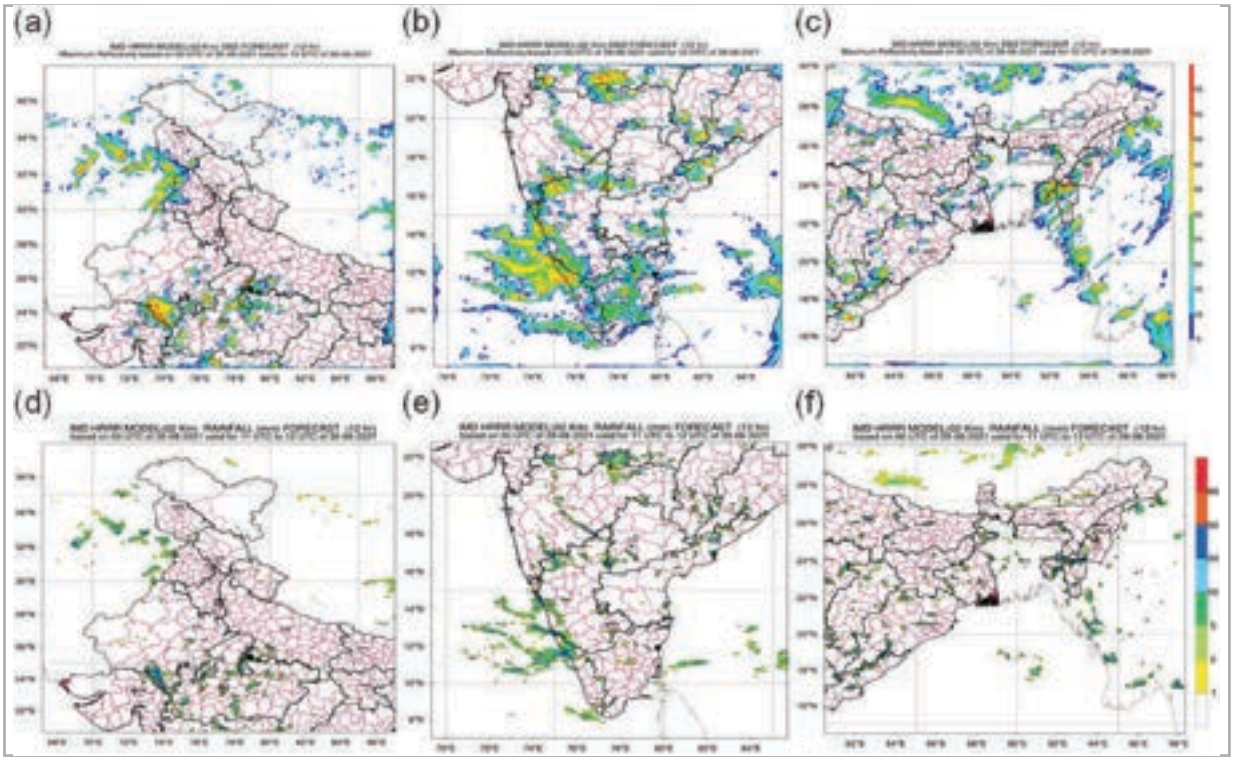

Fig. 2.12 : The upper row figures (a,b,c) shows the Reflectivity forecast product for North West, South and East & North-East India from HRRR model. The lower figures (d,e,f) shoes the rainfall forecast product for North West, South and East & North-East India from HRRR model.

during monsoon 2021 indicating the active phase in June, 2nd half of July and the entire September are shown in Fig. 2.13. The corresponding forecast weekly rainfall anomalies are also shown in Fig. 2.13. The model could capture these active phases of monsoon along with the normal monsoon periods. However, the weak phase of monsoon during 1st week of July, 3rd and 4th week of August were not very well captured as the model slightly over predicted the actual departure of rainfall. On smaller spatial scales (homogeneous regions and met subdivision levels) the forecast shows useful skill up to two weeks. On meteorological subdivision level the category forecasts upto two weeks are being used for agro-advisory purpose.

2.3.6 Thunderstorm Nowcast:

During the year 2021, about 194 stations were added to the Nowcast list. Thus the total number of stations for the nowcast has gone upto 1088 in 2021(till October).

2.4 Monsoon Mission

2.4.1. Seasonal Prediction

The generation of ensembles (40) of a long-term (21 years) coupled ocean-atmospheric analysis using CFSv2 LETKF Weakly coupled Data Assimilation (WCDA) system for the period 1999 to 2019 has been successfully completed. The seasonal prediction runs (hindcasts) using the new WCDA perturbed initial conditions (ICs) for the period 1999 to 2019 shows an increased Indian Summer Monsoon (ISM) Rainfall prediction skill with a gain of one-month lead time. Preliminary result of the Antarctic Sea-Ice simulation experiments conducted using IITM CFSv2 by modification of sea-ice model component of coupled model shows relatively better depiction of sea ice extend over the Antarctic region.

2.4.2. Extended Range Prediction

The extended range forecasts are being generated from a multi-model ensemble prediction system and

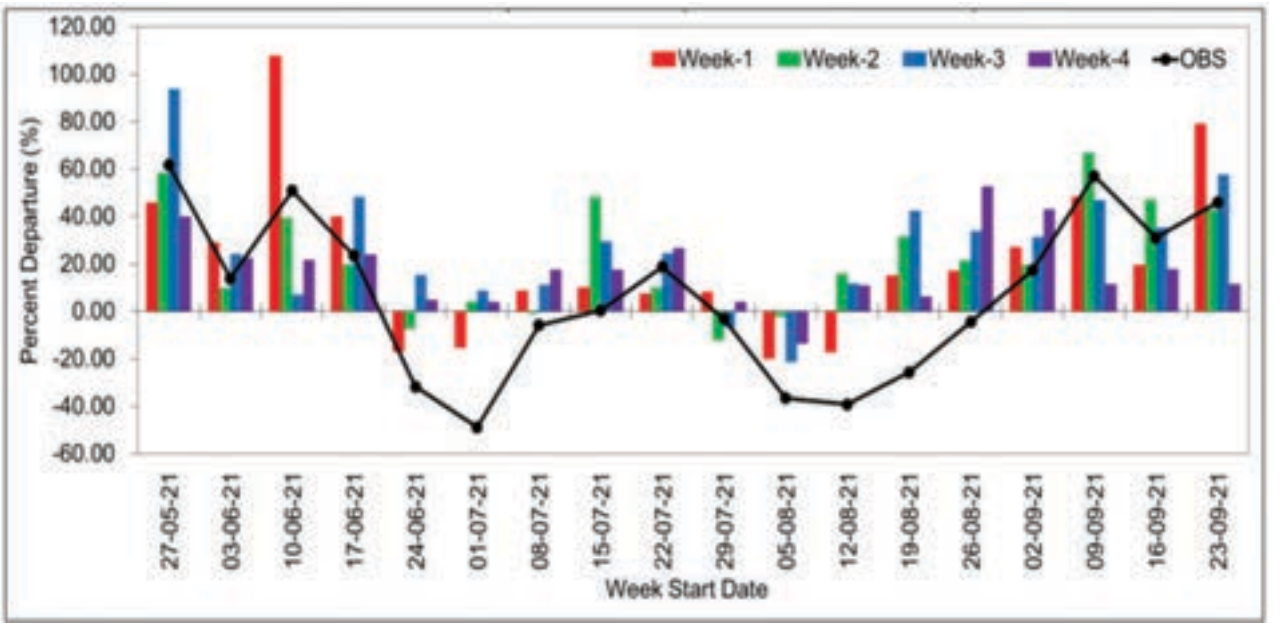

Fig. 2.13 : Weekly observed and forecast rainfall departure during the monsoon season 2021 with 4 weeks lead time.

are issued throughout the year, once in a week for the next four weeks. This operational system (termed as ERPv1) has reasonable skill upto 2 weeks in providing an outlook of the onset, withdrawal and intraseasonal fluctuations within the monsoon season, Madden-Julian Oscillation, cyclogenesis, heat waves and heavy rainfall events and are being used to issue agricultural and health bulletins every week.

Efforts are underway to develop a multi physics multimodel ensemble prediction system (MPMME) and initial results suggest that MPMME has improved skill compared to its predecessor in predicting the large-scale low variability signal and weekly mean rainfall up to 3 weeks lead. The subdivision-wise skill analysis shows that MPMME performs better, especially in the northwest and central parts of India (Fig.2.14).

A tropical cyclone prediction system involving an improved storm evolution index and an objective tracking algorithm for detecting cyclogenesis, evolution and storm tracks from post-processed Multi-model ensemble (MME) outputs from the Climate Forecast System-based Grand Ensemble Prediction System (CGEPS) has been implemented for operational extended range prediction. This provides early guidance on the formation of storms thereby providing enough lead time for better planning and mitigation strategies.

2.4.3. Short range Global Ensemble Forecast (GEFS) / Global Forecast System (GFS) for Short Range Forecast

The GEFS based cyclone tracker has successfully predicted the ensemble track, landfall and strike probability for severe cyclone storms "TAUKTAE" (14-19 May 2021), "YAASH" (22-28 May 2021) and SHAHEEN (30 Sept – 4 Oct 2021) with longer lead time. The GEFS based ensemble forecast showed higher accuracy in longer lead times compared to deterministic GFS forecast. For enhancing the efficiency of flood forecasting, the bias corrected GFS quantitative precipitation forecast was developed for all Indian river basin and shared with IMD for operational utilization. A study revealed that large-scale moisture convergence had a significant role in the extreme rain event of August 2018 and 2019 over Kerala and these are well captured by the ensemble prediction system for longer lead-times compared to deterministic models (Fig. 2.15), and therefore, can provide better early warnings.

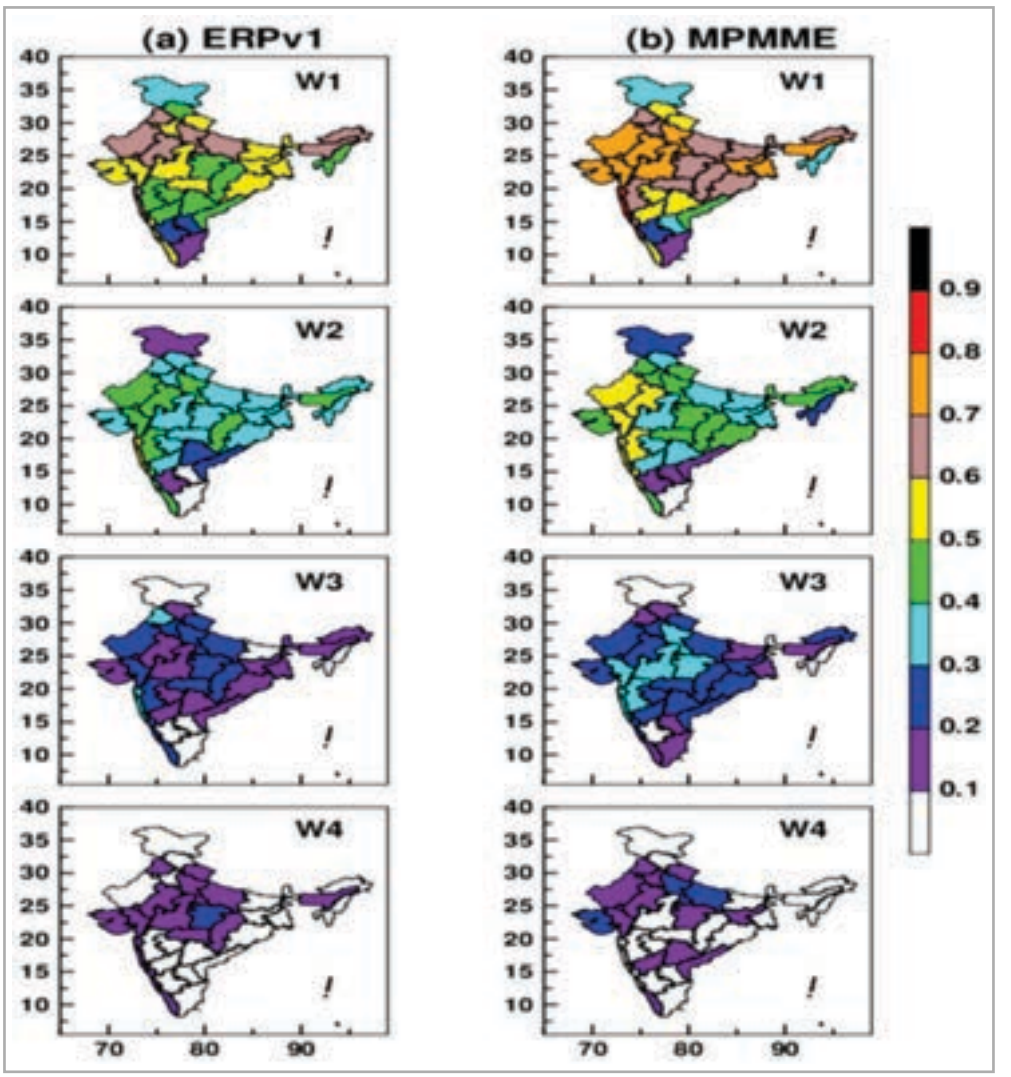

Fig.2.14 : Sub-divisional skill in terms of anomaly correlation coefficient for, (a) ERPv1 (b) MPMME during the Indian summer monsoon season.

2.5. Centre for Climate Change Research

2.5.1. Contribution towards "The Physical Science Basis, Working Group I (WG1), Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC)"

IITM contributed to the IPCCWG1 AR6 which provides the most updated physical understanding of the climate system and climate change, by combining the latest advances in climate sciences and multiple lines of evidence from paleoclimate, observations, process understanding, global and regional climate simulations. Major contributions were made in assessment of future global climate (Chapter 4), water cycle changes, including regional monsoons (Chapter 8), Ocean and Cryosphere (Chapter 9) and the Summary for Policy Makers (SPM). The major highlights of the report include (i) global temperature is expected to reach or exceed 1.5°C of warming, (ii) global mean sea level is likely to rise by 0.46–0.74 m during 2081-2100 (Fig 2.16) (iii) with the decrease in aerosol loading and increase in response to green house gas warming during the 21stcentury, global land monsoon precipitation is projected to increase in all future time horizons and scenarios.

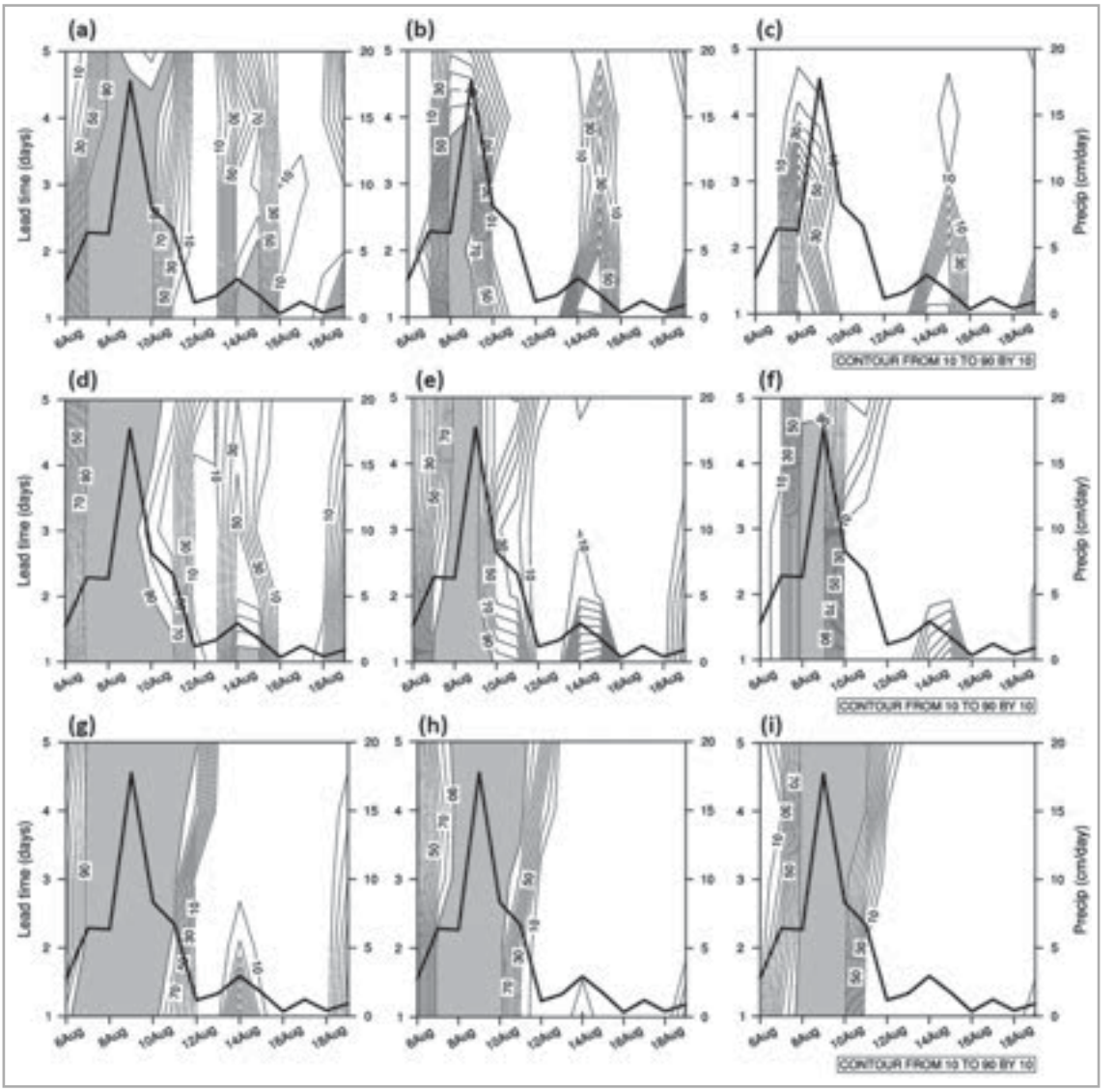

Figure 2.15 : Forecast lead time diagram of the probability for the GEFS forecast (top row), ECMWF (middle row) and NEPS (bottom row) for the daily accumulated rain over Kerala (10°-12°N, 75.5°-77°E) exceeding the observed daily climatology plus 1 standard deviation (SD) (first column), 2SD (middle column) and 3SD (third column). The black line represents the IMD-GPM rainfall (cm day^{-1}) averaged for the same region for the period 6-19 Aug 2019.

The ICTP RegCM4 regional climate model 4 km simulations for three case study experiments are completed and hourly model outputs for selected variables are shared with CPTP modelling working group for inter-comparison of the participating models' performance. Climate simulations using the high-resolution global atmospheric model of IITM-ESM for the period 1981-2015 have been completed for model evaluation. The historical simulations (1951-2015) using the high-resolution (27 km grid) atmospheric component of IITM-ESM are ongoing, with 20 years of simulation completed.

2.5.2 Short Term Climate Variability and Prediction :

A Book titled 'Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond' has been published by Elsevier, Netherlands. The book presents

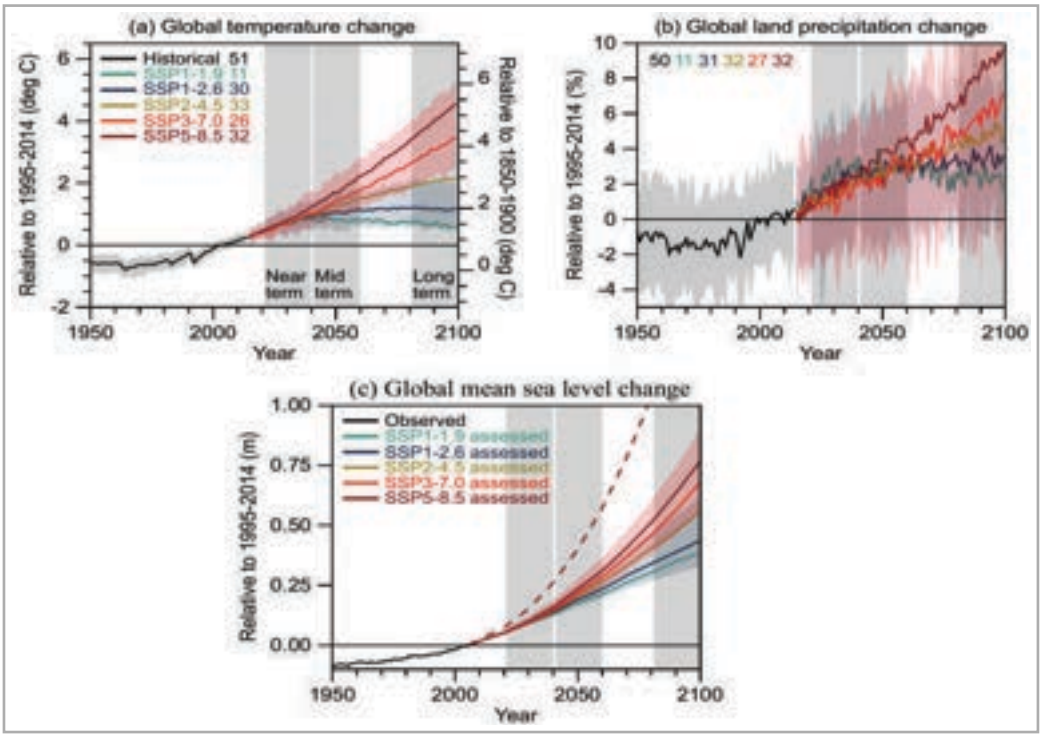

Fig 2.16 : Selected indicators of climate change from CMIP6 historical and scenario simulations. (a) Global surface air temperature change relative to the 1995-2014 average (left axis) and relative to the 1850-1900 average (right axis; offset by 0.82°C, which is multi-model mean and close to observed best estimate); (b) Global land precipitation changes relative to the 1995-2014 average; (c) Global mean sea-level change relative to the 1995-2014 average.

improved understanding on Indian Monsoon teleconnections (ENSO and Non-ENSO), discussing new advances and preferred future steps. Special emphasis has been given to non-ENSO teleconnections, which have been poorly understood for decades.

2.6 South west Monsoon 2021

The southwest monsoon onset over Kerala was on 03rd June 2021. The southwest monsoon seasonal rainfall during June to September for the country as a whole has been normal (96 -104% of LPA). Quantitatively the 2021 all India monsoon seasonal rainfall during 1 June to 30 September 2021 has been 87.0 cm against long period average of 88.0 cm based on data of 1961-2010 (99% of its Long Period Average (LPA)).

The southwest monsoon seasonal (June to September) rainfall over the four homogeneous regions is Normal over Northwest India (96%) and central India (104%). Seasonal rainfall is below normal over East and Northeast India (88%) and above normal over South Peninsula India (111%). The southwest monsoon seasonal (June to September) rainfall over the monsoon core zone, which consists of most of the rainfed agriculture regions in the country is above normal (>106% of LPA).

Out of the total 36 meteorological subdivisions, 20 subdivisions constituting 58% of the total area of the country received normal seasonal rainfall, 10 subdivisions received excess rainfall (25% of the total area) and 6 subdivisions (17% of the total area) received deficient season rainfall (Fig. 2.17).

2.6.1 Verification of Long-Range Forecast Southwest Monsoon 2021

This year, IMD has adopted a new strategy for issuing monthly and seasonal operational forecasts for the seasonal rainfall over the country. The new strategy is

Fig.2.17 : Met-sub-division wise seasonal rainfall of monsoon 2021.

based on the existing statistical forecasting system and the newly developed Multi Model Ensemble (MME) based forecasting system. The MME approach uses the coupled global climate models (CGCMs) from different global climate prediction and research centres including IMD's Monsoon Mission CFS (MMCFS) model. Accordingly, IMD had issued various seasonal forecast for the 2021 southwest monsoon seasonal (June to September) rainfall over the country.

Considering the four broad geographical regions of India, the forecasts issued in 1st June for the season rainfall over Northwest India, Central India, Northeast India and South Peninsula were Normal (92-108% of LPA), Above Normal (>106% of LPA) , Below Normal (<95% of LPA) and normal (93-107% of LPA) respectively. The actual rainfall over Northwest India, Central India, Northeast India, South Peninsula and Monsoon Core Zone were 96%, 104%, 88%, 111% and 107 % of the LPA respectively. The monthly forecast issued for July and August were overestimated whereas for September was within the range of the forecast. The forecast for the second half of the monsoon season (August –September) for the country as a whole was within the forecast limit. Details of the verification of forecast are shown in Table 1.

Table 1 : Verification of long-range forecast southwest monsoon 2021

Region	Period	Forecast (% of LPA)	Actual Rainfall
			(% of LPA)
		(issued on 16th April)	
All India	June to September	Normal (96-104% of LPA) 98± 5 of LPA	99
		(issued on 1st June)	
All India	June to September	Normal (96-104% of LPA) 101± 4 of LPA	99
Northwest India	June to September	Normal (92-108% of LPA)	96
Central India	June to September	Above Normal (>106% of LPA)	104
Northeast India	June to September	Below Normal (<95% of LPA)	88
South Peninsula	June to September	Normal (93-107% of LPA)	111
Monsoon Core Zone	June to September	Above Normal (>106% of LPA)	107
All India	July (issued on 1st July)	July: Normal (94-106% of LPA	93
All India	August & Aug-Sept (issued on 2nd Aug)	August: Normal (94-106% of LPA	76
		Aug+Sept: Normal (95-105% of LPA)	99
All India	September (issued on 1st Sept)	Above Normal (>110% of LPA)	135

2.6.2 Long Range forecast for the Northeast Monsoon rainfall during post monsoon season (October-December, 2021)

IMD issued the forecast for 2021 Northeast Monsoon (October to December (OND)) season rainfall over the south Peninsular India consisting of five meteorological subdivisions (Tamil Nadu, Coastal Andhra Pradesh, Rayalaseema, Kerala and South Interior Karnataka) which is most likely to be normal (89-111% of Long Period Average (LPA)).

2.7. Meteorological Services

2.7.1 Metropolitan Air Quality and Weather Services

A High resolution Emission inventory of Pune region was prepared through mapping of pollution sources in a 400m x 400m grid for 8 major pollutants namely, $PM_{2.5}$, PM_{10}, NOx, CO, SO_2, BC, HC. Around 6 months long emission inventory campaign involving more than 200 students from IITM, SPPU and Utkal University was carried out during 2019-20 in Pune Metropolitan Region (PMR). The **SAFAR-Emission Inventory PMR-2020** was released by Vice-Chancellor, SPPU on 21st May 2021. The Emissions Growth from 2012-13 to 2019-20 has been reported. The overall increase in the emissions of PM_{10} and $PM_{2.5}$ over PMR region, from 2012-13 to 2019-20 is found to be 61% and 70%, respectively.

2.7.2. Air Quality Early Warning System (AQEWS) for Delhi

The air quality early warning system was run operationally at a very high spatial resolution (400 m) in a globally harmonized and standardized way to predict extreme air pollution events in Delhi during January – July 2021. The AQEWS issues timely warnings for forthcoming air quality events and prediction for source contribution for next 5 days and issue timely warnings to take necessary steps as per the newly designed Graded Response Action Plan (GRAP) of GoI. An indigenous Decision Support System (DSS) for advanced air quality management of Delhi NCR was set up successfully which is designed to deliver quantitative information about a) the contribution of emissions from Delhi and the surrounding 19 districts to the air quality in Delhi; b) the contribution of emissions from 8 different sectors in Delhi to the air-quality Delhi; and c) the contribution from biomass-burning activities in the neighbouring states to the air quality in Delhi; d) the possible quantitative effects of emission source-level interventions on the forecast air-quality event in Delhi. The DSS website (https://ews.tropmet.res.in/dss/) was officially launched by the Hon'ble Minister of MoES, Dr. Jitendra Singh on 18 October 2021 in MoES HQ under the auspicious occasion of the Iconic week towards the celebration of Azadi ka Amrit Mahotsav.

2.8 Tropical Cyclone Monitoring and Prediction 2021

The salient features of the cyclonic activity over the NIO during 2021 are mentioned below:

Nine (9) Cyclonic Disturbances (CDs-Depressions and Cyclonic storms put together) developed over the north Indian Ocean (NIO) including 6 over the Bay of Bengal (BoB) and 3 over the Arabian Sea (AS) during the year 2021 against the normal of 11 CDs per year over the NIO during the period 1961-2020. Out of these, 5 intensified into cyclonic storms (CS) (maximum sustained wind speed (MSW) ≥ 34 kt) against the normal of 4.8 CS per year over the NIO during 1961-2020. Out of these 4 CS, 3 intensified into severe category storms (MSW ≥ 50 kt). Over all there was 1 extremely severe cyclonic storm (ESCS) (MSW: 90-119 kt) (Tauktae), 1 very severe cyclonic storm (VSCS) (MSW: 64-89 kt) (YAAS), 1 severe cyclonic storm (SCS) (MSW: 48-63 kt) (Shaheen) and 1 cyclonic storm (CS) (MSW: 34-47 kt) (Gulab) during 2021. Details of these CDs over the north Indian Ocean are listed below:

(i) Depression over north Andaman Sea during 02-03 April, 2021

(ii) ESCS Tauktae over the Arabian Sea during 14-19 May, 2021

(iii) VSCS Yaas over the Bay of Bengal (BoB) during 23-28 May, 2021

(iv) Deep Depression over northwest BoB during 12-15 September, 2021

(v) CS Gulab over the BoB during 24-28 September, 2021

(vi) SCS Shaheen over the Arabian Sea during 30 September - 4 October, 2021

(vii) Depression over eastcentral AS during 7-9 November, 2021

(viii) Depression over southeast BoB during 10-12 November, 2021

(ix) Depression over southwest BoB (18-19 November, 2021)

(I) Extremely Severe Cyclonic Storm TAUKTAE over the Arabian Sea (14th-19th May, 2021)

A low pressure area formed over southeast Arabian Sea & adjoining Lakshadweep area in the morning (0830 hrs IST/ 0300 UTC) of 13thMay 2021. Under favourable environmental conditions, it concentrated into a depression over Lakshadweep area in the morning (0830 hrs IST) of 14th May, 2021. It intensified into the cyclonic storm **"TAUKTAE"** in the midnight (2330 hrs IST/1800 UTC) 0f 14th May, 2021 over Lakshadweep area and adjoining southeast &east central Arabian Sea. It reached its peak intensity of 100 kt in the morning (0530 hrs IST) of 17th May, 2021 over east central Arabian Sea. Continuing to move nearly northwards, it entered marginally unfavourable environment, weakened gradually and crossed Saurashtra coast near latitude 20.8°N and longitude 71.1°E, close to northeast of Diu (about 20 km northeast of Diu) during 2000-2300 hours IST of 17thMay, 2021 with maximum sustained wind speed of 160-170 kmph gusting to 185 kmph. Moving north-north-eastwards, it weakened into a well-marked low pressure area over central parts of Rajasthan in the evening (1730 hrs IST) of 19th May, 2021.

The track, landfall point & time, intensity (Fig. 2.18) and associated adverse weather like heavy rainfall, gale wind and storm surge were well predicted by IMD.

(ii) Very Severe Cyclonic Storm YAAS over the Bay of Bengal (23rd– 28thMay, 2021)

A low pressure area formed over eastcentral Bay of Bengal (BoB) in the morning (0830 IST/0300 UTC) of 22nd May. Under favourable environmental conditions, it concentrated into a depression over eastcentral BoB in the noon (1130 IST/0600 UTC) of 23rd May, 2021. It

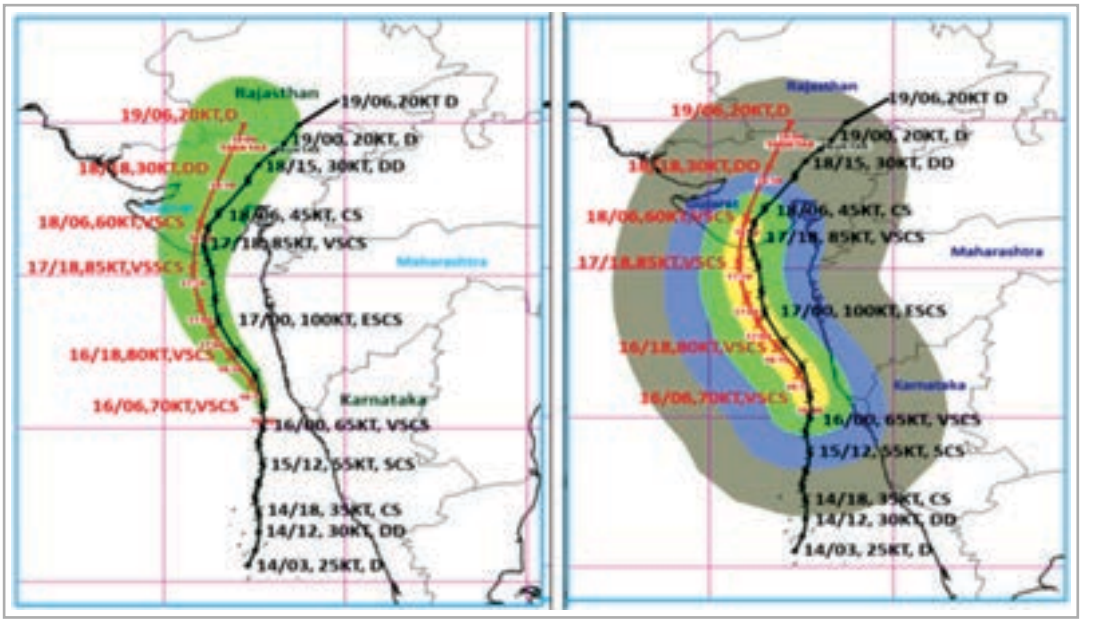

Fig. 2.18 : Observed track (14-19 May) and forecast track issued at 1430 hours IST of 16th May (about 36 hours prior to landfall) demonstrating accuracy in track, intensity and landfall.

moved northwestwards and intensified into the cyclonic storm **"YAAS"** in the early morning (0530 IST/0000 UTC) of 24th May, 2021 over the same region. It started moving northwards from the morning (0830 IST/0300 UTC) of 25th May, 2021 and intensified into a very severe cyclonic storm (VSCS) in the evening (1730 IST/1200 UTC) over northwest BoB. Thereafter, it moved north-northwestwards reached peak intensity of 75 kts and lay centred over northwest BoB about 30 km east of Dhamra Port, Odisha during early morning (0530 IST/0000 UTC) of 26th May, 2021. Continuing to move north-northwestwards, it crossed north Odisha coast near latitude 21.35°N and longitude 86.95°E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed (MSW) of 75 kts gusting to 85 kts (130 -140 kmph gusting to 155 kmph) between 1030-1130 IST(0500-0600 UTC) of 26th May, 2021. It moved northwestwards and weakened into a well-marked low pressure area over Bihar and adjoining southeast Uttar Pradesh (UP) in the early morning (0530 IST/0000 UTC) of 28th May, 2021.

(iii) Cyclonic Storm GULAB over the Bay of Bengal (24 – 28 September 2021)

A low pressure area formed over east-central Bay of Bengal (BoB) and neighbourhood in the morning (0830 hours IST / 0300 UTC) of 24th September. Under favourable environmental and Sea conditions, it concentrated into a **depression** over eastcentral and adjoining northeast BoB in the evening (1730 hours IST/ 1200 UTC) of 24th September, 2021. Moving west-northwestwards, it intensified into the Cyclonic Storm **"GULAB"** over northwest and adjoining west-central BoB in the evening (1730 hours IST) of 25th September, 2021.Thereafter, it intensified gradually and reached it's peak intensity of 75-85 kmph gusting to 95 kmph around noon (1130 hours IST/0600 UTC) of 26th September, 2021. Continuing to move further westwards, it crossed North Andhra Pradesh and adjoining south Odisha coasts near Lat. 18.4°N/ Long. 84.2°E (20 km north of Kalingapatnam) with maximum sustained wind speed of 75-85 kts gusting to 95 kmph during 1930-2030 IST of 26th September, 2021.Thereafter, it weakened into a well marked Low pressure area over western parts of Vidarbha and neighbourhood around noon of 28th September, 2021.

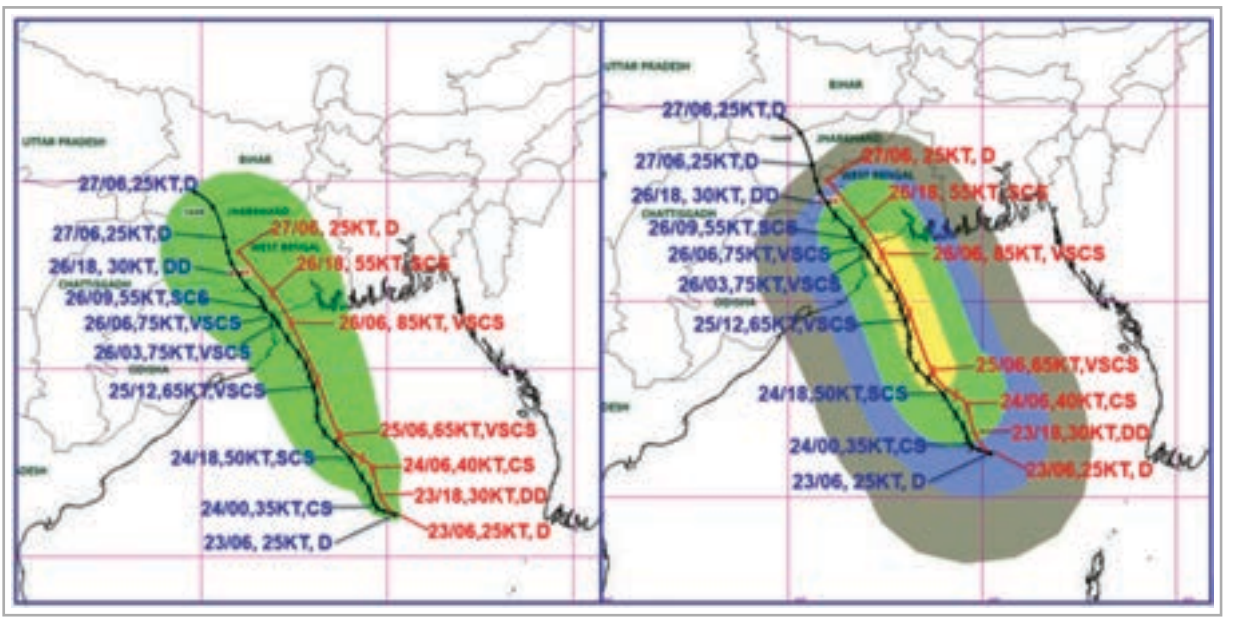

Fig. 2.19 : Observed track (23-28 May) and forecast track issued at 1350 hours IST of 23rd May (about 72 hours prior to landfall) demonstrating accuracy in track, intensity and landfall forecast.

(iv) Severe Cyclonic Storm Shaheen over northeast Arabian Sea adjoining Kutch (30thSeptember – 4thOctober 2021)

The remnant of cyclonic storm Gulab emerged as a well marked low pressure area into south Gujarat region & adjoining Gulf of Khambhat in the morning (0830 hours IST) of 29th September, 2021. Under favourable environmental and sea conditions, it concentrated into a depression over northeast Arabian Sea (AS) & adjoining Kutch, in the morning (0530 hours IST) of 30th September, 2021. It intensified into the cyclonic storm "Shaheen" over the northeast AS off Gujarat coast in the morning (0530 hours IST) of 1st October, 2021. It reached its peak intensity of 60 kts in the early morning (0000 UTC) of 2nd October. It crossed Oman coast during 0030-0130 IST of 4thOctober, 2021. With wind speed of 95-105 gusting to 115 kmph. It weakened into a well marked low pressure area in the evening (1730 hours IST) of 4th October, 2021 over northeast Oman.

2.8.1. Performance of cyclone landfall, track and intensity forecast during 2021

Track forecast

The annual average track forecast errors in 2021 have been 60 km, 93 km and 164 km respectively for 24, 48 and 72 hrs against the past five year average error of 77, 117 and 159 km based on data of 2016-2020. The errors have been significantly lower during this year as compared to long period average (LPA) (2016-20) for almost all lead periods upto 120 hours. The track forecast skills compared to climatology and persistence forecast have been 76%, 80% and 68% respectively for the 24, 48 and 72 hrs lead period against the LPA of 64%, 76% & 78% respectively during 2016-2020. The track forecast errors and skill during 2021 are presented in Fig. 2.20.

Landfall forecast

The annual average landfall point forecast errors for the year 2021 have been 16 km, 20 km and 158 km for 24, 48 and 72 hrs lead period against the LPA of past five years during 2016-20 of 32 km, 62 km and 92 km. The landfall time forecast errors have been 2.5, 6.0 and 19.5 hrs for 24, 48 and 72 hrs lead period during 2021 against the LPA of 2.5, 5.0 and 8.3 hrs during 2016-2020 (Fig.2.21).

Intensity forecast

The annual average errors in intensity forecast (absolute errors) during 2021 have been 6.1 knots, 8.9 knots and 10.8 knots respectively for 24, 48 and 72 hrs lead period of forecast against the LPA of 7.9, 11.4 and 14.1 knots during 2016-20 (Fig. 3 a). The average skill based on absolute errors during 2021 have been 64.4, 80.4 & 85.6 % respectively for 24, 48 and 72 hrs lead period of forecast against the LPA of 52.2, 72.1& 75.1% (Fig.2.22).

2.9. Environmental Meteorology Services

The latest version of Air Quality forecast model "System for Integrated modeLling of Atmospheric

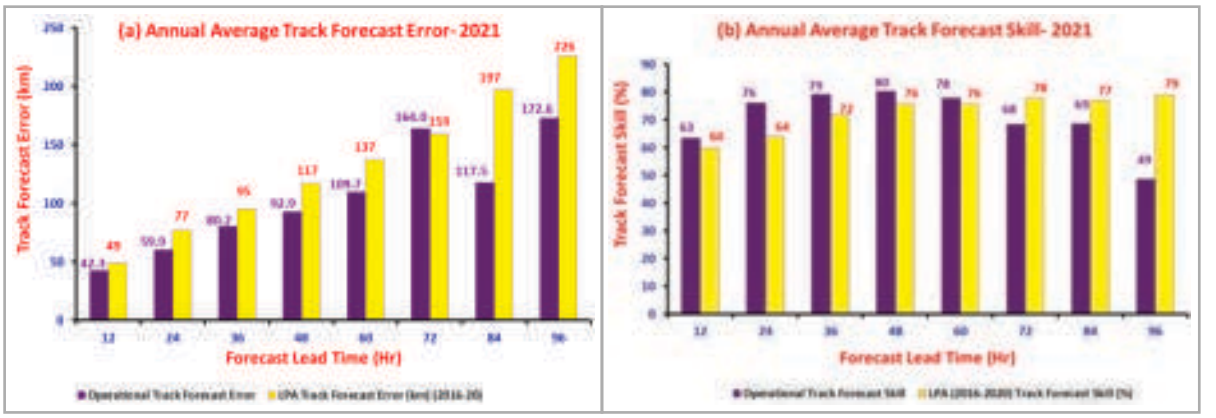

Fig. 2.20 : Annual average (a) track forecast error (km) and (b) track forecast skill against the climatology and persistence forecast during 2020 as compared to the LPA during 2016-2020.

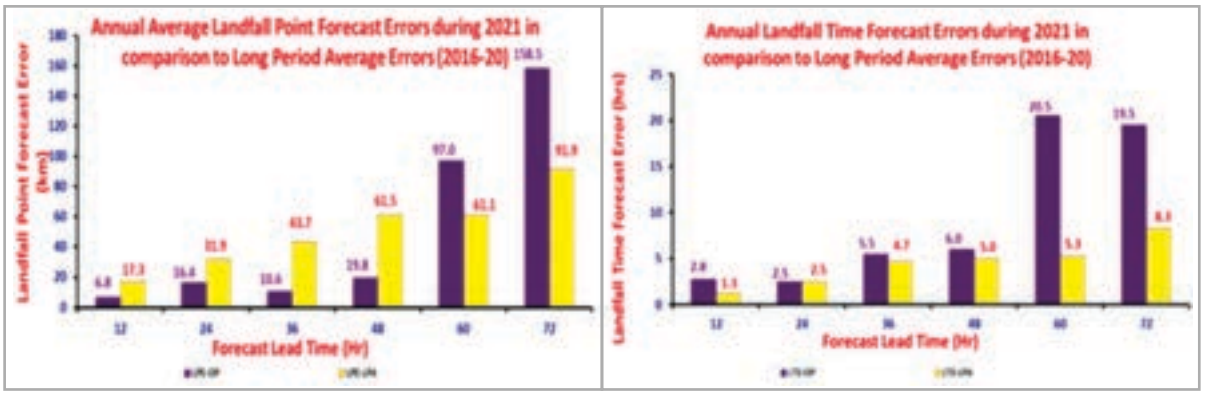

Fig 2.21 : Annual average (a) landfall point forecast error (km) and (b) landfall time (hrs) during 2021 as compared to the LPA during 2016-2020.

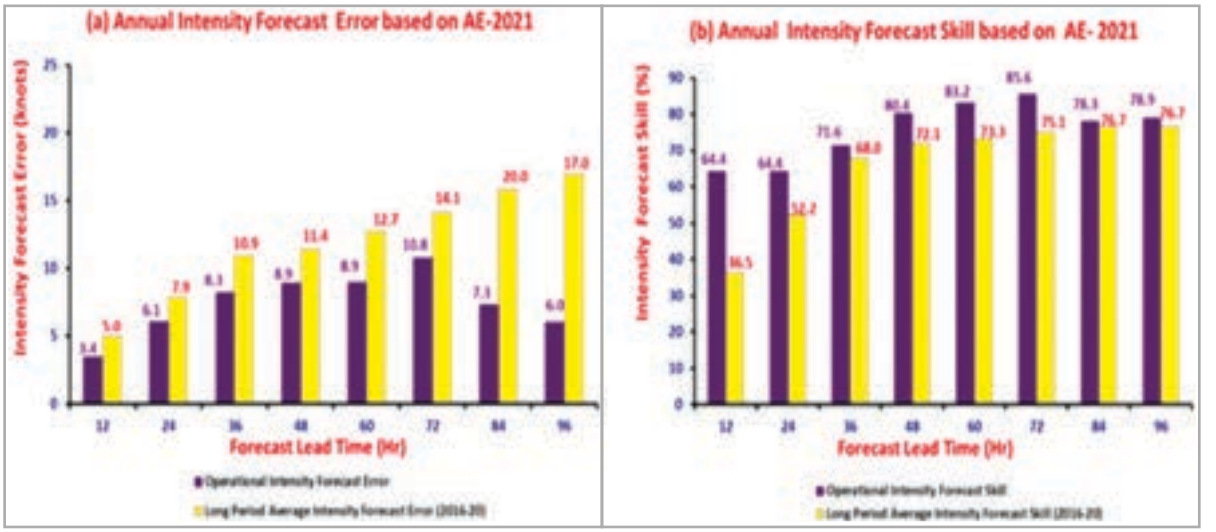

Fig. 2.22 : Annual average intensity forecast (a) Error (knots) based on absolute errors (b) Skill (%) during 2021 as compared to LPA (2016-2020).

coMposition (SILAM v5.7)" has been operationalized for Indian region. Hourly air quality forecast for 72 hours of all criteria pollutants (PM10, PM2.5, O_3, CO, NO_2, SO_2 and other species) is generated for the domain 60-100°E, 0-40°N. SILAM is coupled with hourly 3-km IMD-WRF meteorological forecasts model. The latest emission inventories CAMS-GLOB v2.1, 0.1-deg supplemented with EDGAR v4.3.2 for coarse and mineral-fine anthropogenic particulate matter, GEIA v1 lightning climatology and MEGAN-MACC biogenic climatology for isoprene and mono-terpene are used in SILAM model. The model is validated with air quality observations available from CPCB. A very high resolution city scale air quality model "**ENvironmental information FUsion SERvice (ENFUSER)**" has been also operationalized for Delhi. Hourly air quality forecast for 72 hours of all criteria pollutants (PM_{10}, $PM_{2.5}$, O_3, CO, NO_2, SO_2) is generated for the domain (28.362°N-28.86°N,76.901°E-77.56°E) 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. SILAM and ENFUSER are developed under a collaborative project with Finnish Meteorological Institute. IMD issues AQ Early Warning bulletins based on SILAM and WRF-Chem (IITM) models.

2.10. Agro-Meteorological Advisory Services under GraminKrishiMausamSeva

Dissemination of agromet advisories to the farmers through various multi-media channels like All India Radio (AIR) and Doordarshan, private TV and radio channels, newspaper and internet and SMS through mKisan portal of Ministry of Agriculture & Farmers' Welfare, Reliance Foundation, Kisan Sanchar, Agricultural Technology Management Agency (ATMA) etc. in regional languages was carried out. Alerts and warnings were also issued through SMS by the AMFUs using mKisan portal and other social media during the extreme weather events.

Establishment of District Agromet Units (DAMUs): In the year 2021, 11 DAMUs have been established in the premises of Krishi Vigyan Kendras(KVKs) jointly by IMD and ICAR under GKMS scheme. As such, 327 Agromet Units (197 DAMUs along with the existing 130 AMFUs) prepare medium range weather forecast based biweekly AAS bulletin at district and block levels. At present these bulletins are issued for 700 districts and 3152 blocks in the country.

Farmers' Awareness Programme (FAPs) have been organized at 1210 locations so far by the Agro-Meteorological Field Units (AMFUs) and District Agro-Meteorological Units (DAMUs).

For comprehensive and quicker dissemination of Agromet Advisories, 10,448 WhatsApp groups have been formed covering 90,865 villages of 3,301 blocks reaching 9, 79,696 farmers.

For effective use of weather information in 1000 Markets/ Yards (Mandies) of agricultural produce in 18 states and 3 UT's, a separate section for weather information for 500 districts has been introduced to the portal of National Agriculture Market (eNAM) and API have been shared.

An '**Interactive map for Agromet Information**' through Integration of Agro Advisory with GIS portal have been added to the '**Agromet Advisory Services**' section of the main website of IMD.

A YouTube channel named IMD-GKMS was created during the year to showcase various activities being carried out under GKMS scheme. So far, around 214 short videos under GKMS have been uploaded in the channel.

2.11. Winter Fog Campaign (WIFEX)

The 6th phase of winter fog experiment was carried out at IGI airport, New Delhi and CCHU, Hisar during December 2020 - February 2021. Due to COVID 19 pandemic, only limited measurements were carried out remotely that include vertical thermo-dynamical structure, flux tower, and soil parameters. A new 21 Member Ensemble fog forecasting was developed to provide to probability forecast of fog (visibility) spatially and statistically for the Indo-Gangetic Plain (IGP) region and the IGI Airport, New Delhi with different CATegory fog (CAT2, CAT3A, CAT3B, and CAT3C). The spatial probability forecast of visibility for the IGP region is processed for 36 hours.

Fig. 2.23: FARMERS AWARENESS PROGRAMME AT DHALAI, TRIPURA and Kanpur (U.P.).

Chapter - 3

OCEAN SERVICES, MODELLING, APPLICATION, RESOURCE AND TECHNOLOGY (O-SMART)

The O-SMART scheme is being continuously implemented by the Ministry since more than a decade encompassing oceanographic research and technology development activities for the nation. The focussed with the objectives for providing forecast and services based on the 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 activities are distributed over seven sub-schemes namely Ocean Technology, Ocean Modelling and Advisory Services (OMAS), Ocean Observation Network (OON), Ocean Non-Living Resources, Marine Living Resources and Ecology (MLRE), Coastal Research and Operation & Maintenance of Research Vessels. These sub-schemes are being implemented by autonomous/attached institutes of the Ministry, viz. National Institute of Ocean Technology (NIOT), Chennai; Indian National Center for Ocean Information Services (INCOIS), Hyderabad; National Centre for Polar and Ocean Research (NCPOR), Goa, Center for Marine Living Resources and Ecology (CMLRE), Kochi; and National Centre for Coastal Research (NCCR), Chennai as well as involving other national institutes. A fleet of oceanographic and coastal research vessels of the Ministry provide required research support for scheme.

3.1 Ocean Sciences and Services

3.1.1 Tsunami Warning Services

Indian Tsunami Early Warning Centre (ITEWC) monitored 22 earthquakes of magnitude ≥ 6.5 during last year, of which one earthquake had occurred in the Indian Ocean region without tsunami threat. Being the Tsunami Service Provider (TSP) for the Indian Ocean, the necessary bulletins were also sent to Indian Ocean rim countries and IOC through E-mails, Global Telecommunications System (GTS), FAX and SMS. The most effective way of communicating the early warnings related to Tsunami hazards has been worked through sending emails (~90% success rate), followed by GTS and SMS. ITEWC also organized a webinar on "Tsunami Preparedness and Implementation of Tsunami Ready" for the benefit of the concerned officials of Odisha state in coordination with Odisha State Disaster Management Authority (OSDMA). ITEWC, in association with the National Institute of Disaster Management (NIDM), Ministry of Home Affairs, jointly organized a Webinar on "Tsunami Risk Reduction and Resilience". Inter-governmental Oceanographic Commission of United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) organised a regional workshop on the Standard Operating Procedure (SOP) for broadcasting media to strengthen the involvement of media broadcasters in the Tsunami early warning processes.

3.1.2 Marine Fisheries Advisory Services (MFAS)

INCOIS continued to provide its flagship service of advisories on the Potential Fishing Zones (PFZ), which were disseminated in smart map and text form on daily basis, except during fishing-ban period and during adverse sea-state conditions. During January to September 2021, multilingual PFZ advisories and Yellowfin Tuna advisories were provided for 230 and 174 days, respectively.

In order to design the species specific PFZ advisories based on habitat preferences, the relationship between different environmental parameters and abundance of Hilsa (Hooghly estuary) and the Indian Oil Sardine (south-east Arabian Sea) were analyzed. It has been found that the estuarine water salinity has the largest influence on the availability of Hilsa and regional Sea Surface Temperature (SST) as well as precipitation over land during June-July influence the Indian Oil Sardine availability in the west coast. The habitat suitability of Hilsa in the Hooghly estuary is presented in Fig. 3.1.

3.1.3 Ocean State forecast Services

Daily operational forecasts on the ocean state, which include the parameters such as waves, winds, currents, tides, SST, Mixed layer Depth (MLD) and Depth of thermocline (D20) for various regional and coastal domains within the Indian Ocean, were issued based on the continuous monitoring using, *in-situ* instruments and satellite observations as well as model data. These advisories were provided to specific users like disaster management authorities, fishermen, ports and harbours, ships plying in the seas, offshore industries and the defense authorities. Joint INCOIS-IMD bulletins on the state of the oceans during the passage of cyclones in the Bay of Bengal and the Arabian Sea (cyclones Tauktae and Yass) were also issued. Several High Wave Alerts (HWA) were issued cautioning the users on the impending high waves on the coast (Fig.3.2a). Daily ocean state forecast data was provided to Sri Lanka, Maldives and Seychelles, Comoros, Mozambique and Madagascar. Alert for occurrences of swell surges were issued with lead time of 3 days to coastal communities of west coast and Lakshadweep Islands. INCOIS and Directorate General of Hydrocarbons (DGH) signed an MoU to develop customized and impact-based ocean forecast and information services to cater to the needs of offshore industries (Fig. 3.2b).

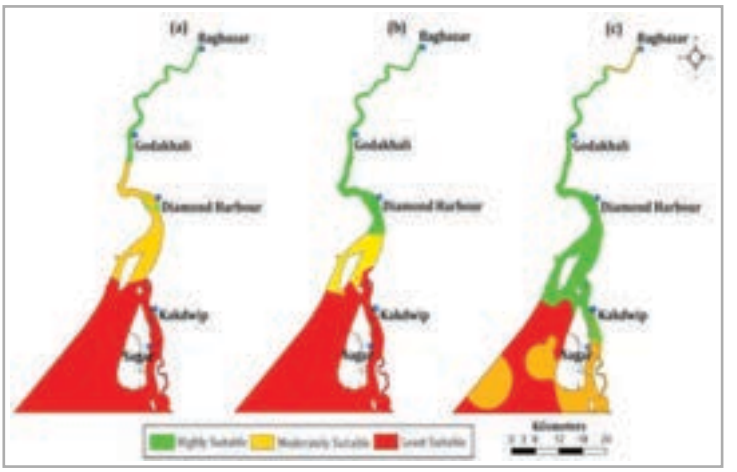

Fig. 3.1: Habitat suitability of Hilsa for a) pre-monsoon, b) monsoon and c) post-monsoon.

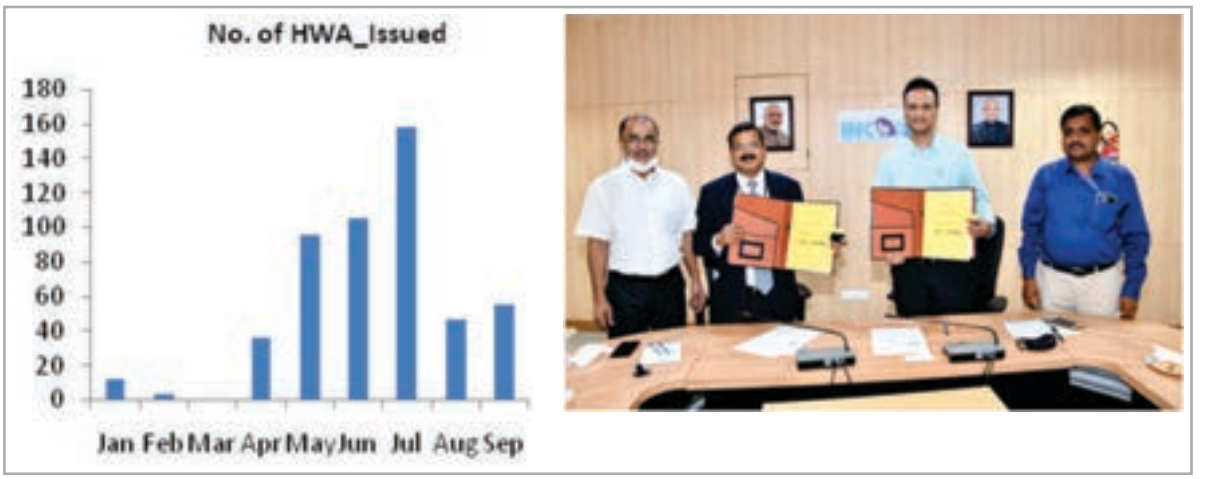

Fig. 3.2 : (a) High Wave Alerts issued during the period January- September 2021(b) MoU signed between INCOIS and DGH.

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

In order to prepare an accurate dataset of bathymetry and topography along the coastal regions of India, the Airborne Lidar Terrain Mapping (ALTM) - Digital Elevation Models (DEM) data collected by INCOIS for multi-hazard vulnerability mapping has been blended with the topographic/bathymetric data collected by MoES, NHO, GSI and GEBCO (Fig. 3.3). This blended dataset will be also very useful for the coastal modeling of circulation, waves and storm surges.

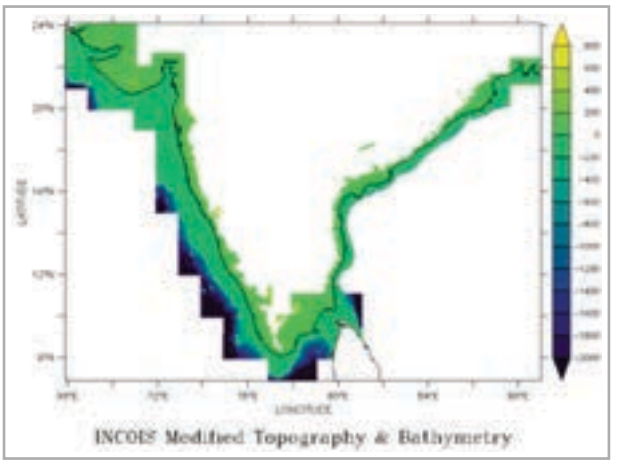

Fig. 3.3: Map showing the coastal topography and bathymetry blended with multiple inputs

3.1.5 Coral Bleaching Alert System

During January to September 2021, several advisories (88 nos.) on possible coral bleaching were provided s comprising of the locations of Hot Spots (HS) and Degree of Heating Weeks (DHWs) estimated using SST anomalies derived from satellite data on a bi-weekly basis. In addition to the one warning issued for Lakshadweep, 26 watch alerts of HS (Andaman-2, Gulf of Kutch -5, Gulf of Mannar -5, Lakshadweep -11 and Nicobar - 3) were also issued.

3.1.6 Data Centre and Services

Being the national oceanographic data repository, INCOIS sustained and enhanced the reception and processing of data from *in-situ* observing systems (viz., Argo profiling profiling Floats, Moored Buoys, Drifting Buoys, XBT/XCTD, Current Meter Moorings, Automatic Weather Stations, Wave Rider Buoys, Wave Height Meters) for operational and research activities of INCOIS in real-time as well as disseminated the data to the various users on request through Ocean Data and Information System (ODIS). INCOIS also continues to receive the remote sensing data from various sensors flown on board Oceansat-2, NOAA series of satellites, METOP, Terra and Aqua, and Suomi-NPP satellites. The data was provided for in-house operational activities and to operational agencies like IMD for developing composite satellite products**.**

3.1.7 INCOIS Flux mooring data analysis

The recovered surface buoy system meant for direct measurements of surface forcing (radiative and turbulent) after one and half year of in the northern Bay of Bengal shed new insights into the low saline water mass formation and its spreading mechanisms in the Bay. Time series data for Ocean salinity, temperature and current upto 150/75 m depth, derived from flux mooring is presented in Fig. 3.4 a, b and c. The preliminary analysis of the data suggests that the bulk derived fluxes exhibit significant deviations from the direct covariance measurements in different background conditions (Fig. 3.4 d & e).

3.1.8 MoES Earth System Sciences Data Portal

To link all the geo-spatial datasets on atmosphere, ocean, polar and geosciences available across multiple MoES data portals at an easily navigable central repository, an Earth System Science Data (ESSD) Portal (fig. 3.5a) has been developed by INCOIS together with other MoES institutions. The data portal, hosted by INCOIS, was inaugurated by Hon'ble Minister for Earth Sciences, Dr. Jitendra Singh, on 27 July 2021 on the occasion of the foundation day of MoES (Fig. 3.5b). This data portal is aligned with the Digital India initiative of the Government of India. The data portal can be accessed at https://incois.gov.in/essdp/.

3.1.9 OMNI-RAMA Data Portal

INCOIS, jointly with NIOT and NOAA-Pacific Marine Environmental Laboratory (PMEL) developed and launched a portal to access the moored buoy data

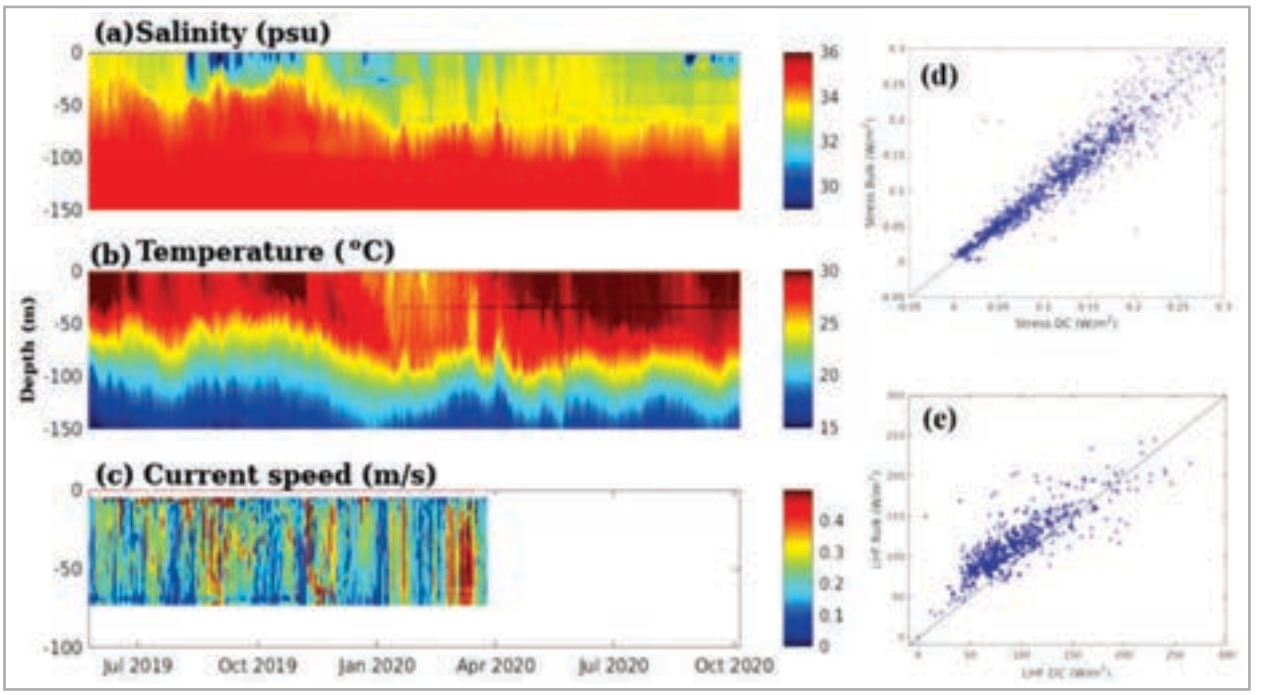

Fig 3.4 : (a) Salinity, (b) temperature and (c) current timeseries sections from INCOIS flux mooring deployed in the Bay of Bengal. Comparison of direct eddy covariance flux against bulk derived (d) momentum fluxes and (e) latent heat fluxes at the mooring location

Fig. 3.5 : (a) Web Page of Earth System Science Data portal (b) Inauguration of Earth System Sciences Data Portal

deployed as part of MoES-OMNI (Ocean Moored buoy Network for northern Indian Ocean) programme and NOAA-MoES Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) programme. Dr. Ashutosh Sharma, Secretary, MoES inaugurated this portal during a virtual event conducted on 11 August 2021 in the presence of Dr. Craig Mclean, Assistant Administrator and Acting Chief Scientist, NOAA. The data portal is hosted by INCOIS and is accessible at https://incois.gov.in/portal/datainfo/buoys.jsp.

3.1.10 Ocean Modelling and Data Assimilation

Modular Ocean Model (MOM6) with Local Ensemble Transform Kalman Filter (LETKF) are proposed to be adopted for data assimilation scheme to generate an

operational analysis and forecast system for the ocean circulation parameters in the global as well as regional ocean. For coastal waters and estuaries, FVCOM- a finite volume, unstructured grid ocean circulation model to be used. The usage of ADCIRC+SWAN for operational storm/swell surge forecasts and Wavewatch-III for wave forecasts in the global and coastal waters to be continued. An Ocean Modeling Mission, which includes 8 work packages, has been initiated at INCOIS.

3.1.11 Data Assimilation of SST in the High-resolution model for North Indian Ocean:

Data assimilation scheme on the operational high resolution (~2.25 km) model (NIO-HOOFS) coupled with local ensemble Transform Kalman Filter (LETKF) scheme has been developed for acquiring satellite track data of sea surface temperature (SST) obtained from GHRSST along with temperature and salinity profiles. Multiple sensitivity experiments are conducted varying the coarse-graining length-scale to arrive at the optimal length scale and for SST observation over a length scale of 13 km (1/8□) shows the highest correlation in the ocean analysis.

3.1.12 Coastal water quality observations

Several cruises were carried out in the Bay of Bengal at a seasonal scale covering pre and post SW monsoon. Analysed water quality data indicated that the cold-core eddy plays a vital role in fuelling Chlorophyll-a (chl-*a*) during pre-monsoon with a three-fold increase in the chl-*a* concentration. In contrast, the impact of warm-core eddy in reducing the chl-*a* concentration was apparent during post-monsoon. The chl-*a* concentration was found to be relatively lower despite having higher nutrients and adequate light in the water column. The impact of COVID-19 lockdowns on the Indian coastal water quality was also studied with the aid of satellite remote sensing, which showed a significant reduction in the magnitude of the chl-*a* and particulate organic carbon (POC) in the Indian coastal water particularly in the western Bay of Bengal. The map showing anomaly of chlorophyll-a during April 2021 (Fig. 3.6).

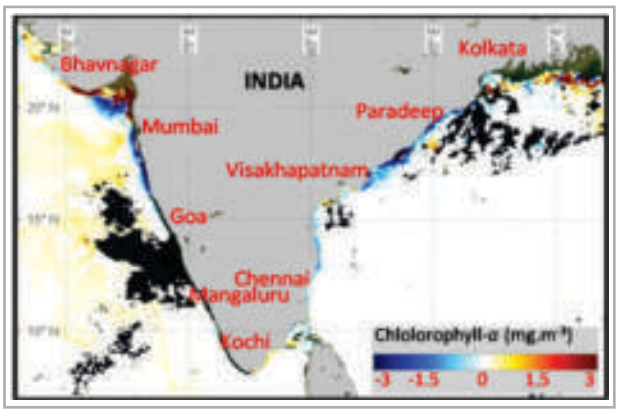

Fig. 3.6 : Anomaly of chlorophyll-a during April 2021

3.2 Studies in Marine Living Resources (MLR)

3.2.1 Marine Ecosystem Dynamics of eastern Arabian Sea (MEDAS)

MEDAS project is implemented by CMLRE along the Eastern Arabian Sea (EAS) with the objective to address the major physical mechanism, that are upwelling and convective mixing and their interplay on the biogeochemistry and ecosystem response**.** The new coherent datasets collected as part of the project revealed that the world's largest coastal hypoxic-anoxic zone along the west coast of India (Fig. 3.7) is not anthropogenically driven. Instead, it is formed naturally through the upwelling of deoxygenated waters during the summer monsoon. The coastal water oxygen deficiency during the Summer Monsoon (SM) upwelling gradually intensified from hypoxic during early SM to suboxic/anoxic (≤5 µM) by late SM. The suboxic/anoxic zone was confined only to the central shelf between 11 and 18□N, which is equivalent to almost half of the western Indian shelf. Demarcated anoxic zone is located away from major coastal cities like Mumbai and Kochi, where substantial anthropogenic input is obvious. It is evident that increased anthropogenic activities have not impaired these coastal waters, where the anoxia is confined. Further findings are that the coastal hypoxia in the south remained unchanged compared to the conditions five decades ago, and the monsoonal estuaries of India act as heavy sink zones and export only <10% of anthropogenic nutrients to the coastal seas.

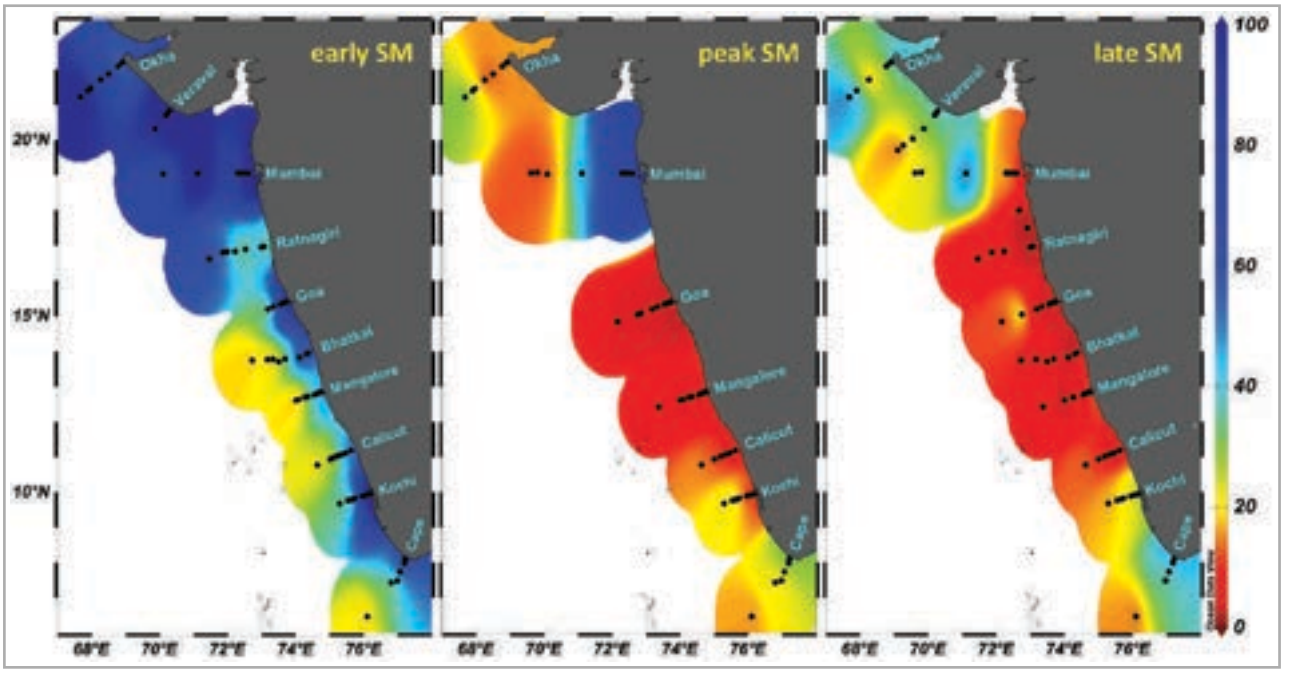

Fig. 3.7 : Map showing increasing intensity of hypoxia/anoxia during the intra-seasonal progression of summer monsoon upwelling over the eastern Arabian Sea.

The distribution of phytoplankton pigment under contrasting warm, oligotrophic and cold, nutrient-rich south to north regimes along the EAS during winter monsoon presented in Fig. 3.7. The dominance large phytoplankton (diatoms, as inferred from the major marker pigment fucoxanthin concentration) dominated the coastal regions while the offshore waters were characterised by large proportions of pico-nano plankton (as observed in the high concentration of marker pigment zeaxanthin) along with considerable contribution of diatoms. Both physical and chemical conditions chiefly controlled the offshore phytoplankton population while nutrient chemistry played a major role in the coastal regions during the WM. The large proportion of pico-nano plankton in the offshore of EAS suggests a transition of the ecosystem to a mixotrophic condition where micro-fraction of phytoplankton continued to contribute to the total phytoplankton biomass. Whereas the dominance of large phytoplankton like diatoms indicates herbivorous control in the food chain in the coastal regions. MEDAS programme also brought out the influence of nutrient status on mesozooplankton community, revealing that the nutrient enrichment favoured a shift in the mesozooplankton community structure from nutritionally superior crustacean plankton to fewer desirable jellyfishes, which in turn, might lead to a threat on the estuarine pelagic energy transfer and ecosystem deliverables.

3.2.2 Resource Exploration and Inventorization System (REIS)

Under REIS programme taxonomic studies of samples collected on-board FORV Sagar Sampada within the Indian Exclusive Economic Zone (EEZ) yielded six new species of decapod crustaceans, one new species of polycheate and two species of deeps eels (Fig. 3.8). In addition to the above, 1 cnidarian, 9 polychaetes, 5 decapods, 9 echinoderms and 3 deep-sea fishes were documented as new zoo-geographical record from the Indian EEZ. SCUBA diving as well as intertidal surveys carried out around Agatti Island, Lakshadweep revealed 3 new species of polyclad flatworms and 2 new zoo-geographical records for the Indian Seas. A total of 5,916 records covering 7

groups (polychaetes – 1,031, polyclads – 68, crustaceans – 1,653, molluscs – 1,788, echinoderms – 686, fishes – 664, mammals – 26) have been submitted to the Indian Ocean Biodiversity Information System (IndOBIS) portal hosted by CMLRE. Moreover, Referral centre maintains a total of 2,840 voucher specimens under different phyla, which has also been documented and disseminated through IndOBIS data portal. To build up data on molecular systematics, short sequences (660 bp) of mitochondrial gene, CO1 and 16S is developed for 15 species of deep-sea eels, one species of dwarf whale,8 species of brittle star, 6 species of polyclads, 12 species of heterobranchs, 6 species of anomuran crab and 25 species of portunid crabs from Indian waters.

3.3 COASTAL RESEARCH

3.3.1 Marine and Coastal Pollution

Seawater Quality Monitoring (SWQM) is a continuing program of the National Centre for Coastal Research (NCCR) to assess the coastal water quality at 50 locations covering the coastal states and union territories along the Indian coast. Various physicochemical, biological and microbiological characteristics of seawater and sediments are monitored. The data generated are shared with the Ministry of Statistics and Programme Implementation (MoSPI) for developing Sustainable Development Goal (SDG) index for the SDG 14 targets (14.1 and 14.3). It is also been shared with agencies like NITI Aayog, Central Pollution Control Board (CPCB), State

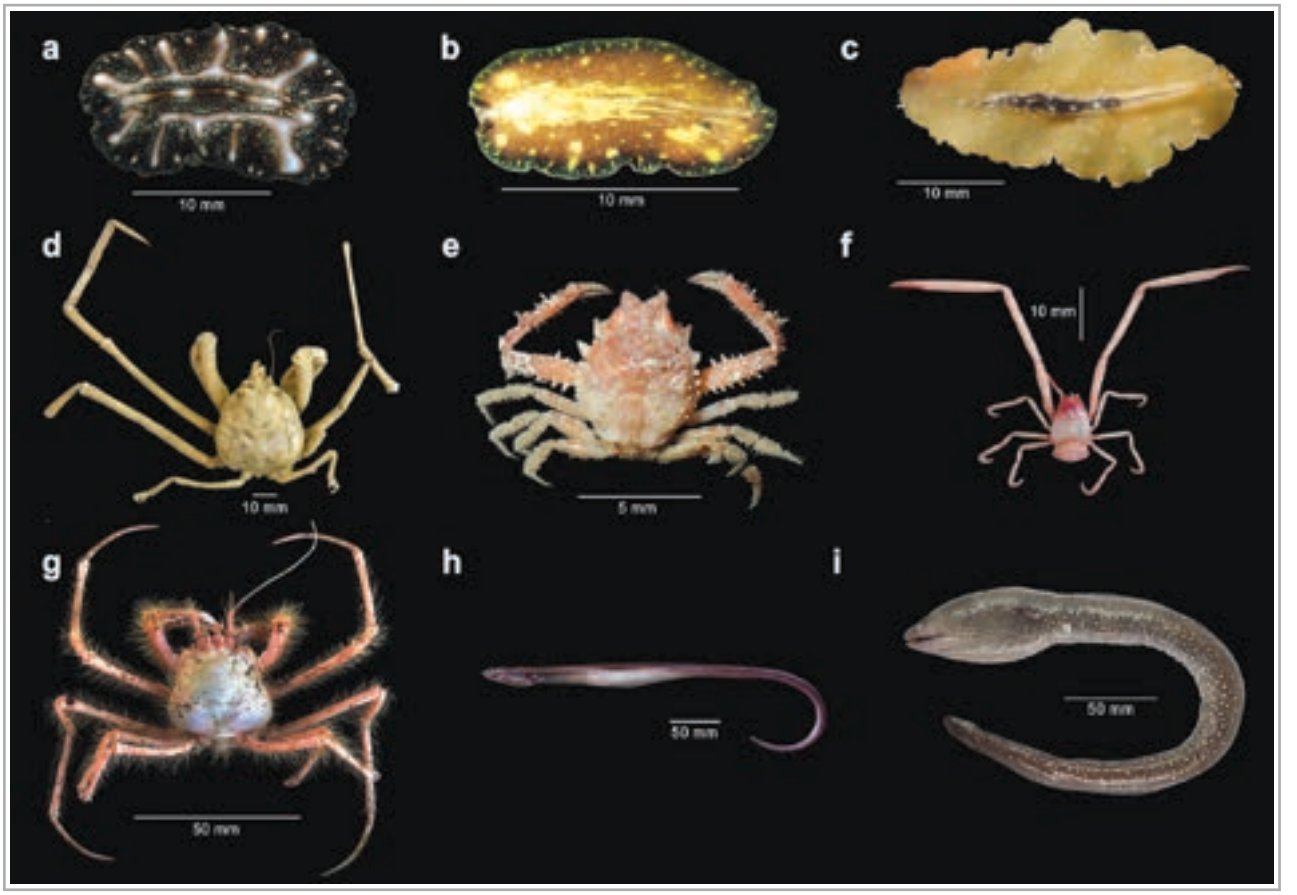

Fig. 3.8 : Species new to science, collected from surveys of FORV Sagar Sampada, (a)Pseudoceros agattiensis, (b) P. stellans, (c) Bulaceros newcannorum, (d) Gordonopsis robusta, (e) Kasagia sudhakari, (f) Uroptychus sampadae, (g) Homalodromia rajeevani, (h) Ophichthus mccoskeri, and (i) Gymonthorax smithi.

Pollution Control Boards and Committees (SPCB/PCCs) and others. During 2021-22, three cruises were undertaken from Tuticorin in Tamil Nadu to Porbandar in Gujarat and Field sampling was carried out at Kavaratti and Agatti islands of Lakshadweep.

To assess the level of pollution in the coastal waters and develop a prediction system for coastal water quality for the benefit of the coastal stakeholders combined approach of monitoring and modelling has been taken up. In addition to the *in-situ* discrete measurements, automated buoys mounted with meteorological and water quality sensors were deployed off Chennai and Puducherry at 12m depth (3.9a). The buoy at Puducherry was inaugurated by the Hon'ble Chief Minister of Puducherry on 28th July 2021 Fig. 3.9b).

A water quality model developed for the Chennai coastal waters simulates for the parameters viz., sea surface temperature, salinity, dissolved oxygen, ammonia, nitrite, nitrate, phosphates, chlorophyll-a, faecal coliforms, and total coliforms and Enterococci using *in-situ*, buoy data and forcing from global models. Presently, the model provides 5 days forecast of coastal water quality and is disseminated through digital platforms. Marine Ecotoxicology and ecological risk assessment are being undertaken with the objective to develop Seawater Quality Criteria (SWQC) for coastal waters, waste disposal zones, fishing ports, harbours and ecologically sensitive habitats. In this regard, focus was given for ecological risk assessment of metals in Ennore, Uppanar, and Vellar estuaries. The primary water quality standards for SW-III [Industrial cooling, recreation (non-contact) and aesthetics] and SW-V (Navigation and Controlled waste disposal) for metals (Cd, Cu, Hg, Zn, Pb, As, Cr) and pesticide has been notified in the MoEF&CC draft amendment based on the reports submitted by NCCR.

Mesocosm 'the real-world experiments' were carried out with an objective to evaluate the impact of contaminants on marine organisms and to examine the applicability of seawater quality standards in ambient environmental conditions. NCCR in collaboration with NIO-RC Visakhapatnam, in conducting big bag experiments (mesocosm) to investigate the impact of environmental contaminants on marine biota using customized mesocosm bioassays (Fig. 3.10).

Samples from coastal water, beach and offshore sediment, and biota are analysed for micro/ meso/ macro plastics pollution. An increase in the abundance of microplastics is observed along the east

Fig. 3.9 : (a) Water Quality Buoy deployed off Puducherry (b) Inauguration of Buoy by the Hon'ble Chief Minister, Puducherry.

coast during the monsoon. The stations nearer to the river mouth had higher microplastics concentrations. The Beach litter survey revealed that the maximum accumulation occurs in the backshore than in the intertidal zone. Moreover, Urban beaches have higher accumulation rates than rural beaches.

3.3.2 Coastal Processes and Hazards

Extensive modelling study was carried out for the management of coastal erosion problems at Chellanam Coast of Kerala (Fig. 3.11). Combining numerical models, long term historical shoreline

Fig. 3.10 : Open Sea Mesocosm experiment at Vishakhapatnam off-shore waters

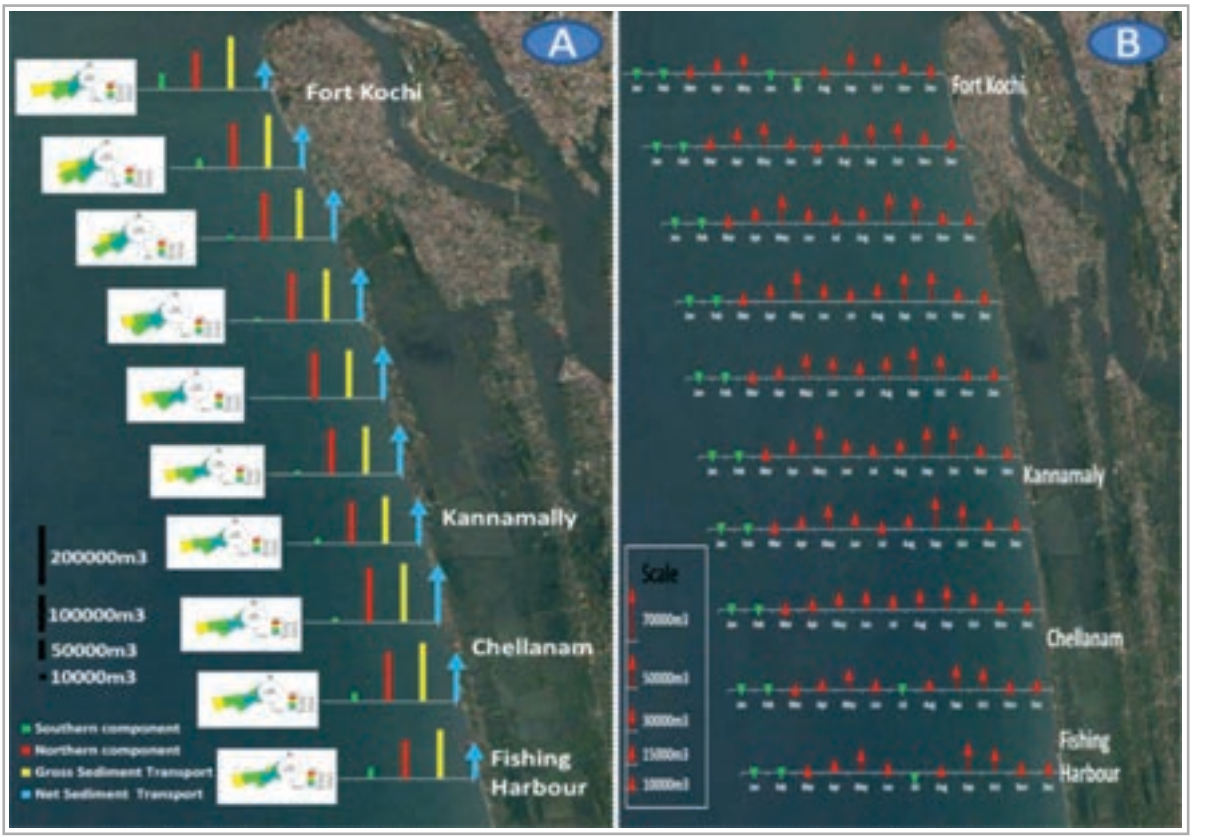

Fig. 3.11 : (A) Wave climate and sediment transport regime along Chellanam Coast (B) and Seasonality in sediment transport at selected locations of the coast.

change, topographic and oceanographic observation, a detailed project report was prepared and submitted to State Irrigation Department, Kerala for successful implementation of engineering solutions to abate the coastal erosion due to high waves during the monsoon season. Besides, status/investigation of existing seawall and hard structures were examined and reviewed for its structural functionality against the defense mechanism to high waves. As a shoreline monitoring program, long term shoreline change maps have been prepared at 1:25000 scale for dissemination to different stake holders of the state for management of coastal resources. The Shoreline change mapping for some of the Islands has been prepared on long term scale (1990-2018).

Integrated Flood Warning systems (i-flows) for Chennai and Mumbai are presently in operation and are used to provide impact-based warnings by IMD. Probable flood inundation is forecasted one day in advance based on the NCMRWF Unified Model (NCUM) 4x4km model from NCMRWF. Flood inundation maps are also prepared from the actual rainfall data from a network of automatic rain gauges (120 stations) from IITM, IMD and Municipal Corporation of Greater Mumbai (MCGM). The inundation maps along with details of inundation at ward level forms part of the IMD bulletin that is provided to the state government for their mitigation operations. The i-flows system was in operation during the Tauktate cyclone and the bulletins were issued for the heavy rainfall days in Mumbai.

3.3.3 Coastal Habitats and Ecosystems

Ecosystem modelling studies are being carried out for the west coast shelf waters to understand the complexity and interplay of upwelling and winter convective mixing in different seasons from Okha to Kanyakumari. Data pertaining to the various physical and biogeochemical parameters were collected from the field to study the ecosystem aspects such as Greenhouse gases (GHGs) scenarios, benthic biology and micro plastic accumulation in benthos. Data analysis clearly indicate the health of the ecosystem is deteriorating particularly to a distance of 2km from the coast. Ecosystem modelling of Pulicat lake, which is the second largest brackish water lake in the country revealed that regional climatic and hydrological imbalance caused unprecedented regime shift in salinity, which adversely affecting its biodiversity. The trophic status using TRIX index ranged from 2 to 7.3, indicating a 'meso'- to the eutrophic status of the lagoon with nutrient limitation in the form of phosphate. The hypersaline conditions and elevated pH together resulted the system to act as net sink for atmospheric CO_2. An integrated ecosystem functioning model of Pulicat Lake is presented in Fig. 3.12. Long term reef health monitoring for Gulf of Mannar continued to assess the live and dead coral coverage, community structure of reef-building corals, species diversity, anthropogenic impacts, and emerging new threats to the ecosystem. Community structure represented 79 species of hard corals belonging to 13 families and 22 genera of coral species and the average live.

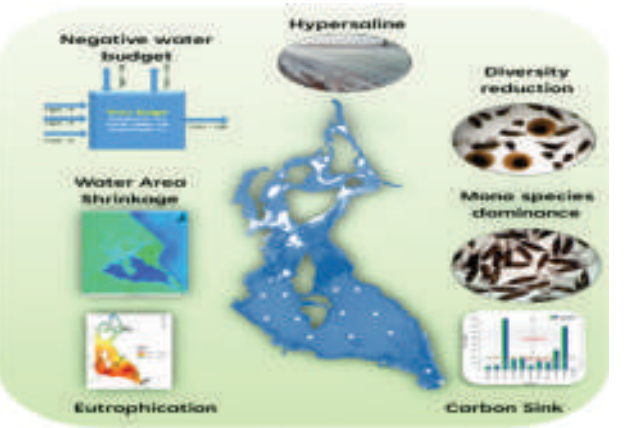

Fig. 3.12 : Integrated Ecosystem functioning of Pulicat Lake

3.4 Ocean Technology

3.4.1 Ocean Observation System (OOS)

Ocean Observation systems maintained with the network of Argo floats, drifting buoys, coastal Acoustic Doppler Current Profiler (ADCP) moorings, equatorial current meter moorings, eXpendable BathyThermographs (XBT) / XCTD transects, Tsunami Buoy (STB) with Bottom Pressure Recorder (BPR), Tide Gauge, Wave Rider Buoy and Automatic Weather Station on ships by INCOIS in collaboration with

relevant academic and research Institutes. In addition, recently two gliders were deployed in the Bay of Bengal to monitor the deep ocean physical and biogeochemical parameters with special emphasis to understand the temporal and spatial variability of the Oxygen Minimum Zone (OMZ). Both the gliders after covering 5000 km distance are recovered and collected data was retrieved.

Moored Ocean Observation systematically maintained through the present buoy network consisting of 12 deep ocean buoy systems with surface and subsurface sensors, 3 coastal buoys, one Calibration - Validation (CAL-VAL) buoy system, one Arctic mooring and 2 tsunami buoy systems. The data collected by these buoys are disseminated to INCOIS, Hyderabad in real-time and are shared in GTS and made available in DBCP website for global community. The time series observations of the moored buoy network are utilised to identify the characteristics and variability of air-sea interaction and upper ocean dynamics in the North Indian Ocean. Joint data portal OMNI-RAMA with public access to moored buoy data in Indian Ocean was established. The moored buoys provided real-time data during the cyclones Yaas & Tauktae (Fig.3.13(a)), which contributed for issuing cyclone warnings by IMD. The Underwater Seismic Sound Recorder System is developed and deployed in OMNI buoy at 1000-meter depth in the Bay of Bengal. Monitoring marine plastics in designated deep sea and coastal stations is undertaken and published in the newsletter of Ocean best practices work group of Global Ocean Observing System (GOOS) and the International Oceanographic Data and Information Exchange (IODE). An Indigenous rain gauge working on capacitive principle has been developed (Fig. 3.13 b). An Indian patent has been granted for the invention titled 'REAL TIME TSUNAMI MONITORING SYSTEM', patent No. 369964 on 22nd June 2021. Six Indigenous Ocean observation technologies developed and has been successfully transferred to M/s L&T for commercialisation.

3.4.2 Energy and Freshwater

For establishment of the proposed Ocean Thermal Energy Conversion (OTEC) powered desalination plant at Kavaratti is in progress and issuing work order for 'High Density Polyethylene Pipes (HDPE) pipe supply and welding', Supply and Commissioning of Plant equipment and Civil Works are under process. Establishment of 2 Million Litres per Day (MLD) Low Temperature Thermal Desalination (LTTD) plant at Tuticorin Thermal Power Station (TTPS) is also under process.

The studies in Open Cycle OTEC laboratory were continued to gain deeper insight in to open cycle OTEC and LTTD systems. Tests were conducted to characterize turbine and generator combinations and assess its performance at various speed ranges. India is coordinating a subtask on OTEC for the Ocean Energy Systems (OES) Technology Collaboration Program (TCP) under International Energy Agency (IEA) for the

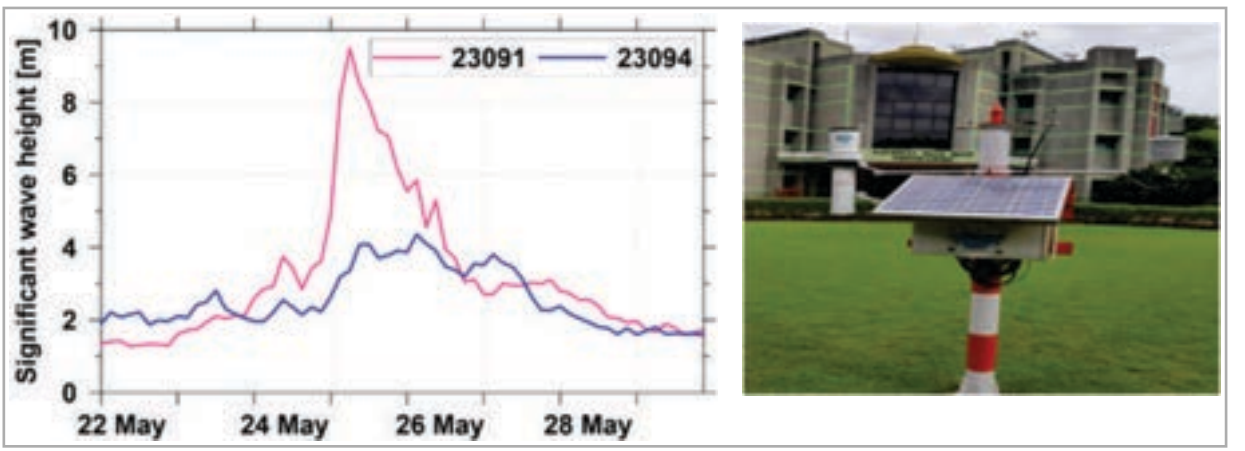

Fig. 3.13 : (a) Significant wave height observed by Buoy during the passage of cyclone (b) Testing Indigenous Rain gauge at NIOT

preparation of a white paper on OTEC for policy makers. Dr. Purnima Jalihal was elected as Vice-Chair of the OES TCP Executive Committee, becoming the first Indian to become part of the committee.

3.4.3 Development of technologies for Offshore structural components:

In addition to sustain Low Temperature Thermal Desalination (LTTD) plant at Kavaratti, Minicoy and Agatti islands establishing 6 plants at Amini, Androth, Chetlat, Kadamat, Kalpeni and Kiltan islands of UT Lakshadweep is under process. Construction and installation of all components of the plant at Kalpeni island have been completed.

Based on the studies on coastal processes construction of nearshore reef, offshore reef with beach nourishment were proposed and executed for Puducherry coast, which resulted in the formation of a wide beach to the south of the reef (Fig. 3.14). NIOT organized a workshop for officials of the Puducherry government to improve their understanding of the project and a public event attended by the Hon'ble Minister of Earth Sciences, dedicating the restored beach to the public. The project site is being regularly monitored post-implementation through field measurements of bathymetry, topography and wave climate, and the response of the coast is in line with the numerical simulations.

3.4.4 Coastal and Environmental Engineering

NIOT has carried out the restoration of eroded beaches along the Kadalur coast near Kalpakkam in Tamil Nadu, using submerged breakwaters made of sand filled geosynthetic tubes. Performance of the submerged breakwater was evaluated by monitoring the beach and sea bed profile behind the breakwater segments through bathymetry, photographs and satellite imageries. Sediment deposition immediately

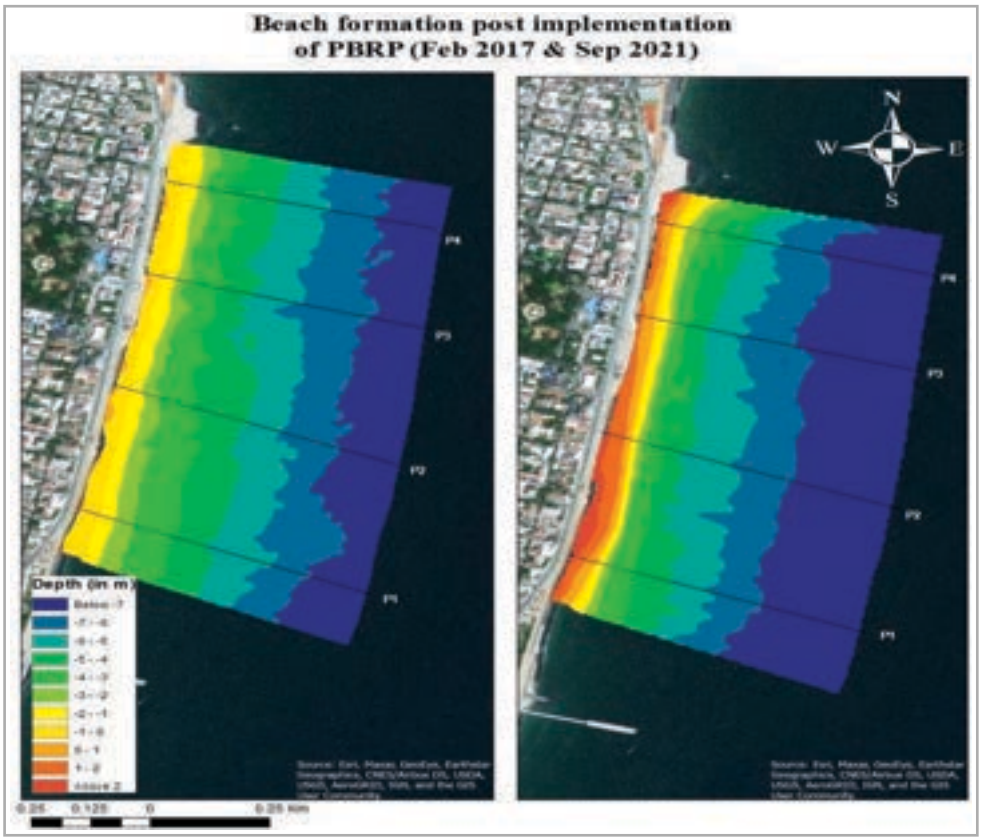

Fig. 3.14 : Comparison of bathymetry at Puducherry coast before and after beach restoration

behind the breakwater segments and settlement of the structure were recorded. A coastal monitoring system has been established for the Indian coast, which provides wave, current, tide and met-ocean parameters along the Indian coast. North Indian Ocean Tide (N.I.O.T) mobile App was developed with observation data along the Indian Ocean (Fig. 3. 15 a). A ready to use wave atlas for the Indian coast (mainland) is developed using 22 years of wind data as model input and validation from observations. Indian Coastal Ocean Radar Network operates and maintains 10 systems along the coast of India including two systems in the Andaman Islands. Velocity data from the HF radar Network are combined on standard grids (Fig. 3. 15b), and this data is disseminated through central servers at NIOT and INCOIS for operational and academic use.

3.4.5 Shallow water Bathymetry- East Coast of India

Shallow water bathymetry data (0 – 30 m water depths) for the east coast of India are being collected. Presently, bathymetry along 700 km of Tamil Nadu coast and 160 km along the coast of West Bengal has been completed.

3.4.6 Ocean Science and Technology for Islands

Experimental scale outdoor culture of marine Spirulina in 2-ton raceways has been established and microwave assisted extraction of c-phycocyanin (C-PC) is optimized using Response surface methodology with augmentation of c-phycocyanin yield to 115.5 ± 4.32 mg/g. The purity ratio (A620/A280) of C-PC was enhanced from 1.0 to 4.76 by multistage aqueous two-phase extraction and ammonium sulphate precipitation. Culture of native seaweed species *Gracilaria edulis* was carried out in Chidiyatapu, Andaman and a production of 15 kg was obtained in 45 days (Fig. 3. 16 a). Several hydrocarbonoclastic bacteria capable of utilizing petroleum hydrocarbon (PHC) as sole carbon (food) source has been identified and isolated. Technology for biodegradation of PHC through marine microbial consortia is developed and transferred to industry through NRDC (Fig. 3. 16 b). Whole genome sequence of petroleum hydrocarbon degrading bacteria B. subtilis EB1 is developed and functional coding genes revealed 34 genes associated with degradation of xenobiotics.

The open sea cage components are indigenized and manufactured in India for demonstration of cage

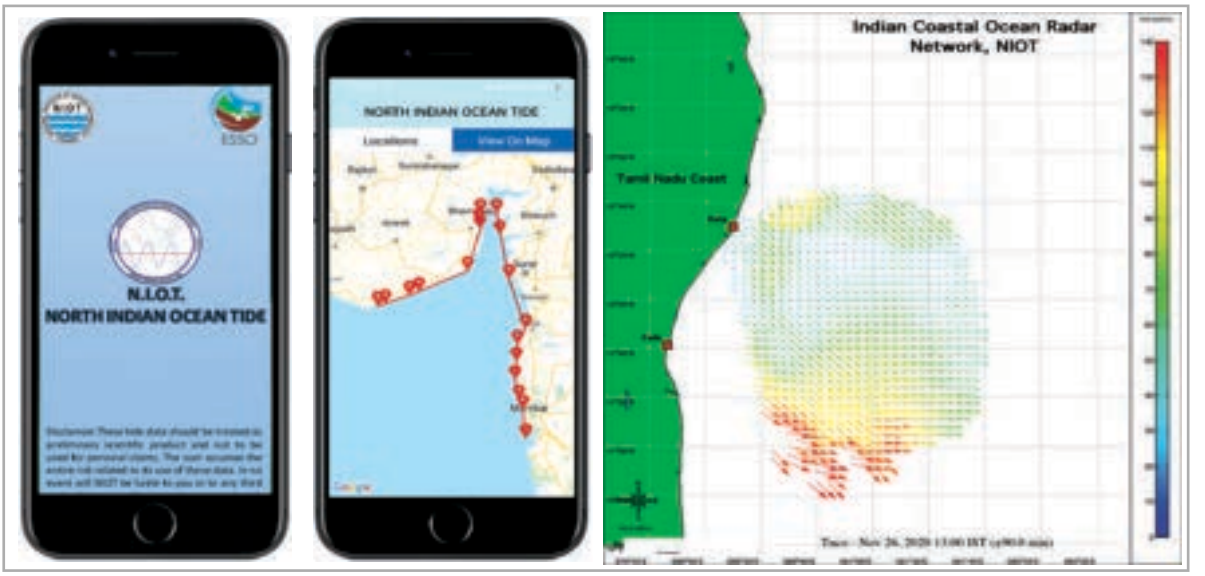

Fig. 3.15 : (a) North Indian Ocean Tide Mobile app and (b) HF radar network data

Fig. 3. 16 : (a) Open sea *Gracilaria edulis culture* and (b) Biodegradation of PHC Technology transfer

culture in other maritime states. MoU signed with ICAR-CMFRI for joint demonstration of offshore cage culture. Process of construction of marine finfish hatchery at Atal Centre for Ocean Science and Technology for Islands (ACOSTI), Port Blair, is initiated through CPWD. Geo-spatial planning for identification of the potential area for seaweed culture along the A&N coastal waters is carried out. NABL accreditation for testing chemical parameters in ballast water samples is obtained. Baseline survey of the sea water quality and biological parameters of Pamanji coast is completed and open sea as a suitable site for intake of ballast water test water is identified.

3.4.7 Deep Sea Technologies

The underwater mining system was deployed from Ocean Research Vessel (ORV) Sagar Nidhi (Fig. 3. 17 a) and Seabed locomotion trials of the experimental undercarriage system of underwater mining system (Varaha-I and II) was successfully undertaken over a distance of 120m on water-saturated soft soil at 5270 m depth in the Central Indian Ocean (CIO) during March – April 2021. Photograph showing locomotion trial given below (Fig. 3. 17 b) and this was the deepest trials ever so far, for a seabed mining system. The sea trials provided valuable information on the sub-sea navigation and positioning, controlled locomotion on soft water saturated soil of the seabed and related sinkage, performance of the electro-hydraulic systems at high hydrostatic pressure and low temperatures and handling of the mining machine from the deck for deployment and retrieval. These trials are stage level tests in the eventual development of an integrated deep-water poly-metallic mining system for collecting nodules from depths upto 6000m.

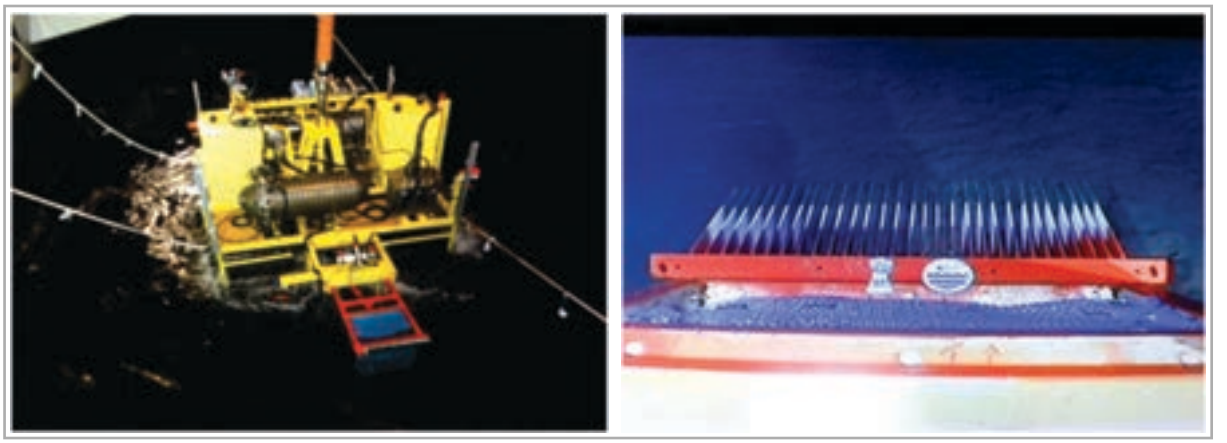

Fig. 3.17: (a) Deployment of Mining Machine and (b). Locomotion at 5270 m water depth in Central Indian Ocean

Indigenous design for the development of a 6000m depth rated Manned Submersible related components like arrangement of subsystems for achieving the hydrostatic stability and hydrodynamic shape, considering dimensions and weight of the subsystems is completed to proceed for scale down model studies. Preliminary design phase is complete and shifted critical design phase. Concept of Operation for Manned Submersible is approved by DNV for normal operational condition. Subcomponents such as Brushless DC thrusters for vehicle propulsion, shallow water penetrator assembly are realized and Factory Acceptance Test is underway for the realization of Li-Po battery with the approval of certification agency. Contract was signed for realization of the human support and safety system along with Det Norske Veritas (DNV) certification. Qualification trial for 6000m depth rated Autonomous Underwater Vehicle (Ocean Mineral Explorer 6000 - OME 6000) at 1270 m water depth at Norway is completed for its realization and usage for deep sea exploration in the Indian Ocean.

3.4.8 Marine Sensor systems

Development of indigenous Underwater Acoustic Telephone (UAT) for underwater voice communication through analogue or digital modulation techniques has been initiated and Single Side Band (SSB) Modulation Technique for underwater voice communication has been implemented with 12.5kHz Carrier Frequency and demonstrated in ATF tank (Fig. 3. 18 a & b). For proof of concept of synthetic aperture side scan sonar, low frequency 2x5 array has been realized with indigenously developed NIOT-BEL transducers. The array has been tested in Acoustic Test Facility (ATF) of NIOT for the expected response. Sub system assembly and integration are in progress.

3.4.9 Ocean Electronics

Technology transfer licensing agreements with 7 Indian industries has been signed including L&T Defence. Establishment of Incubation facility at NIOT to promote development of marine technologies is in progress. 500m workable Deep Sea Autonomous Underwater Profiler is developed in-house using 1000CC variable buoyancy engine which suits operations in the Bay of Bengal. Two units integrated and tested for basic functionality at sea conditions and are ready for field deployment.

Automation of open sea fish cage culture system and a solution for automatic fish feed system developed using a rigid sphere type cages and proto unit was deployed at Andaman Islands. Developed bio-mass

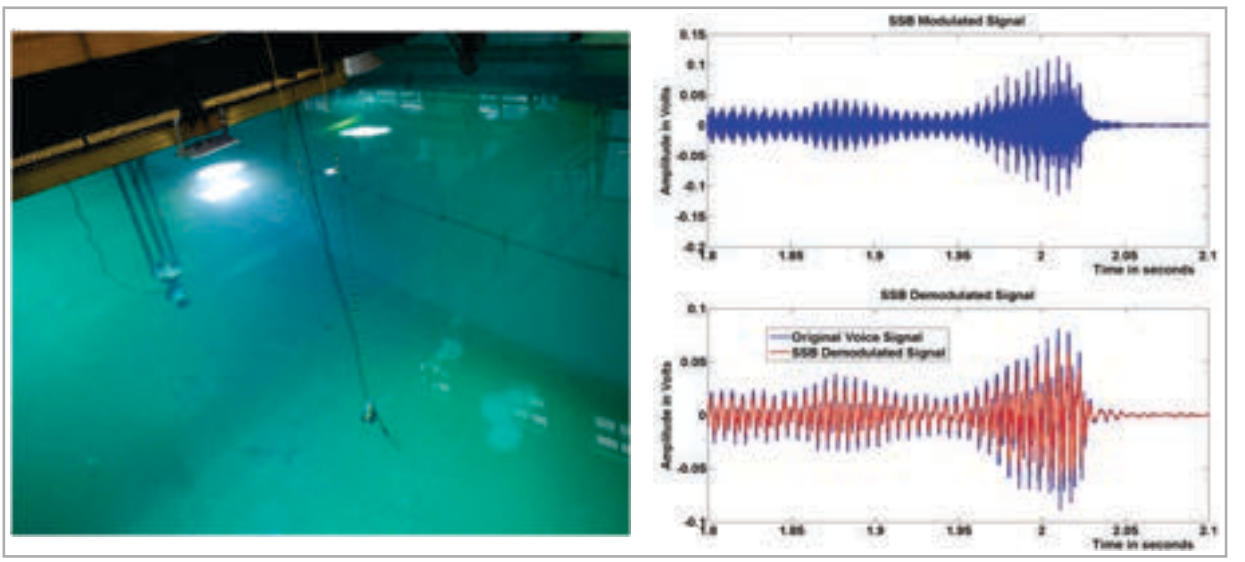

Fig. 3.18 : (a) Transducer setup for Underwater Voice Communication Test and (b). Voice Signal and SSB modulated signal

estimation using Artificial Intelligent (AI) method which supports the fisherman community in evaluating fish growth being nurtured inside the surface and submersible cages.

Development of Ocean Glider, indigenization of CTD sensor with IIT-Madras, development of C profiler system and thermal engines for profiling floats to recharge the profilers using the thermal gradient available in the Ocean are in progress. Sea trial with automatic water quality sampler has been undertaken using a Drone at Near Kovalam coast, Chennai for demonstration of feasibility of using Drone technology for Environment Impact assessment studies.

3.4.10 Ocean Acoustics

The Autonomous Ambient Noise Measurement System for the Arctic region has been enhanced with two separate noise recorders in the upper and lower water column, which are enabling to characterize noise primarily due to ice melting and anthropogenic sources. Advance data acquisition system capable of performing with low power consumption is developed to record over a period of two years, which was tested in the laboratory successfully for incorporation in the noise recording system for Arctic region.

Deep Water Ambient Noise system has been successfully tested and deployed in the Bay of Bengal as part of OMNI buoy BD11 (13.53 N & 84.17 E) at 3250 m depth during February 2021. The Acoustic Recorder has been deployed positioned at 510 m depth from the ocean surface. The indigenously dveloepd Vector Sensor Array (VSA) has been tested in the Acoustic Test Facility for different azimuth positions and Direction of arrival (DoA) estimation compared well with the actual azimuth. Subsequently sea trial of VSA was carried out by deploying it as an autonomous system at 17m water depth for three days during first week of September 2021.

3.5 Ocean Survey and Mineral resources

3.5.1 Geoscientific Studies of the Exclusive Economic Zone (EEZ)

The "Geoscientific studies of the Exclusive Economic Zone (EEZ)" programme is a multi-institutional endeavour lead by NCPOR, Goa; NIOT, Chennai; CSIR-NIO, Goa and Geological Survey of India (MCSD, GSI) to generate high-resolution bathymetric charts of the Indian EEZ. The coverage of surveys undertaken so far is shown in Fig. 3.19. An area of about 1.7 Million km^2 has been surveyed so far comprising about 90% of the deep-water (more than 500m depth) blocks. Compilation of charts for the west coast region in 2°x 2° format is in progress, as per the Marine map

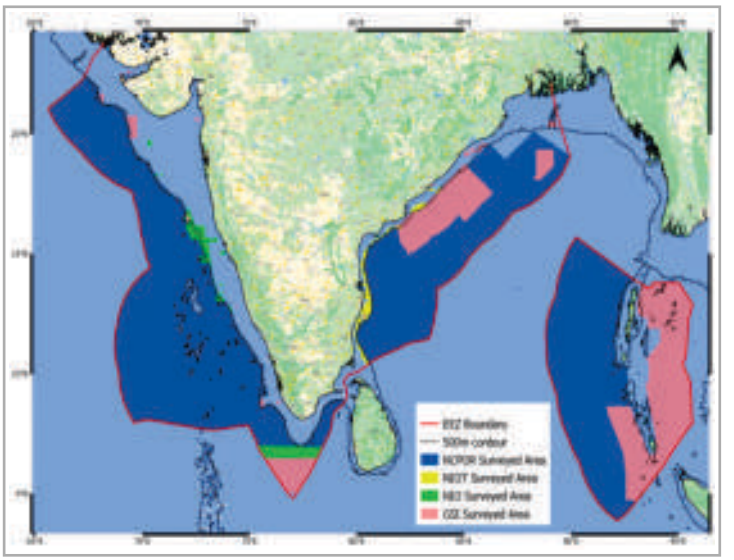

Fig 3.19 : Map showing total area surveyed so far in the Indian EEZ.

compilation index. The Marine Geo-Scientific Database (MGSDB), at NCPOR, is updated as and when new datasets are acquired. Geomorphological studies with high-resolution multibeam bathymetric data of the Arabian Basin region revealed the presence of Guyot, isolated Hill and Seamount near Laccadive Plateau (Fig. 3.20). Such data in the Gulf of Mannar revealed the presence of many smaller canyon systems culminating into a larger main canyon. The canyons are roughly aligned with the major/minor perennial rivers in the peninsular region of Tamil Nadu. The length of the main canyon is approx. 400 km along the thalweg.

3.5.2 Hydrothermal Sulfide Exploration Program

Exploration of seafloor hydrothermal sulphides are being carried out under a signed contract with the International Seabed Authority (ISA) in the allocated area of the Indian ocean. Survey exploration carried out involving MAPR survey, CTD operations, Lowered Acoustic Doppler Current Profiler (LADCP) casts, water sampling, gravity coring and dredge operations were carried out for identifying the locales of hydrothermal mineralization and for baseline data generation in the Central Indian ridge (CIR) and South west Indian Ridge (SWIR). New potential locations of inactive sulphide mineralization in the CIR and few new locations of hydrothermal activity in CIR and SWIR has been identified. Hydrothermal plume particles collected from a depth of 2570 m showed different morphological features consisting of sulfides (barite, pyrite, and chalcopyrite) and Fe-oxyhydroxides (Fig 3.21a). A high abundance of sulfide particles indicates the high-temperature hydrothermal venting in the vicinity and buoyant stage of the plume. Mineralogical studies revealed the presence of a chalcocite-digenite group of minerals with high Cu (~76 wt %), covellite (CuS) with silver (Fig 3.21 b). The recovery of altered ultramafic, sheared gabbro and altered basalt from the site along with sulphide mineral assemblages suggest an Oceanic Core Complex (OCC) setting associated with the sulphide mineralization.

Sequential chemical extraction of 'Fe' was carried out in sediment core collected from the SWIR to understand the distribution of Fe among the different mineral phases. High contents of Fe-oxides suggest oxidation and precipitation of Fe during the plume dispersal. Geochemical data suggest that the hydrothermal activities altered the sediments. Thus, significant sources of Fe into the sediment are through the hydrothermal input. The plume and background seawater samples collected from the CIR and SWIR were subjected to metagenomic sequencing which identified 39 bacterial metagenomic assembled genomes showing taxonomic similarity with refractory hydrocarbon decomposers in the deep-sea water samples. Two new carnivorous sponge (Demospongiae: Cladorhizidae) species were discovered in the Seamounts of Central Indian Ridge. The study highlights the importance of seamount benthic habitats for supporting the CIR's rich and endemic carnivorous sponge fauna.

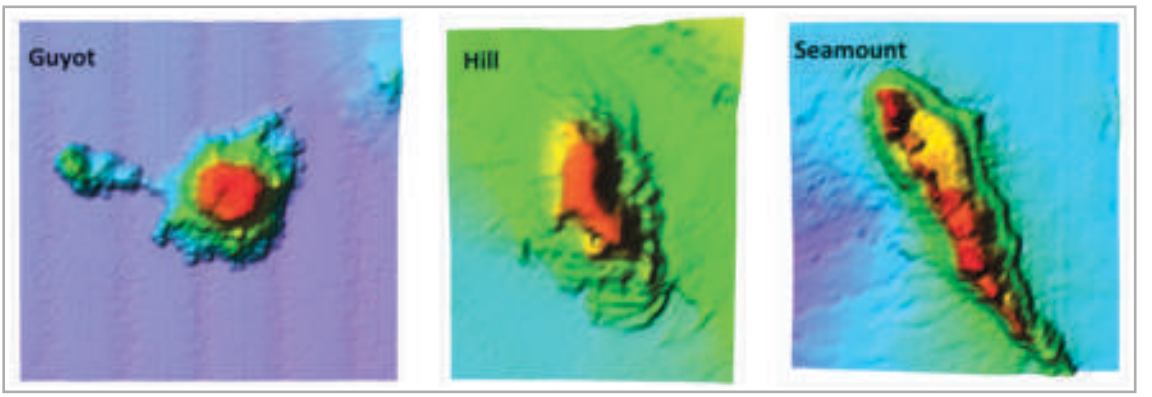

Fig. 3.20 : 3D maps showing various bathymetric high features near Laccadive Plateau

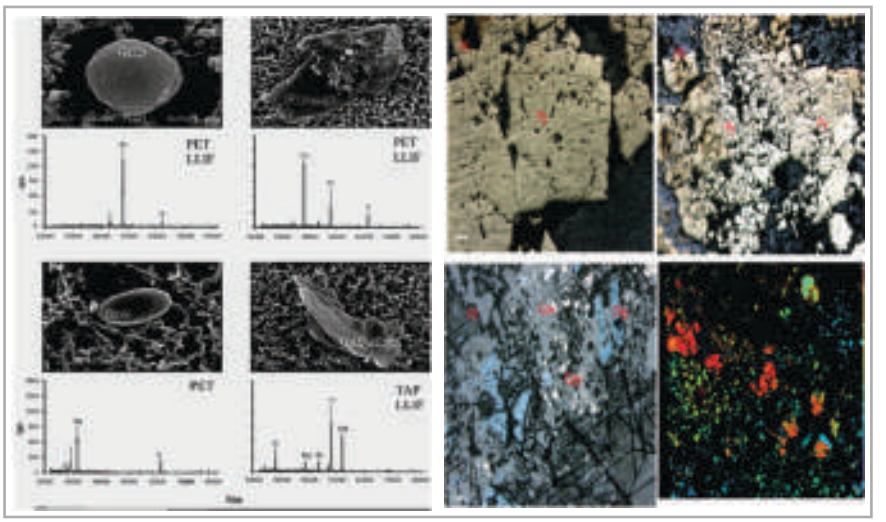

Fig. 3.21 : (a) SEM images and (b) Petrographic and BSE image related to mineralogical studies.

3.5.3 Extended Continental Shelf Program of India

The submission by India has been examined by the Sub-commission formed by Commission on the limits of the Continental shelf during 51st and 52nd sessions of the CLCS at New York, USA. The observations made by sub commission has been responded. Next session scheduled to be held at DOALOS, United Nations Headquarters in New York has postponed due COVID restriction. Further required necessary documents is under preparation for submission.

3.5.4 Survey and exploration of Polymetallic nodules

Chemical analyses of strategic metals of the already collected nodule samples (sampled at 6.25km X 6.25 km) from the Revised First Generation Minesite during February- March 2020 has been completed. Further expedition has been planned for close grid sampling Revised First Generation Minesite. Baseline data collection covering environmental variability of water column and bottom sediments is being undertaken by CSIR-NIO, Goa in the nodule-bearing areas of the Central Indian Basin (CIB) during March and December 2021 onboard oceanographic research vessel *RV Sindhu Sadhana*. The extractive metallurgy of the Polymetallic nodule is being carried out at CSIR-IMMT aiming to maximize value addition and minimize waste generation through hydro and pyrometallurgical process routes for the recovery of metals like Cu, Ni, Co and Mn. An integration into the ammoniacal process towards minimizing liquid effluent generation and generating input chemicals is under process. Pilot-scale study on reduction roasting was carried out at 20 kg/ day capacity. Processing of residue to obtain an Mn enriched material suitable as feed material for Fe-Si-Mn alloy preparation were carried out.

3.6 Research Vessels:

Research ships Sagar Kanya, Sagar Manjusha and Sagar Purvi has been awarded "Certificate of Merit" by India Meteorological Department [IMD] in recognition of the Commitment to Excellence and Commendable Contribution toward Climate Research. Coastal Research Vessel "Sagar Anveshika" was dedicated to the Nation by Dr. Harsh Vardhan, Hon'ble Union Minister for Earth Sciences, Science & Technology and Health & Family Welfare on 9th January 2021 at Chennai Port. Research Vessel Sagar Nidhi continued to support R & D activities following COVID compliances. Newly acquired Coastal Research Vessels Sagar Tara and Sagar Anveshika are operated and maintained performing well. Three cruises were undertaken onboard ORV Sagar Kanya and the vessel spent 76 days at sea to support Geoscientific studies of EEZ in the Arabian Sea and India Ocean Geoid law (IOGL) programme in the Indian Ocean.

Chapter-4

POLAR AND CRYOSPHERE RESEARCH (PACER)

4.1. Scientific Studies in Antarctica

4.1.1 Three-decade surface mass balance of the Nivlisen Ice Shelf, central Dronning Maud Land, East Antarctica

Shallow ice-penetrating radar sounding was conducted to visualize firn stratigraphy in the top 35 m over ~400 km of profiles across the Nivlisen Ice Shelf, and in a grid pattern over two adjacent ice rises (Djupranen and Leningradkollen). The six reflectors (isochrones) were tracked and dated using two ice cores taken at the ice rise summits, from which Surface Mass Balance (SMB) over six periods in the past three decades was retrieved. The overall SMB pattern across the ice shelf remained similar for all periods; however, the east-west contrast in SMB varies by a factor of 1.5–2 between the Leningradkollen and Djupranen grounding lines (Fig 4.1). The SMB patterns over the ice rises are more varied owing to complex interactions between topography, snowfall, and wind.

4.1.2 Polar Micropaleontology and Past Climate

Multi-proxy organic and inorganic studies were carried out on sediment cores collected from three lakes of Larsemann Hills viz., LH73 (11.8 kyr) in Broknes Peninsula, Mochou Lake (27 kyr) in Mirror Peninsula and Pup Lagoon (7 kyr) in Stornes Peninsula.

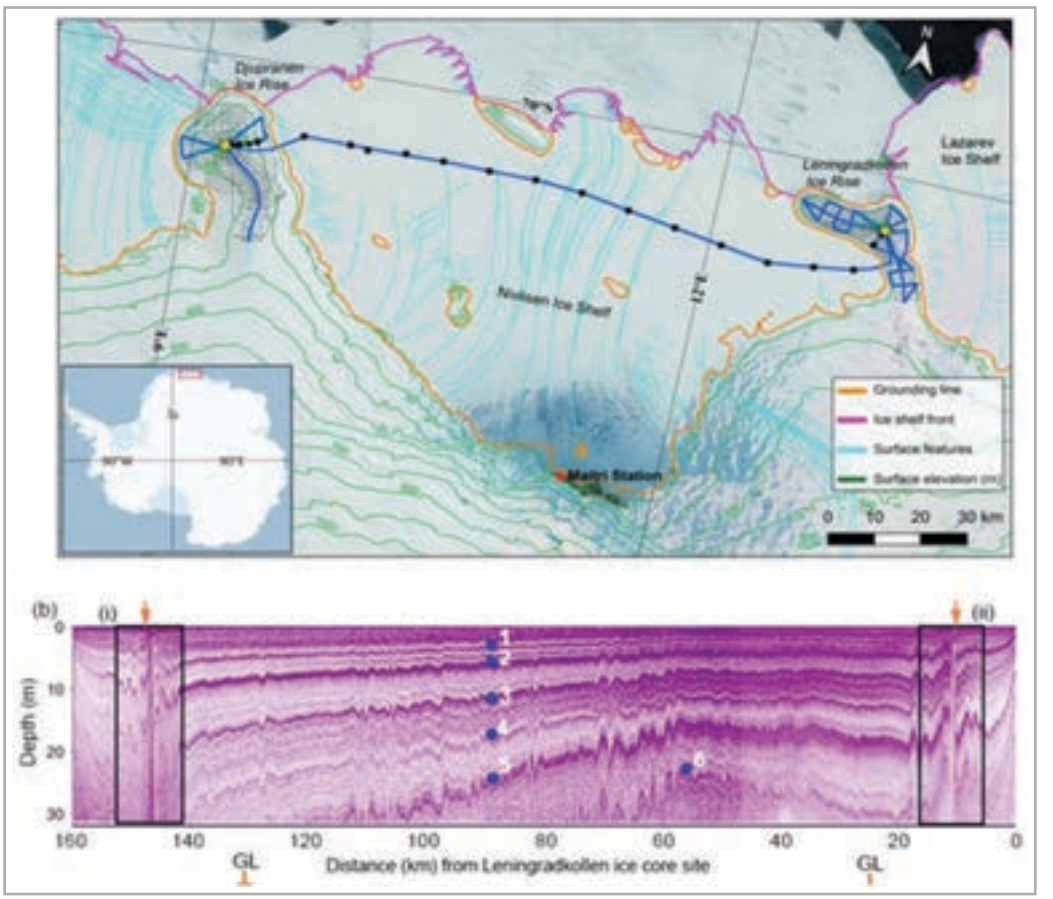

Fig 4.1. Shallow radar profiles of Djupranen and Leningradkollen ice rises, East Antarctica

Evolutionary inferences from the sedimentary deposits of Lake LH73, Larsemann Hills, East Antarctica

A 60 cm long radiocarbon-dated sediment core spanning the last 11.8 kyr from Lake LH73 located in Broknes Peninsula of Larsemann Hills is studied for grain size fractions, magnetic susceptibility, and diatom abundance . Based on the diatom and grain fraction data, it is inferred that the lake persisted as a proglacial lake during the early-Holocene (11.8 to 7.2 ky BP) dammed by ice-sheet towards the south. The lake level was at least 3 m higher than the present level (4 m) as inferred from the diatom transfer function owing to the presence of ice dam. The retreat of the ice-sheet and the collapse of the ice dam between 7.2 and 7 ky BP resulted in the lake transitioning to an isolated lake with the lake level attaining current level (4 m).

Holocene sedimentology in an isolation basin in the Larsemann Hills, East Antarctica.

The grain size (sand-silt-clay) and organic matter variations of a sediment core (51cm) from Pup Lagoon spanning the last 6109 years provides information on environmental changes in two different settings, i.e., (a) under the marine influence, and (b) as an isolated lake (Fig. 4.2). Three cluster zones were identified viz., LZ1 (6109 to 2427 y BP: marine environment), LZ2 (2427 to 2101 y BP: transition zone) and LZ3 (2101 to 116 y BP: freshwater environment). Fine grain sediments (silt) are dominant in LZ1, indicating a strong hydrodynamic energy condition affected by tidal currents with low organic matter. Higher sand content during the transition period (LZ2) indicates the strongest hydrodynamic condition and sediment deposition from sea ice. The increasing trend of OM (cyanobacterial benthic mat) beginning at ~ 2101 y BP suggests the isolation of the lake. The highest fine grained sediments (silt-clay) in LZ3 suggests lowered meltwater derived detritus in response to mild austral summer conditions during the Late Holocene.

Glacial-Holocene climate-driven shifts in lacustrine and terrestrial environments: Rock magnetic and geochemical evidence from East Antarctic Mochou Lake

The environmental history spanning the last 25,400 years was reconstructed using geochronology, lithology, rock magnetism and geochemistry to understand the effect of glacial–deglacial climate

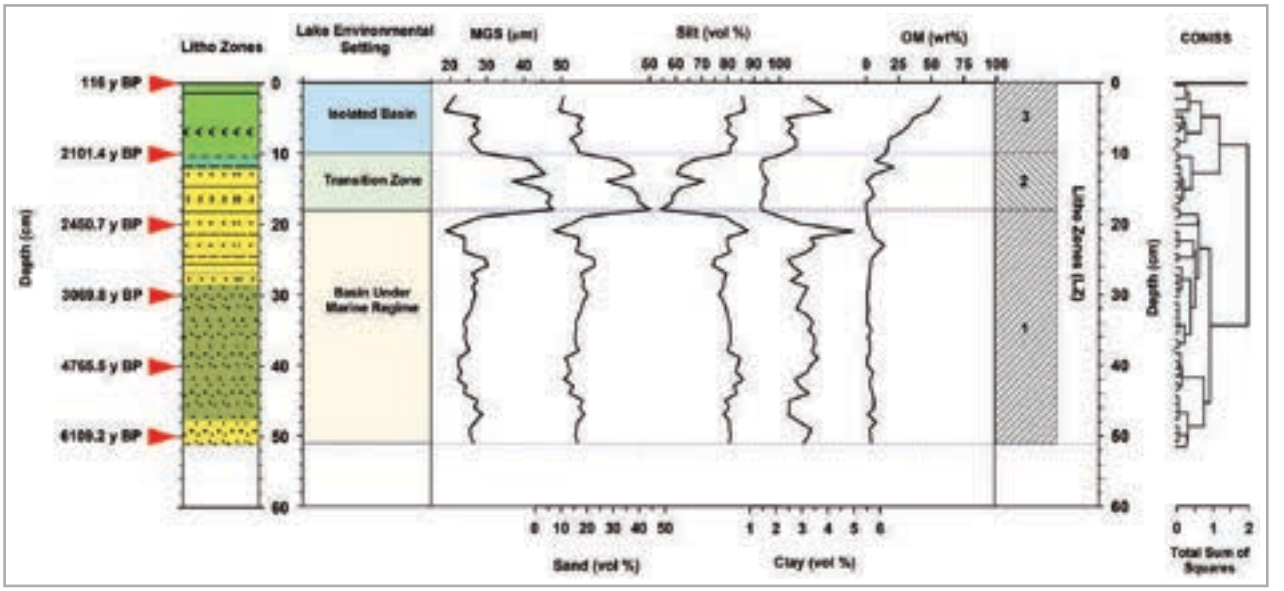

Fig 4.2 Temporal variation of the textural parameters, organic carbon, lithology of the lithozones and paleoenvironmental settings of Pup Lagoon sediment core.

variations on surface processes and Mochou Lake ecology . During the last glacial period (25.4 to 18.8 cal. kyr BP), intensified winds and the freeze-thaw action of ice actively weathered the high elevation western catchment that was a dominant sediment source to the lake. The glacial environmental conditions induced a persistent perennial lake ice-cover resulting in anoxia, low sedimentation, primary production and weak brackish conditions. Progressively, as deglacial conditions augmented around 18.8 cal. kyr BP, increased catchment meltwater flow enhanced sediment transport and also transformed the lake into a freshwater basin, although perennial ice-cover still prevailed.

4.1.3 Operations and management of Indian Antarctic stations

Indian Scientific Expedition to Antarctica:

The 40th Indian Scientific Expedition to Antarctica (40-ISEA) was launched from Murmugao, Goa in January 2021 with 43 Indian members on board expedition vessel MV Vasiliy Golovnin. After resupplying Bharati and Maitri stations and changeover of winter crew during the austral summer, the vessel returned to Cape Town, South Africa on 10 April 2021. In the spirit of international cooperation in Antarctic science, MV Vasiliy Golovnin took a slight detour while returning to Cape Town and successfully retrieved two remotely operated Norwegian Ocean observing instruments (a sea glider and sail buoy) at ~67 degrees South. These Ocean observing systems will help to fill in the gaps of the scantily available information in the Indian Ocean sector of the Southern Ocean. For the 41-Indian Scientific expedition to Antarctica, detailed planning such as recruitment and engagement of the manpower, hiring of ship and helicopters, procurement for resupply of stations, etc. were undertaken.

4.2 Himalayan Studies

4.2.1 Glaciological studies in Chandra Basin, Western Himalayas

Systematic and long-term scientific investigations of six representative glaciers of Chandra basin (Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Gepang and Kunzam), western Himalaya were continued to understand the response of Himalayan Cryosphere to changing climate. Glaciological field campaigns have been carried out for six glaciers during May 2021 to October 2021 covering total glacierized area of ~300 km^2. Various field activities like stake networking, water level data collection, ice velocity and river cross section measurements, Automatic Weather Station (AWS) data collection and maintenance, snow pit/ snow corer measurements for winter snow accumulation, kinematic GNSS survey over the Gepang Glacier and the proglacial lakes, and static GNSS survey at each stake's location for glacier surface displacements were carried out.

4.2.2 Thermal resistance variability over the debris-covered glaciers of Chandra basin

Thermal resistance is an important index to understand the evolution of several glaciers. It describes the thermal characteristics of debris pack, which is important to analyze the heat transfer from debris surface to ice for glacier ablation. The in-situ field measurements of point-wise ablation rate, supraglacial debris thickness, and debris temperature were conducted to examine the thermal resistivity of the debris pack and its influence on ablation over three glaciers (Bara Shigri, Batal, and Kunzam) in Chandra Basin, Western Himalaya during 2016-2017. The estimated annual thermal resistance was highest at the 4100 m asl (Bara Shigri) and lowest was at the 5200 m asl (Kunzam) . Similar variability was observed during the ablation and accumulation seasons, at the 5200 m asl. During the ablation season (June to October), a linear trend in the thermal resistance was observed as per the increasing altitude. The thermal resistivity measurements revealed low resistance (0.009 ± 0.01 $m^2°CW^{-1}$) under thin debris pack and high resistance (0.55 ± 0.09 $m^2°CW^{-1}$) under thick debris. Our study revealed that the thickness of supraglacial debris significantly retards the glacier ablation due to its high thermal resistivity.

4.3 Scientific Studies in Arctic

4.3.1 Indian Polar Aerosol Network(POLAERNET)

Climate change is having a significant influence on the

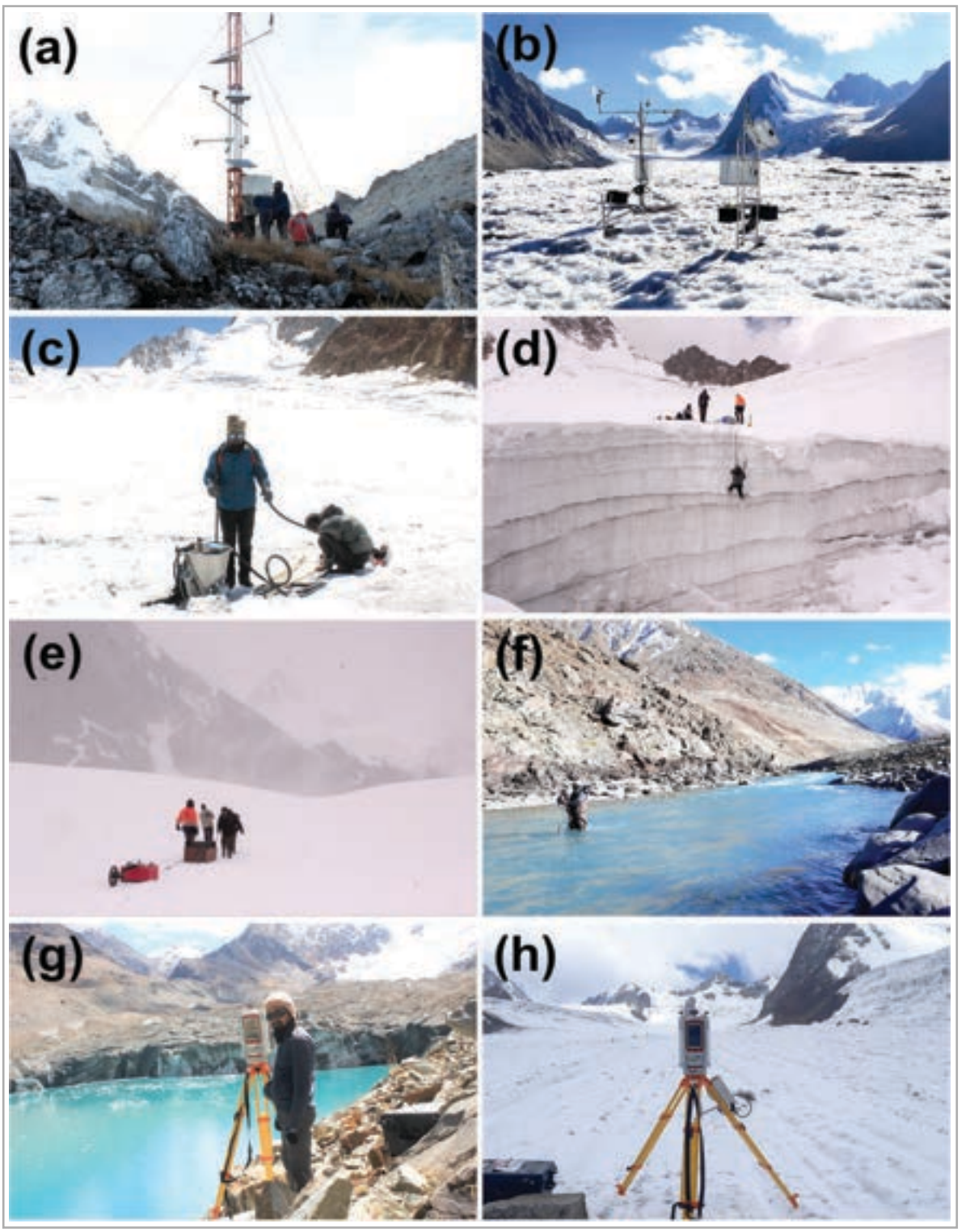

Fig. 4.3 : (a) Installation of Automatic Weather Station (AWS) in Sikkim (Central Himalaya) at 4550 m asl (b) On-glacier AWS over the Sutri Dhaka Glacier (c) mass-balance stake installation, (d) Glacier stratigraphy survey, (e) Ground Penetrating Radar (GPR) survey, (f) Hydrological discharge measurement, (g) TLS survey over the proglacial lake of Gepang Gath glacier, and (h) Terrestrial lesser Scanner (TLS) survey over Sutri Dhaka glacier.

Polar Regions. Aerosols have increased in the Earth's atmosphere as a result of anthropogenic activities. The absorbing aerosol deposited over the surface covered with snow, has a significant impact on snow albedo. Therefore, continuous observations of aerosols over the Polar Regions are very important to understand the variability in aerosols and their radiative impact. India is developing POLarAERosol NETwork (POLAERNET) for long-term and continuous observations of aerosols over the polar (Arctic and Antarctic) and Himalayan regions (Fig. 4.4). The main objective of the POLAERNET is to understand Spatio-temporal variations in aerosols and their properties over the polar region; and their climatic impacts on regional and global scales.

4.3.2 Role of ocean advection on decadal variability of sea-ice in the Arctic

Role of ocean horizontal and vertical advection on recent decadal (2000–2019) decrease of sea-ice in the Arctic is investigated using a global ocean sea-ice couple model, Modular Ocean Model with Sea Ice Simulator (MOM-SIS). The model showed maximum decadal decrease of Sea Ice Concentration (SIC) and increase of Sea Surface Temperature (SST) during summer (June–August) and autumn (September–November) seasons of Arctic compared to winter (December–February) and spring (March–May) in the Norwegian, Barents and Kara sea regions of the Arctic(Fig. 4.5). Using heat budget analysis within mixed layer, it has been confirmed that atmospheric forcing related to heat flux play most dominant role for decadal decrease (increase) of SIC (SST) in the Arctic. Decadal variability associated with the decrease of ocean advection is prominent in the Norwegian Sea region during summer and spring seasons compared to winter and autumn.

4.3.3 Microbiological studies

Phylogenetic null modeling of bacterial communities in Kongsfjorden

Using phylogenetic null modeling the relative influence of selective and stochastic (random) mechanisms that assemble free-living(FL) and particle-associated (PA) bacterial communities throughout the water column in a high Arctic fjord were quantified. Assembly processes acting on FL and PA are similar in surface waters but become

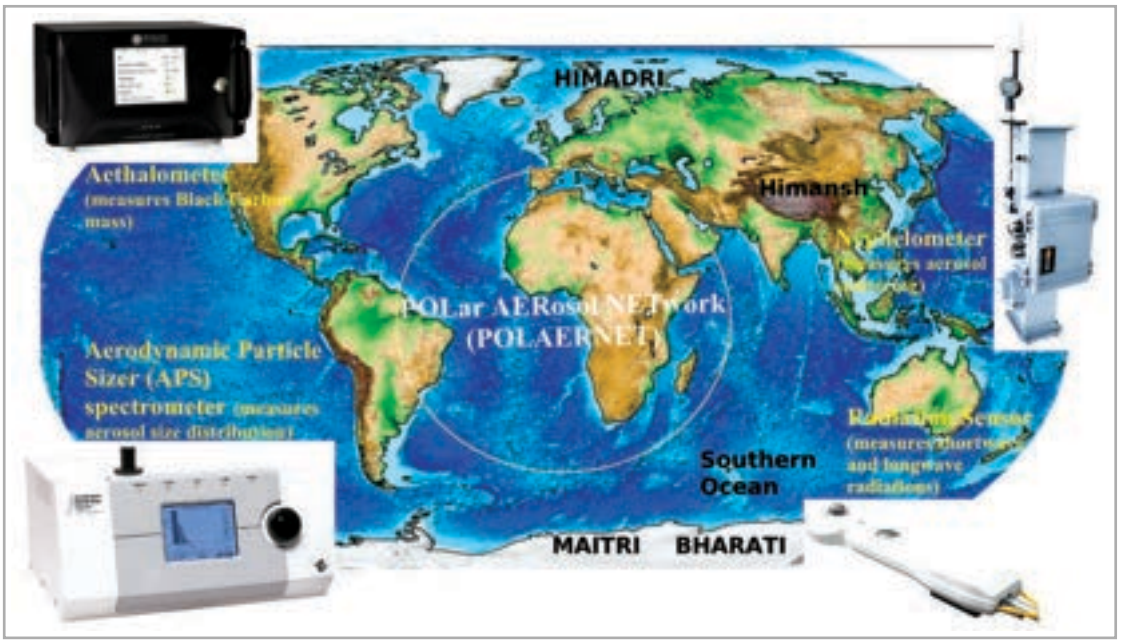

Fig. 4.4. Locations of POLarAERosolNETwork (POLAERNET) and the instruments installed (or planned to be installed).

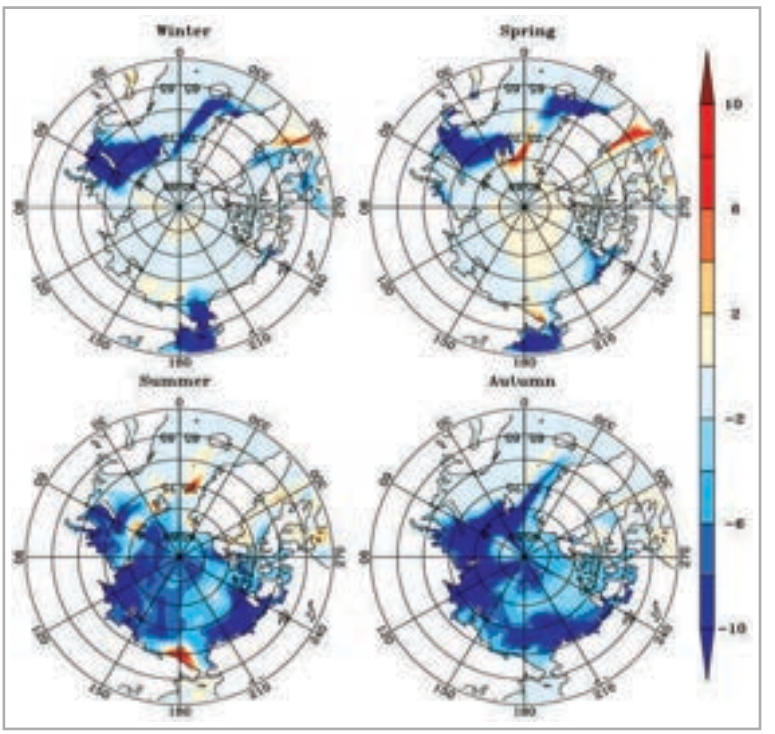

Fig. 4.5 Decadal changes between decade of 2010 -2019 and 2000 – 2009) in seasonal climatology of sea-ice concentration (SIC) in percentage (%) during four seasons (winter, spring, summer and autumn) in the Arctic using MOM- SIS. The scale (on the right-side) represent the variation in percentage (%).

increasingly distinct in deep waters (Fig. 4.6). As depth increases, dispersal limitation and variable selection increases with depth for PA, but not for FL communities, indicating increased residence time of taxa on particles and less frequent decolonization.

Metagenome assembled genomes (MAGs) from MidtreLovénbreen glacier foreland ecosystems

The soil samples collected from MidtreLovénbreen glacier foreland were studied using shotgun metagenomic approach. Total genomic DNA was extracted and sequenced using 2X 150bp sequence chemistry to generate about 130 million paired-end sequence reads. The metagenomics yielded a total of 140 metagenome assembled genomes (MAGs) among the glacier foreland ecosystems. Of the reconstructed MAGs, 10 of them belonged to novel microbial candidate phyla groups. Besides, MAGs representing proteobacterial lineage (Alpha and Gamma), *Actinobacteriota*, *Bacteroidota* were predominantly identified in the recently deglaciated soils. In contrast, MAGs belonging to *Acidobacteriota* and Gemmatimonadota phylum dominated the older stage samples. Metabolic prediction analysis also showed distinct metabolic diversity and biogeochemical processes across glacier foreland ecosystems.

4.3.3 Phytoplankton dynamics and biogeochemistry of Kongsfjorden

Sea-ice decline and melting glaciers are influencing photoperiods and zones. This in turn affects the phytoplankton dynamics- the base of food web in the Arctic. Keeping these ongoing changes in mind, the interplay of physical dynamics and biogeochemistry on the phytoplankton bloom in Kongsfjorden, is investigated using continuous time series from IndARC mooring that is equipped with various physical and biogeochemical sensors. Data is being recorded annually on an hourly interval. The recent

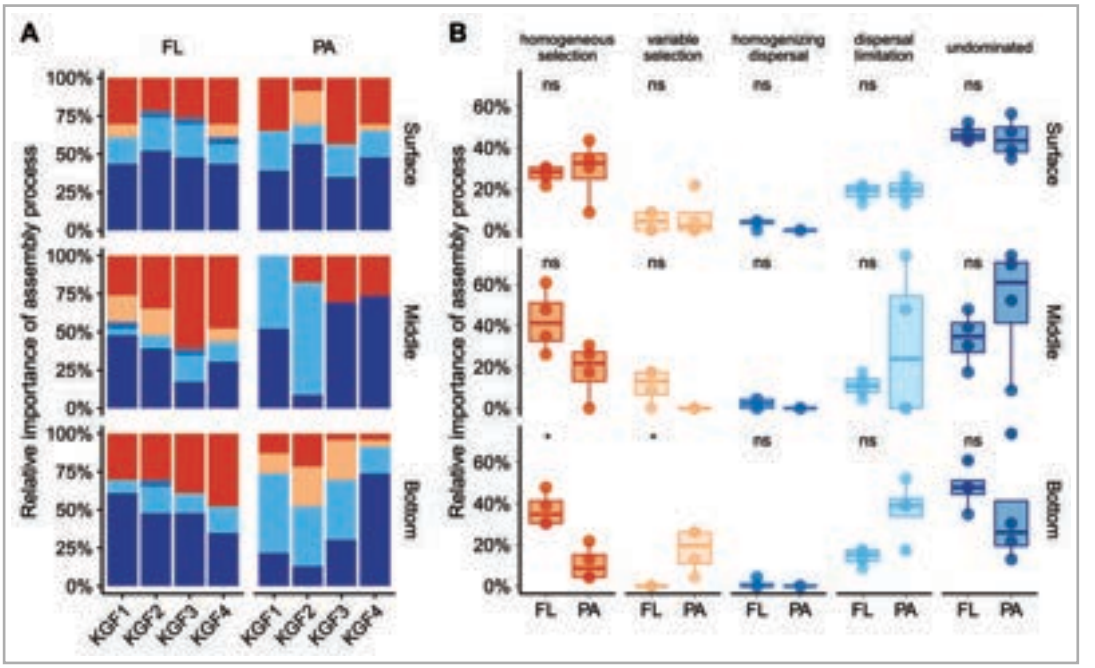

Fig. 4.6. The relative importance of bacterial community assembly processes (A) separated by the assembly and size fraction, and (B) separated by size fraction and assembly process in the surface, middle, and bottom depths. Asterisks in (B) denote $p < 0.05$ using Wilcoxon test. NS = not statistically significantly different.

work has revealed the contribution of high frequency oscillations in winds and currents shaping nitrate variability in a significant manner (Fig 4.7).

4.4. Southern Ocean Studies

4.4.1 The possible linkage between the Indian monsoon rainfall and Southern Ocean sea ice cover

The linkage between the satellite-derived sea ice over the Southern Ocean and Indian summer monsoon rainfall (ISMR) by interacting physical processes occurring between the ocean-atmosphere-sea ice system from 1979 to 2016 (38 years) was explored. Lead-lag cross correlation indicated a significant relationship between Southern Ocean sea ice (SOSI)

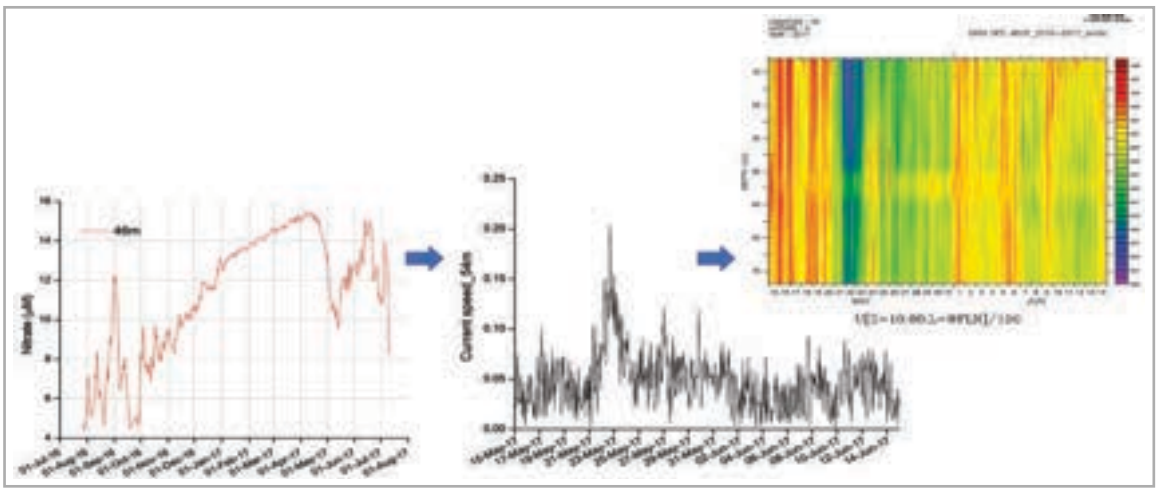

Fig 4.7 : Nitrate spike in Kongsfjorden in Jun-Jul 2017 coinciding with strong currents.

extent and ISMR over the Bellingshausen–Amundsen Sea (BAS). The most significant relationship was obtained in austral autumn (r = -0.5, p < 0.05), where SOSI extent leads ISMR by 2-3 months. The atmospheric circulation patterns over the BAS and Ross Sea in the austral autumn season were analyzed using a composite of extreme rainfall event years. Excess (deficit) rainfall years showed anomalous cyclonic (anticyclonic) wind patterns that led to anomalous positive (negative) air temperature that facilitated anomalous negative (positive) sea ice conditions in BAS (Fig. 4.8 **a-d**). Hence, the excess rainfall (deficit) events were observed corresponding to a large negative (positive) anomalous sea ice condition in the BAS (Fig. 4.8. **e, f**). This linkage possibly occurred through El Niño–Southern Oscillation (ENSO) associated sea surface temperature (SST) variability. Therefore, wavelet analysis was performed to explore the coherence, dominant mode of variability, and common frequency distribution in the SOSI extent, Niño3.4 SST and ISMR. The spectral and wavelet analysis results showed that the SOSI extent and ISMR have dominant oscillations in 2-8 years frequency bands similar to the ENSO. An improved understanding of the complex relations between the polar and tropical regions will help for the better prediction of the ISMR. Hence, the observed relationship can be used as the input for future works for physically linking SOSI conditions with the tropical coupled ocean-

4.4.2 Causes and impacts of anomalous warming in the Prydz Bay, East Antarctica during austral summer 2016-17

Understanding of the coastal waters of Antarctica is

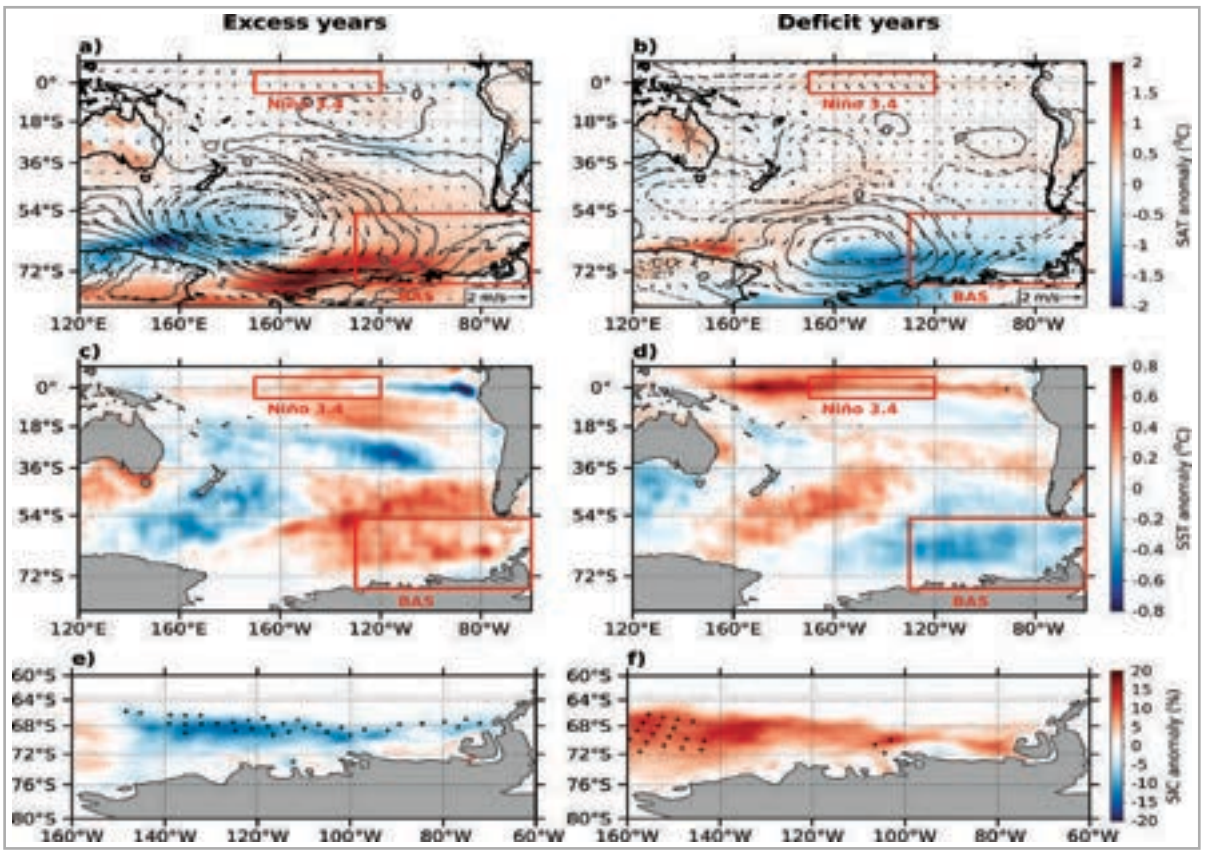

Fig. 4.8 : The composite anomaly maps for austral autumn (March-May) corresponding to rainfall excess years (a, c, e) and deficit years (b, d, f). (a-b) 2m surface air temperature (colour shaded), mean sea level pressure (contours), and 10 m winds (arrows). (c-d) sea surface temperature. (e-f) sea ice concentration. The hatching in figures (e) and (f) represent regions of significant correlation (p < 0.05) between sea ice concentration and Indian summer monsoon rainfall. The red boxes represent the regions of Niño 3.4.

crucial in determining the ocean-ice system response to climate change. In this study, the observational evidence of anomalous warming (>1C) in the Prydz Bay during austral summer (Fig. 4.9a) was provided using hydrograph data. Even though the warming was centered at 68S, 74E, the presence of warmer waters were also noticed close to the Amery Ice Shelf. The study further explored the causes and impact of this anomalous warming using satellite and re-analysis data. It was suggested that the advection of warmer waters towards the shelf region of the Prydz Bay between 72E and 75E was the main driver for the mixed layer warming (Fig. 4.9**b**). The surface heat flux played a weak role in the observed warming. The warm water advection and surface circulation during the observation period were anomalous compared to the normal pattern. The analysis further confirmed that warming caused a drastic reduction in sea ice and chlorophyll in the Prydz Bay region. The study suggests that regional oceanographic processes have

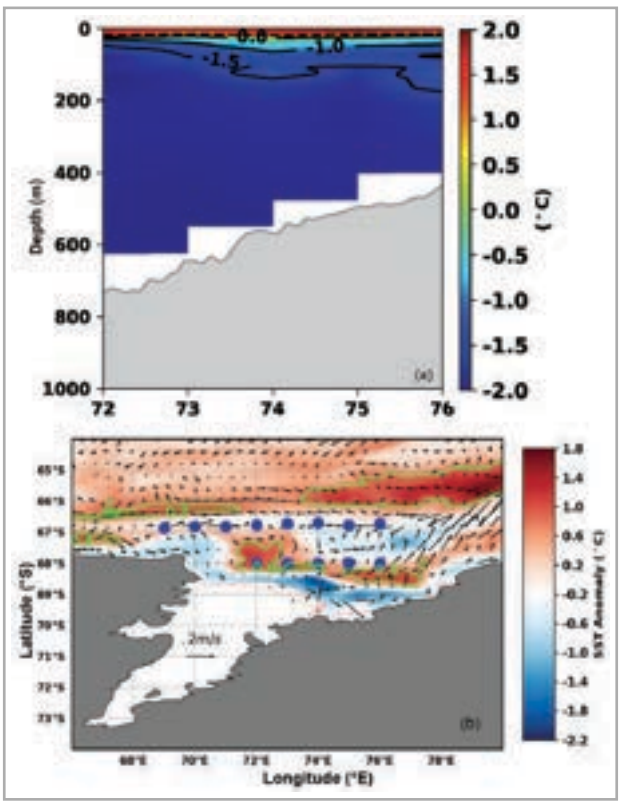

Fig 4.9. (a) Vertical distribution of Temperature along 68°S and (b) HYCOM surface currents anomalies overlaid on HYCOM SST anomalies during January 2017

significant implications on the sea ice and biological productivity of the coastal waters of Antarctica.

4.4.3 Past Climate and Oceanic Variability

Sea Surface Temperature changes in the Indian Sector of the Southern Ocean govern the Indian monsoon variability on millennial timescale

The first high-resolution (centennial-scale) quantitative sea surface temperature (SST) data of the past ~40,000 years from the Indian Sector of the Southern Ocean is used to investigate the Southern Hemisphere's influence on the Indian Monsoon system. The newly generated SST record and advanced computer simulation indicate that surface temperatures of the mid-latitudes of the Indian sector of the Southern Ocean controlled the long-term variability of the Indian summer monsoon, causing a series of millennial-scale changes monsoon intensity.

Higher South Asian Summer Monsoon precipitation during Mid Pliocene Warm Period - a period of high CO_2 and global warming

A study using geochemical proxies in sediment collected during the IODP Expedition 355 from the Arabian Sea was carried out under the Indo-Norwegian PACT (Pliocene Arctic Climate Teleconnection) project. It was found that the monsoon precipitation intensified during warm periods of the MPWP. The results further points out that in the near future of increased global warmth and CO_2 concentration the Indian monsoon precipitation will also increase. Additionally, it is found that the monsoon shifted to a higher mean state at 2.95 million years ago near the beginning of the INHG probably because of the tectonically induced reorganization of the Indonesian Throughflow (ITF), which enhanced the cross-equatorial pressure gradient by changing the source of water (colder) to the southern equatorial Indian Ocean.

Stronger stratification in Arctic Ocean found during a past global warming period (MPWP) analogous to present

To improve our understanding of the impact of global warming on the Arctic Ocean, past climates with similar conditions like Mid-Pliocene Warm Period (MPWP, around 3 million years ago) need to be examined when the CO_2 concentration and warmth were similar to that expected in near future. Our study

finds that stratification was stronger during the warmer periods of the MPWP likely due to the higher sea ice melt, river discharge from the hinterland, and North Atlantic Current inflow. Our results imply that in the current scenario of global warming, we expect strong stratification and upper layer freshening in the Arctic that may lead to more sea ice melting.

Surface pH Record (1990–2013) of the Arabian Sea from Boron Isotopes of Lakshadweep Corals—Trend, Variability, and Control

Instrumental records of ocean pH and its reconstruction utilizing boron isotope ($\delta^{11}B$) composition of corals demonstrate a long-term ocean acidification (OA) trend characterized by large spatio-temporal variability in both Pacific and Atlantic oceans. Our investigation reveals that physical oceanographic processes for example, upwelling, downwelling and convective mixing modulated by El Niño-Southern Oscillation (ENSO) largely control surface pH variability and masked expected long-term OA trend resulting from anthropogenic CO_2 rise. Combining the model-based predictions of increase in frequency and amplitude of ENSO events in a future warming scenario and the observed ENSO dependency of surface water pH, we predict more frequent and large pH variability ("pH extremes") in this region (Fig 4.10). Such pH extremes and their occurrences might be critical for the resilience and adaptability of corals and other calcifiers in Arabian Sea and other similar oceanic settings elsewhere.

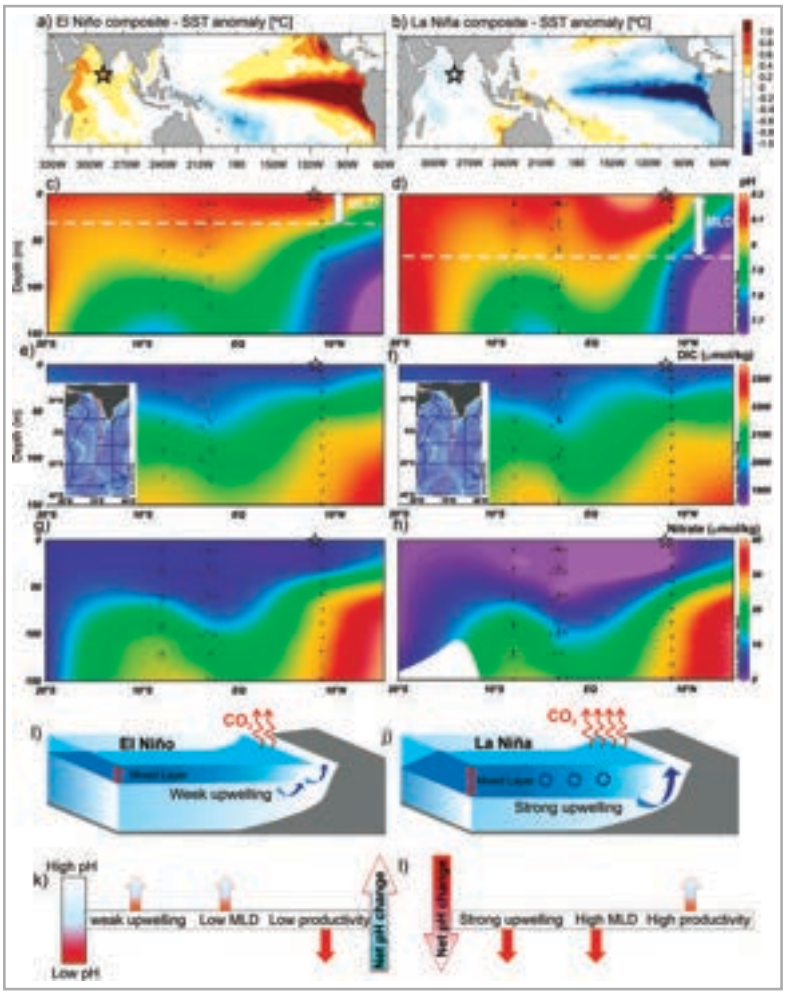

Fig 4.10 : Schematics showing the influence of El Niño-Southern Oscillation on pH variability.

Chapter-5

SEISMOLOGY AND GEOSCIENCE RESEARCH (SAGE)

5.1 Observational Seismology, Earthquake Monitoring and Services:

National Center for Seismology (NCS), an attached office of the Ministry of Earth Sciences, is the nodal agency of the Government of India for monitoring earthquake activity in the country. NCS currently maintains the National Seismological Network (NSN) of 150 stations, each having state-of-the-art equipment consisting of seismic broadband velocity sensor, accelerometer and data acquisition systems spread all across the country, to monitor earthquake activity through its 24x7 around-the-clock monitoring center. Existing National Seismological Network has now been strengthened to 150 stations with the addition of 35 new seismic observatories to improve the operational capability to detect any earthquake of M:3.0 or above in most parts of the country (Figure 5.1). A Central Receiving Station (CRS) set up at NCS, New Delhi receives the digital waveform data from field stations in real-time mode. Preliminary earthquake source parameters are determined and disseminated to various user agencies immediately after the occurrence of earthquakes in the country.

NCS prepares the earthquake bulletins and disseminates information about the earthquake parameters to all the user agencies and the disaster management authorities within 5 minutes of occurrence. NCS is also involved in the monitoring of aftershock and swarm activity, if occurred anywhere in the country. It is planned to strengthen the existing national seismological network with additional 100 seismic stations in next 5 years or so to increase the detection capability of earthquake up to M 2.5 throughout the country and enhance location capabilities for earthquake mitigation efforts.

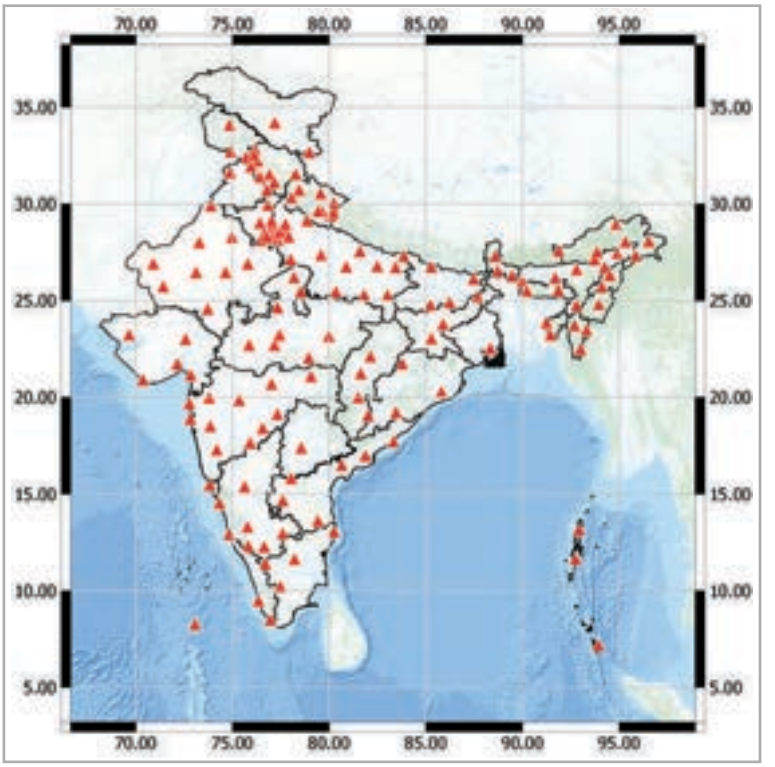

Figure 5.1 : National Seismological Network of the country with 150 stations

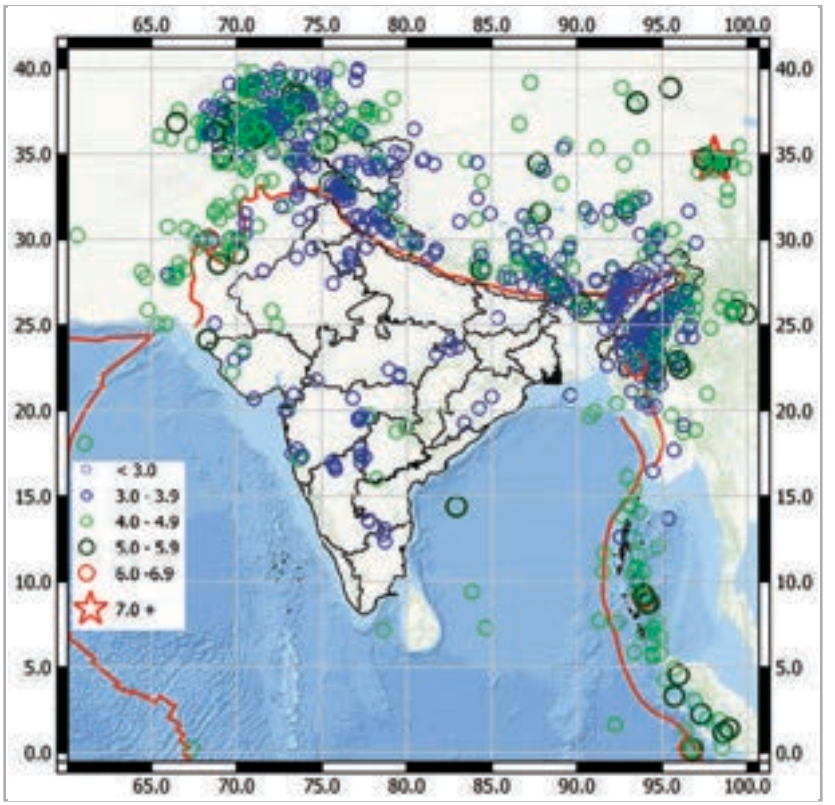

Figure 5.2 : Location of earthquakes detected/located by National Seismological Network of NCS during 01st Jan – 31st December 2021 in India and in its neighbourhood (0-40 ^{0}N and 60-100 ^{0}E).

The data collected from all these network stations is compiled, processed, analyzed and archived systematically at the National Seismological Database Centre (NSDC) of NCS located at IMD Headquarters, Lodi Road, New Delhi. The earthquake data/ information and seismicity reports are supplied to various user agencies such as, insurance companies, industrial units, river valley projects and various scientific, academic and R&D institutions in India and abroad for research purposes. Seismological data and earthquake related information is also supplied to various agencies dealing with relief and rehabilitation measures, earthquake disaster mitigation and management related matters, seismic zoning, etc. Replacement of old dissemination system in being initiated with the development of customized software for Unified Dissemination System (UDS) for dissemination of earthquake parameters. Mobile App of NCS has been enriched with value added feature and renamed as "BhooKamp".

During the last 11 months (January- December 2021) a total of **1398** earthquakes were located and reported (Fig 5.2). Out of these earthquakes, **58** events are of magnitude M:5.0 and above**.** Magnitude wise distribution of earthquakes during reporting period in the form of histogram is shown in Figure 5.3. Information pertaining to significant events was provided to all concerned state and central government agencies, dealing with relief and rescue operations in the region through different modes of communications, such as Mobile-App BhooKamp, SMS, FAX, Email, Twitter and Facebook and published with value added products on NCS's Website (www.seismo.gov.in). As per regular practice, earthquake bulletins were prepared on monthly basis and archived (https://seismo.gov.in/monthly-reports) and sent to the International Seismological Center.

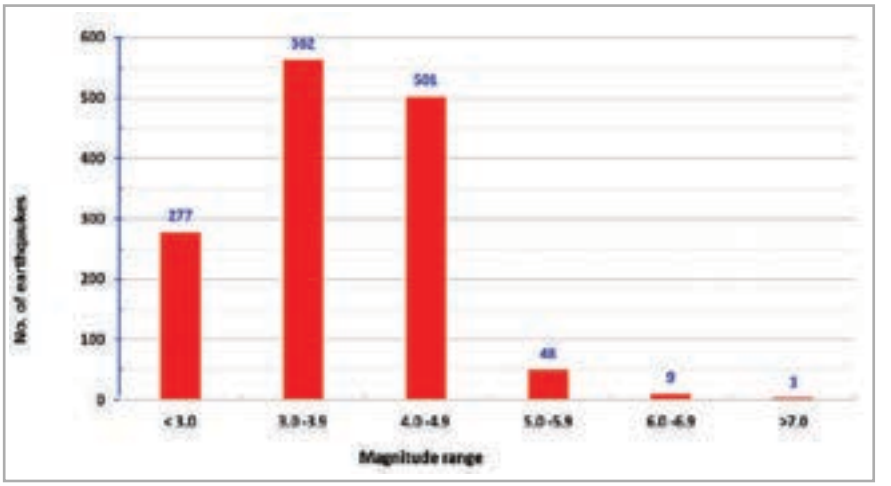

Figure 5.3 : Distribution of 1398 earthquakes occurred during 01st Jan – 31st December 2021 in different magnitude ranges in India and in its neighbourhood (0-40 ^{0}N and 60-100 ^{0}E).

5.1.1 Monitoring of Delhi National Capital Region (NCR) Earthquakes

Due to a spurt in the seismicity in the Delhi region during April-August 2020, it was decided to strengthen the seismological network at the local level and carry out a few specific studies for delineation/ characterization of major faults in the Delhi region. Accordingly, two surveys viz., Magnetotelluric (MT) and Active fault Mapping based on Geological studies, have been initiated by NCS. The MT survey is being conducted in collaboration with the Wadia Institute of Himalayan Geology (WIHG), while Active fault mapping has been initiated in collaboration with IIT, Kanpur.

Magneto-telluric (MT) is a geophysical method that uses natural time variation of the earth's magnetic and electric fields to understand the geological (underground) structure and processes. In the current year, the Magneto-telluric survey has been conducted across the Moradabad Fault and Great Boundary Fault (**Figure 5.4**) in the month of January-February 2021 in collaboration with the Wadia Institute of Himalayan Geology, Dehradun. A total of 18 sites were acquired. These sites are in addition to 34 sites acquired from October 2020 to December 2020 in the Delhi region. The data processing of all the sites is completed, modelling and interpretation of the MT data are in progress.

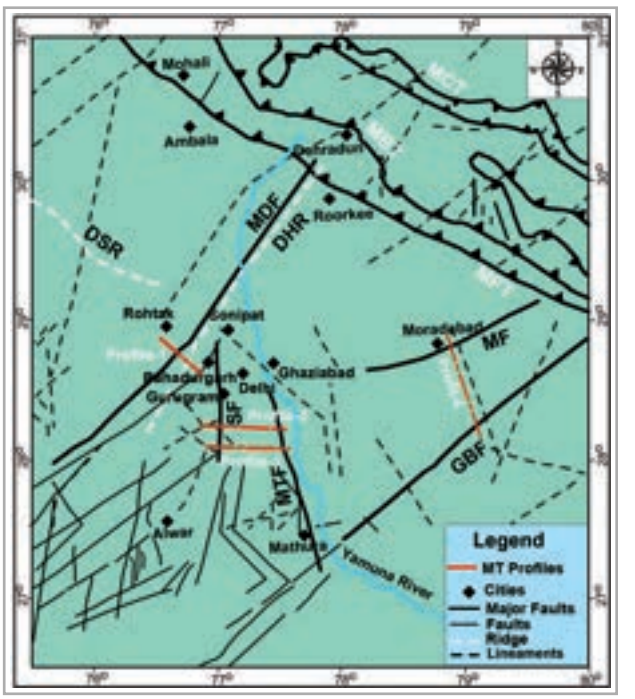

Figure 5.4: Tectonic map of the Delhi and surroundings (after GSI, 2000) overlapped with the acquired MT profile (shown with red colored line).

Magnetotelluric Investigation in the Rohtak and surroundings:

The Mahendragarh Dehradun (MDF) is a major NNE-SSW trending fault that links the Indian peninsular craton in the south to Himalayan Frontal Thrust (HFT) in the north. It is an active fault passing in the vicinity

of densely populated habitat (Rohtak (Haryana) in the west and Delhi in the east). MT data from 8 sites were acquired to delineate the MDF along a NW-SE profile (Profile-1, **Figure:5.5**) of ~50km length from Sunaria village in the NW to Mundhela village in the SE. From preliminary data modeling, it appears that the thickness of the Quarternary+Tertiary deposits is varying along the profile. Two resistive blocks R1 (below sites 1 to 5 (between villages Sunaria and Bhaproda)) and R2 (below sites 6 to 8 (between villages Mattan and Mundhela) with a resistivity of 150 to 1000 Ohm.m. have been observed. It appears that the Mehdragarh-Dehradun Fault (MDF) is a basement fault with a probable location in-between 'R1' and 'R2' and villages Bhaproda and Mattan (**Figure 5.5b**).

Figure 5.5 (a): Photographs of a typical MT site and field setup of MT equipment for data recording in the field.

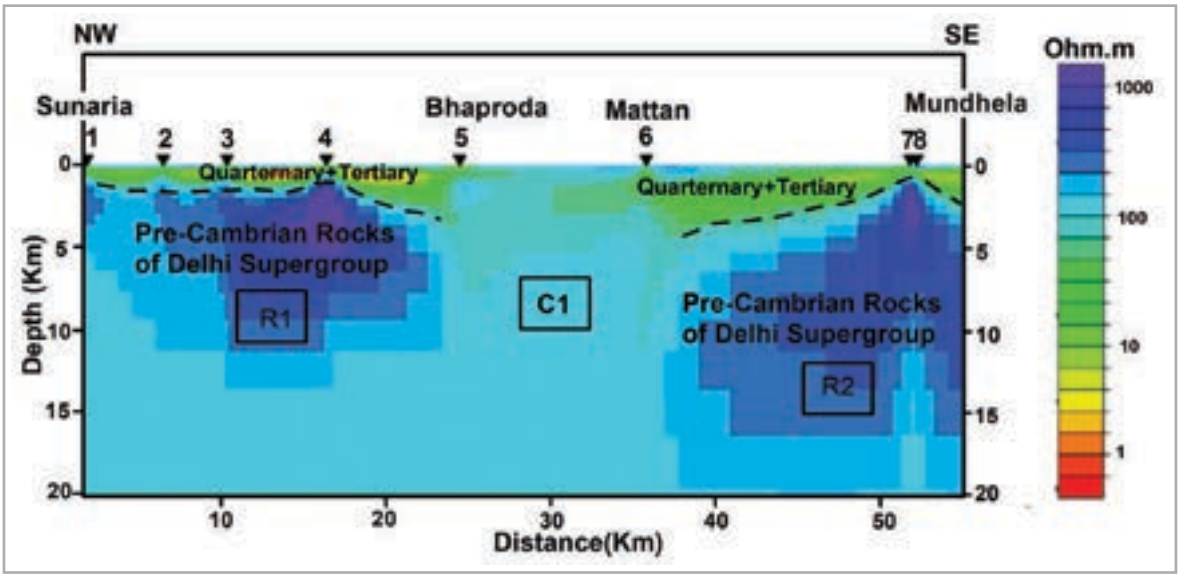

Figure 5.5 (b) : The resistivity depth section of Profile-1 acquired between Sunaria and Mundhela villages of Rohtak, Haryana.

Active Fault Mapping (AFM) involves satellite data interpretation, ground truth testing as well as the dating of sediments collected from suitable sites. The satellite data interpretations helped us towards the identification of prominent active tectonic features like linear valleys, sag-ponds, offset streams, vertically stacked meta-sedimentary beds, elongated ridges, fault scarps etc. Based on preliminary interpretations the potential sites were identified, and accordingly field visits were planned. Two field visits were conducted for ground-truthing in the months of January and February 2021. In the first phase of the study, the ground-truthing at Ghamroj Earth Dam (about 33 kms southwest of Delhi), Sector-56, Gurgaon, Khetri (Rajasthan), Asola Wildlife Sanctuary (Delhi), Rohtak (Haryana) were conducted. Another visit was undertaken along the trace of Sohna Fault south of Delhi mega fold around Kotla, Nuh and Firozpur Jhirka, Khanpur Japti Fault in NE Delhi and active tectonic features in Mundawar-Rewari (Haryana) and Baghpat and Khurrampur (Uttar Pradesh). After the initial analysis, the identified geological features at each site are summarized in Table 1.

Table 1 : The list of locations visited during fieldwork and identified features at these locations.

Sr. No.	Location	Active Fault Signature
1.	Ghamroj Earth Dam Anticline (about 33 kms southwest of Delhi)	A highly deformed/folded structure was observed, which is displaced by NE-SW and NW-SE striking conjugate fractures/faults.
2.	Liner valley south of Sector-56, Gurgaon	A prominent deeply incised linear valley trending N-S was identified south of Sector-56, Gurgaon. The western and eastern flanks of the valley demarcate distinct stream offsets with a right-lateral sense of movement
3.	Khetri, Rajasthan	A linear feature striking NNE-SSW was identified about 6 km southeast of Khetri, Rajasthan. Based on the fault topography marked by NW facing fault scarps and distinct sag-pond as well as shear zone, it is inferred as a trace of active fault and may represent the active portion of Mahendragarh-Dehradun Fault.
4.	Asola Wildlife Sanctuary ~8km northwest of Faridabad	A deeply incised linear valley was identified along the NWW-SSE striking fault. The fault trace is prominent on satellite data as well as in field.
5.	Rohtak, Haryana	An NNW-SSE trending topographic mound was identified on satellite data near Rohtak town. The observed feature falls west of the Mahendragarh-Dehradun Fault. Soil samples were collected to determine the age of the mound using the Optically Stimulated Luminescence (OSL) dating technique
6.	Kotla, Nuh and Firozpur Jhirka, Haryana	Satellite data interpretations suggested a prominent offset of streams displaced along a right-lateral fault system. It is inferred that the features identified probably mark the southern extension of the Sohna Fault.
7.	Yamuna Bank (Wazirabad) and Timarpur, Delhi	Distinct hairpin meanders along the Yamuna channel were observed near Wazirabad and Khanpur Japti (Jagatpur Khadar village). This combination of hair-pin meanders and straight channel may be attributed to ongoing active tectonic deformation influenced by a parallel sub-surface ridge traversing the west of the Kamla Nehru Ridge.
8.	Rewari (Haryana), Mundawar (Rajasthan) (03 sites)	A shear zone and west-facing fault scarp along the NNE-SSW striking fault was observed on satellite data at Mundawar
9.	Baghpat (Uttar Pradesh) and Baqipur (Haryana)	A sudden (sharp) change in channel course, as well as paired terraces, are observed near Baghpat town and Baqipur Village.

5. 1. 2 Seismic Microzonation of selected cities

Microzonation is a site-specific study that provides a more realistic and reliable representation of ground motion characteristics. Seismic Microzonation involves various components related to Seismo-Geophysical, Geotechnical (In-situ and Laboratory), Geological, Seismological and other several parameters integrated at one platform in form of comprehensive maps. The related description for the Seismic Microzonation is given in **Figure 5.5**. Microzonation and earthquake hazard assessment related studies are being undertaken in seismically vulnerable areas falling in Zone III, IV, V of Seismic Hazard Zonation in the country with population of half a million or more in a phased manner. The seismic microzonation work of four cities, Bhubaneswar, Chennai, Coimbatore and Mangalore, is at advanced stage of completion and work related to eight more cities (Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad) has been started and various Geophysical & Geotechnical surveys are in progress.

Peak Frequency and Peak Amplification Maps (**Figure 5.6**) have been prepared for various cities under investigations, a similar map has been shown below for the City of Coimbatore (**Figure 5.7**), and its report will be published by March 2022.

5. 2. Scientific Deep Drilling in the Koyna Intraplate Seismic Zone, Maharashtra

5.2.1 Evidence of deep-water percolation in the Koyna Seismogenic Zone

A number of damage zones have been delineated between 2 and 3 km in the Koyna pilot borehole based on the physical and mechanical properties of the rock formations. In such zones, P-wave velocity (V^P) and S-wave velocity (V^S) show up to 20% and 39% reduction respectively relative to the adjacent intact zones. V^P/V^S ratio across most of these zones is ~2.0 when compared with the intact host rock (~1.7). High porosity (~10 % to >25%) across the damage zones, along with high V^P/V^S and Poisson's ratio (up to 0.4) imply the presence of water-bearing fractures and/or altered rocks containing hydrous minerals such as clay

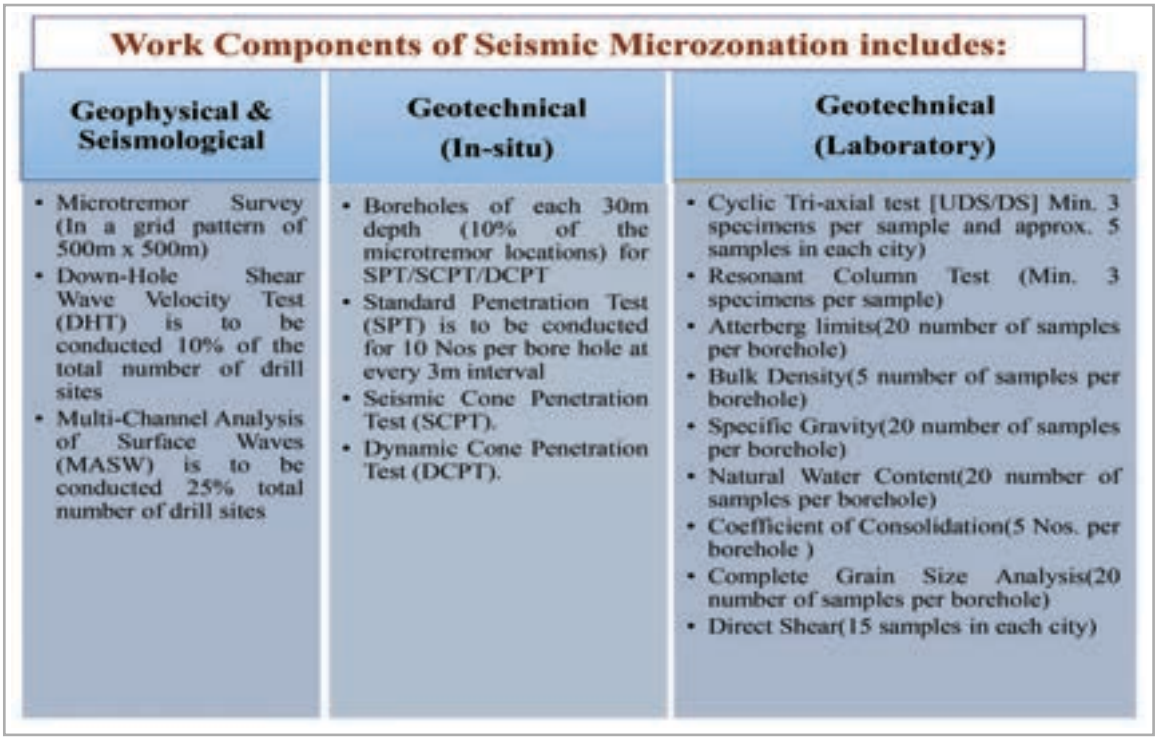

Figure 5.6: Description for the Seismic Microzonation and its various components

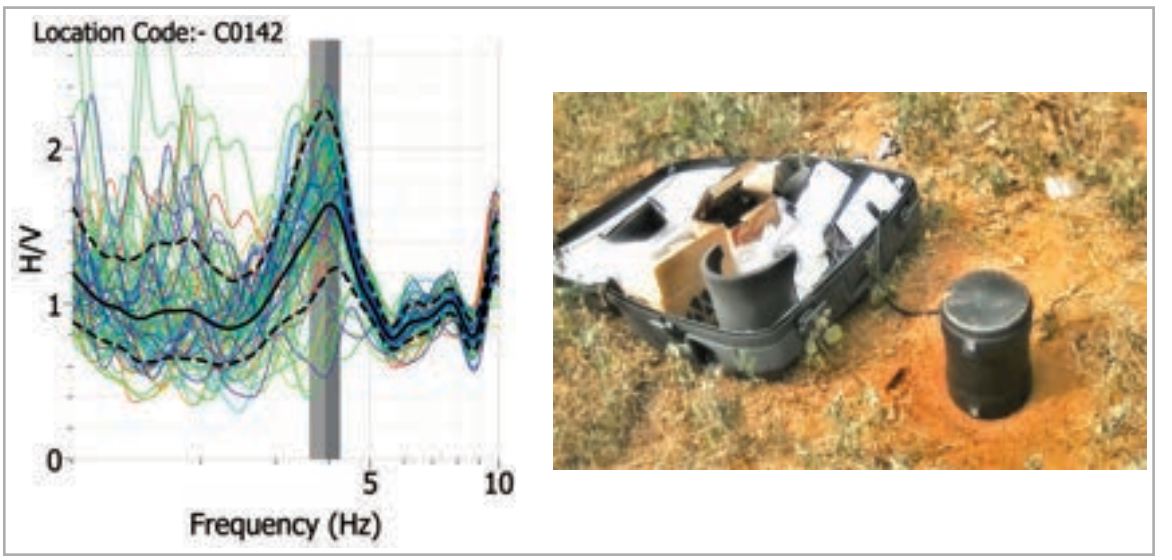

Figure 5.7 : An example for H/V curve and its corresponding field setup.

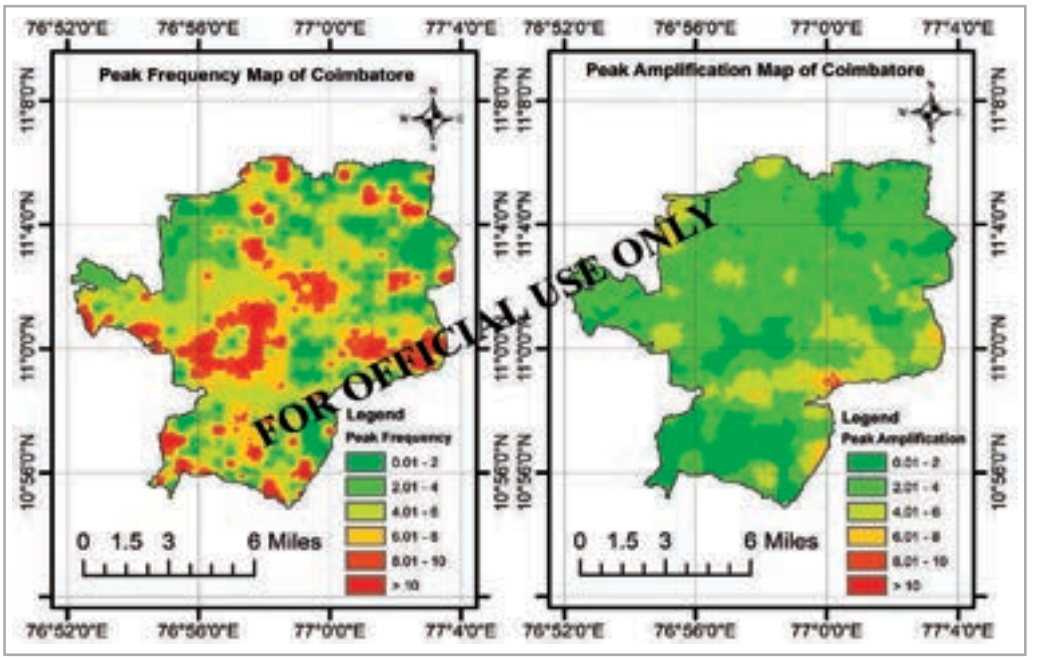

Figure 5.8: Peak Frequency and Peak Amplification Maps for Coimbatore city.

and support water percolation to deeper levels (Fig. 5.8). Thus, besides pore pressure diffusion, the study has opened up two other mechanisms for recurrent triggered seismicity: (i) direct fluid pressure imparted by the percolating water in a relatively impermeable principal slip zone, and (ii) reduction in fault frictional strength due to lubricating action of water if fault gouge is highly permeable.

5.2.2 Donichawadi fault: a potential target for further deep probing

Integration of the datasets from geological, geophysical, geochemical and seismological studies provides clinching evidence that the Donichawadi fissure zone is the surface manifestation of a deeper crustal fault that has been active for more than 55

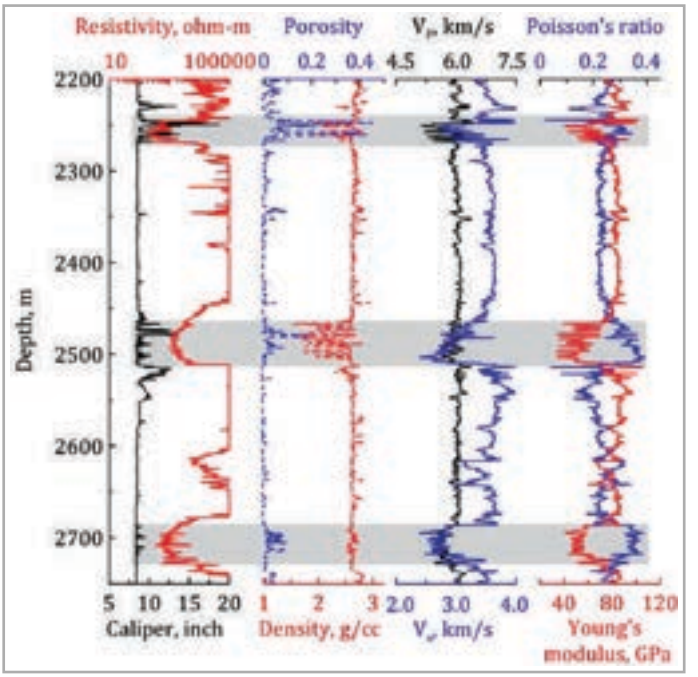

Fig. 5.9 : Geophysical well logs in the section 2200-2750 m showing three damage zones (shaded grey) characterized by low resistivity, high porosity and high Poisson's ratio.

years. The studies yield new insights on the subsurface disposition of the fissures and associated fractures in the subsurface. Hence, deep probing of the Donichawadi fault zone through scientific drilling, downhole measurements, and long-term monitoring may provide valuable information to constrain the genesis of triggered earthquakes in the Koyna region.

5.3 Geological and Geophysical studies:

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

Deep sea drilling and coring through the International Ocean Discovery Program (IODP) provides long sediment and rock cores that help us decipher history of past tectonic and climatic changes. IODP-India at NCPOR, Goa under MoES acts as the nodal agency responsible for coordinating all Indian scientific activities pertaining to this program. Amid COVID-19 pandemic, IODP consortium managed to complete a few scientific drilling expeditions with limited participation. Due to travel restrictions, Indian scientists participated virtually in IODP-386 (Japan Trench), IODP-395 (Reykjanes Mantle Convection and Climate) and IODP-396 (Mid-Norwegian Continental Margin) expeditions however, they would get their requested samples for further research.

5.3.1.1 History of long term sedimentation in the eastern Arabian Sea

The deep sea drilling expeditions in the Bay of Bengal and the Arabian Sea in recent years (includes 5 scientific expeditions) helped unravel vital links between the Himalayan orogeny and long term Asian monsoon variability. It also enabled better understanding of the nature of the oceanic crust along Indian margins and history of long term sedimentation.

NCPOR scientists continued further research using information obtained from scientific drilling in the Arabian Sea (IODP-355), to construct long term stratigraphic records of deposition since its inception. Sediments offer important insights about past climate and post-depositional tectonics. Delineation of major seismic facies and subsurface structural variations were completed using lithological knowledge from drilling and detailed interpretation of extensive multi-

channel seismic (MCS) reflection profiles (acquired by NCPOR, Goa). Detailed isopach maps in the Laxmi basin of Arabian Sea were prepared and published (Figure 5.9). New results would be extremely significant for understanding past depositional environments along a tectonically evolving margin.

5.3.1.2 Climatic and Tectonic Control on the Bengal Fan Sedimentation since the Pliocene

Detailed geochemical and mineralogical analyses of cored samples from IODP expedition-353 in the Mahanadi basin of Bay of Bengal threw light on sediment provenance and temporal variability of the lithogenic fractions over the last 6 Ma. The researchers (Peketi et al., 2021) showed the marked influence of glacial-interglacials on the relative sediment contribution by Ganga and Brahmaputra rivers during 0–1.8 Ma, while the sedimentation during the 1.8–6 Ma time window was likely influenced by both climatic and tectonic forcings such as uplift of the Shillong plateau, eastern syntaxis development of Indo-Burma wedge, reorganization of Brahmaputra river system. Their findings also show multiple isotopic fluctuations linked to climatic and tectonic forcings. This study inferred dominant control of Ganga-Brahmaputra discharge along deep waters adjoining Indian coast.

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

The 'Geoid' refers to the mathematically computed gravitational potential surface that approximates to the mean sea level. It varies considerably across the globe due to the uneven subsurface mass distribution. Therefore geoid undulations can provide useful information about physical properties of Earth's interior. The most prominent geoid low in the world is observed in the Indian Ocean with a deficit of -106 metre, known as the Indian Ocean Geoid Low (IOGL). Interestingly, this region also experiences one of the

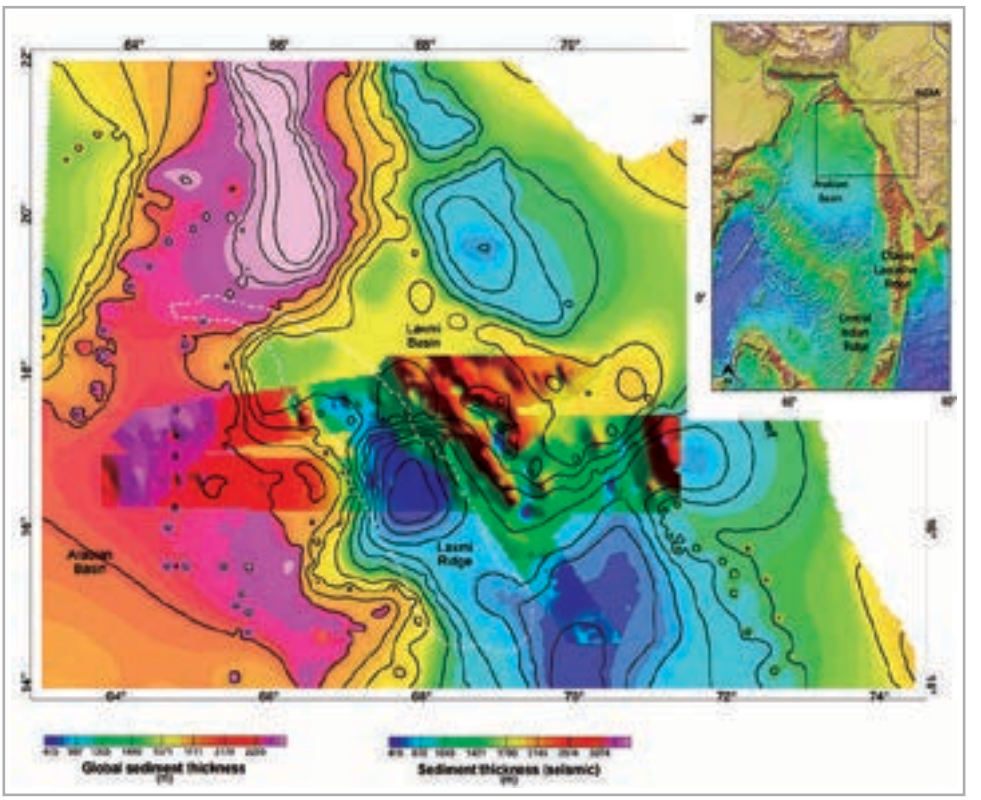

Figure 5.10 : Significantly enhanced map of sediment thickness in the Laxmi Basin of the eastern Arabian Sea (Nair et al., 2021). The inset figure shows its location.

most enigmatic intra-plate crustal deformation. NCPOR under the aegis of MoES has initiated an extensive marine geophysical experiment (active and passive OBS arrays) to image deep subsurface structures and their relationship with an enigmatic geoid low and intra-plate deformation.

5.3.2.1 The Central Indian Ocean Basin: A place to examine plume-ridge interaction in the past

The Indian sub-continent and its adjoining ocean basins have experienced wide range of tectonic activities since their inception, which are evident from morpho-tectonic elements present in the Indian Ocean. The modeling and interpretation of ~420-km long wide-angle seismic profile in the Central Indian Ocean Basin (CIOB), south of Comorin Ridge (CR), which lies in close proximity to the central part of IOGL, reveals early genesis of the CIOB. It also indicates that the southern part of the CR is underlain by anomalously thick (~14 km) and underplated oceanic crust by way of close interactions between spreading ridge and coeval Marion plume around 88 Ma (Fig. 5.10 & 5.11).

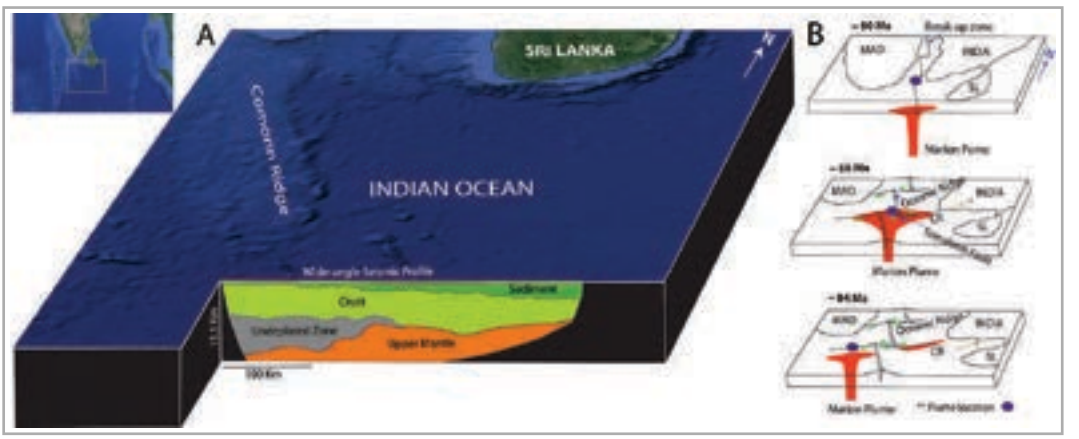

Figure 5.11: (A) Location of the wide-angle seismic profile and the resulted sub-surface structure (Ningthoujam et al., 2021). (B) A schematic diagram shows emplacement mechanism of the CR.

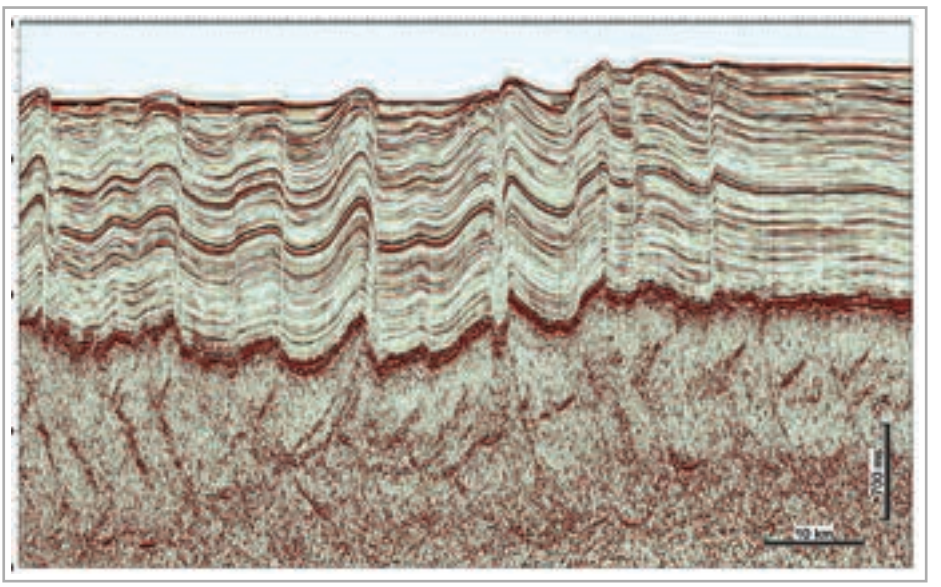

Figure 5.12: A snapshot of extensive crustal deformation in the CIOB inferred from the seismic reflection data acquired by NCPOR (Pandey et al., 2021).

5.3.2.2 Upper Mantle Structure in IOGL Region

The surface wave analysis of the teleseismic data from IOGL OBS array suggests a considerably thin lithosphere beneath IOGL region. This could be attributed to plume-lithosphere interactions in the past. The lithospheric thickness appears ~55 km and the lithosphere-asthenosphere boundary (LAB) appeared at ~75 km depth with a thickness of ~ 25 km. It is followed by a broader low velocity zone (LVZ) of ~ 125 km thick which could be explained by the presence of a low velocity anomaly in the uppermost mantle beneath the IOGL region (Kumar et al., 2021; Fig. 5.12).

5.3.2.3 Mantle plume upwelling beneath IOGL

Receiver function of teleseismic data from the IOGL OBS array confirms an extensive (~800 km wide) depression at mantle discontinuities corresponding to 410 km and 660 km depths (Fig 5.13). These new findings suggest that a garnet dominant hot mid-mantle prevails towards the centre of IOGL. Good correlation with global tomographic models, our results indicates possibility of a hot mantle plume residing at the upper boundary of the lower mantle with high probability of its extension to the upper mantle (Fig. 5.13). The buoyancy for mantle upwelling provided by this extremely hot mantle plume source with a probable pyrolytic composition could result in lowering the bulk density of the ambient mantle to eventually produce such large-scale negative geoid anomalies.

5.3.3 Gravity inversion for heterogeneous sedimentary basin with b-spline polynomial approximation using differential evolution algorithm.

NCESS developed a MATLAB-based inversion program, b-spline polynomial approximation using the differential evolution algorithm (SPODEA), to recover the concealed basement geometry under heterogeneous sedimentary basins. Earlier inversion techniques used the discretized subsurface interface topography into a grid of juxtaposed elementary prisms to estimate the basement depth of a basin. Such discretization leads to the failure of the depth profile continuity and requires a higher number of inversion parameters for achieving the desired accuracy. The novel approach of SPODEA overcomes such limitations of earlier inversion techniques. SPODEA is based on the segment-wise b-spline optimization technique to estimate the basement depth by using high-order polynomials. Moreover, it can achieve an optimal misfit with minimal parametric information, which reduces the computational

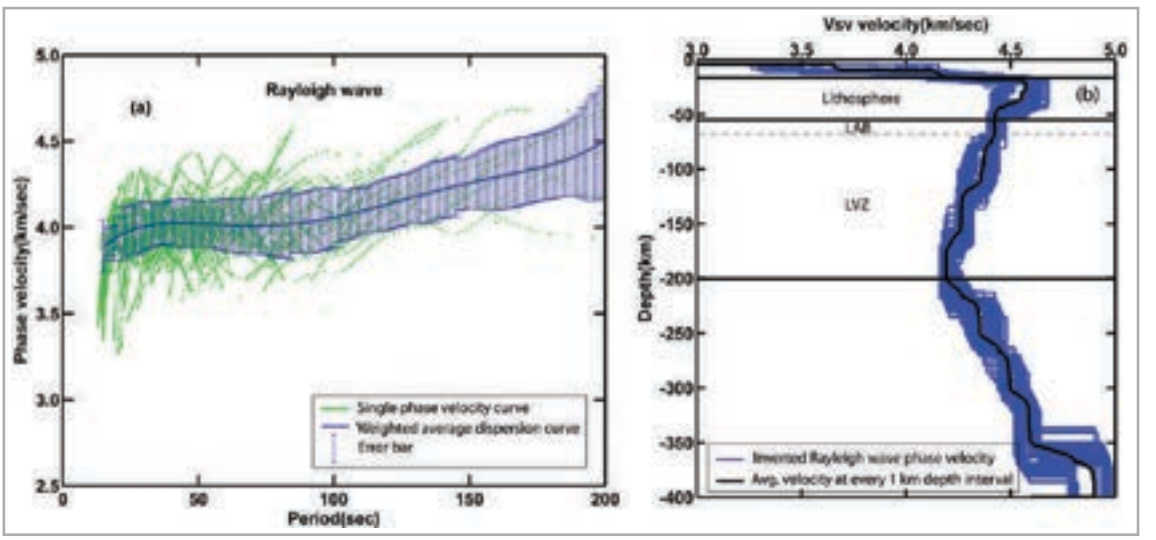

Figure 5.13: (a) Estimated average phase velocity (b) Inversion of Rayleigh wave phase velocity (Kumar et al., 2021).

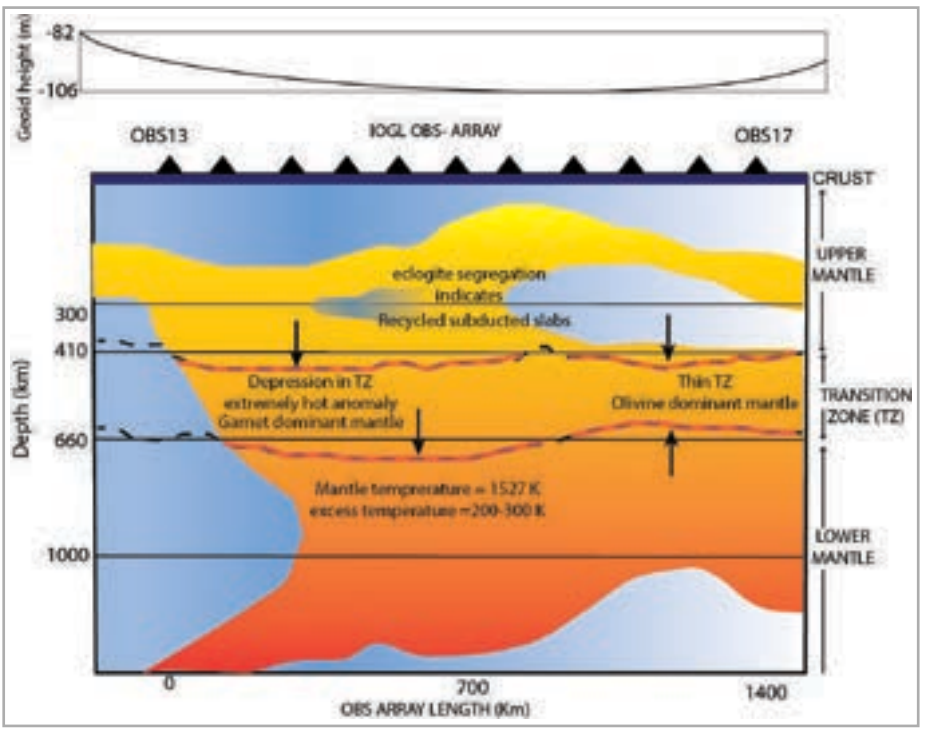

Figure 5.14. : Schematic model of the mantle structures beneath the IOGL region depicting the results from the present study (Negi et al., 2021).

expense. The inversion approach uses the differential evolution algorithm, which provides real parametric optimization and uses b-splines for accurate estimation of continuous depth profiles. The efficiency of the algorithm was determined with two complex synthetic sedimentary basin models comprised of constant and depth-varying density distributions. Furthermore, the uncertainty analysis of the inversion technique is evaluated by incorporating white Gaussian noise into the synthetic models. Finally, the utility of SPODEA is evaluated by inverting gravity anomalies for two different real sedimentary basins. It produces geologically reasonable outcomes that are in close agreement with basement structures from previously reported results (Fig.5.14).

5.3.4 Gravity inversion of 2D fault having variable density contrast using particle swarm optimization

A Matlab-based optimization algorithm is introduced for inverting fault structures from observed gravity anomalies. A convenient graphical user interface is also presented for incorporating the input parameters without any technical complexity to any users (Fig. 5.15). The inversion code uses particle swarm optimization, and all control parameters are tuned initially for faster convergence. There is no requirement of prior choice of an initial model, that is the advantage of using global optimization. The optimization technique is versatile enough to handle any depth-varying density distributions. The maximum number of iterations and stopping criterion is fixed initially for getting the best optimized solution. The inverted model's output in terms of fault structure, observed and inverted gravity anomalies and dip, and vertex location of fault plane can be viewed in the graphical user interface at the end of the optimization process. The optimization algorithm is applied to different synthetic models with fixed and depth-varying density contrasts. All synthetic models are further contaminated with white Gaussian noise for sensitivity analysis, and detailed uncertainty appraisal was also performed for the reliability estimation. Finally, the optimization is implemented

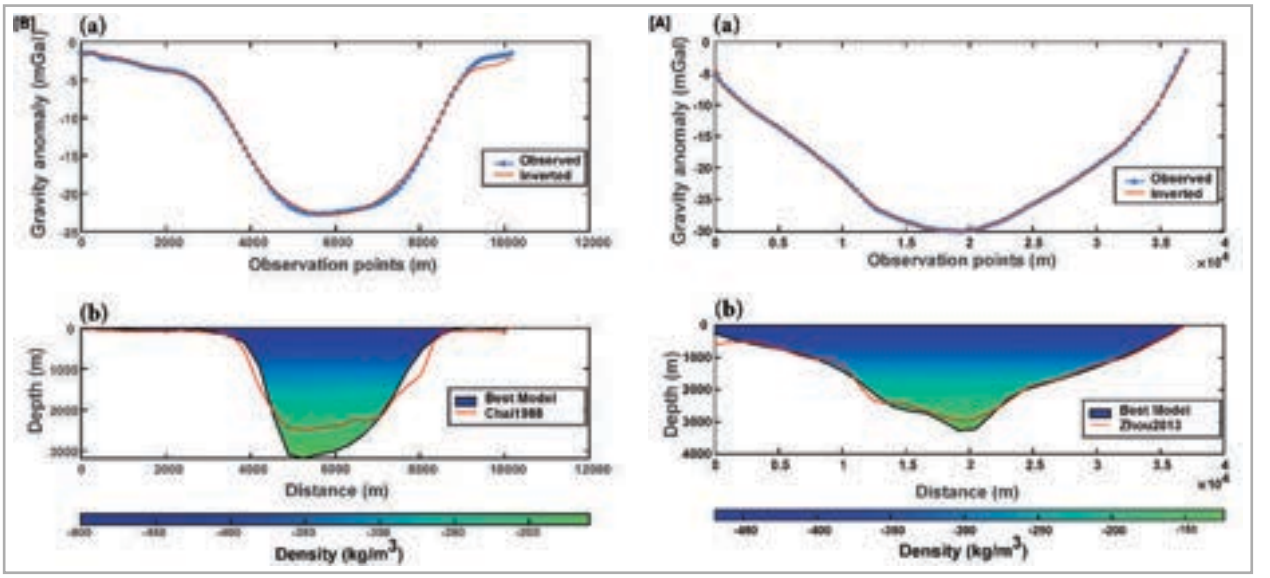

Fig. 5.15 : Estimated basement depth profile from the (A) Godavari Basin, India, (B) San Jacinto graben, California, USA. The blue dotted curve in (a) represents the observed gravity anomaly, and the solid red line shows the inverted gravity anomaly. The solid red line in (b) represents the inverted depth profile from Zhou (2013), and the filled region represents the inverted sedimentary basin using SPODEA.

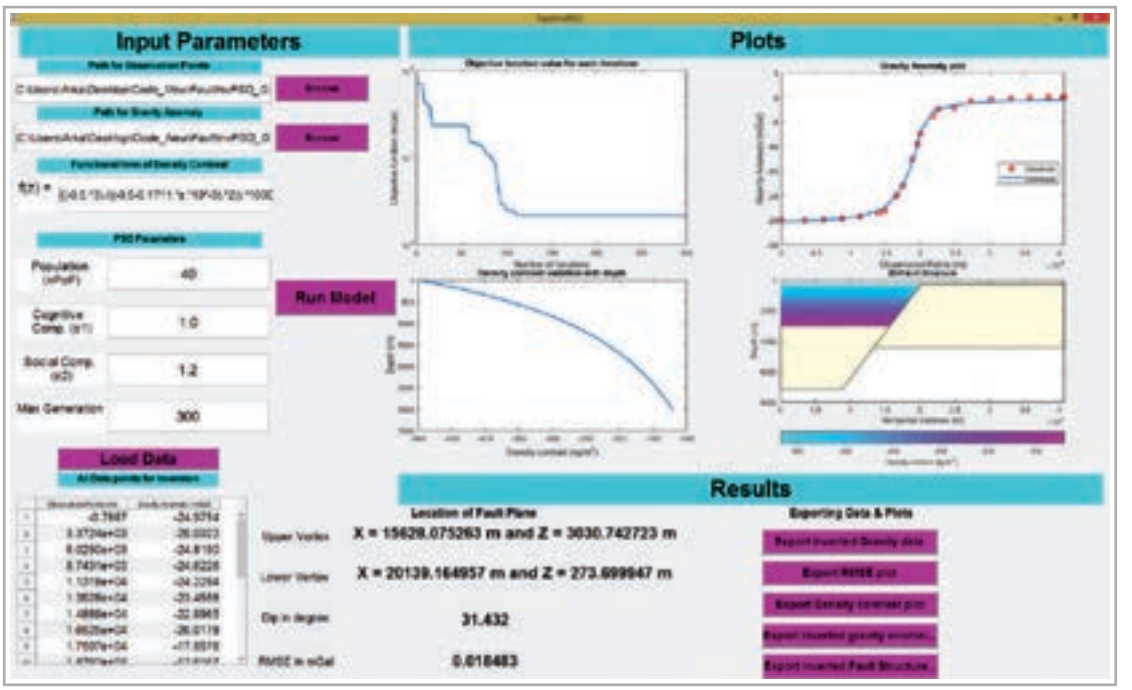

Fig. 5.16: Overview of FaultInvPSO graphical user interface for inverting Aswaraopet Boundary Fault, India.

for fault structure inversion of the Aswaraopet boundary fault, India, and found that the optimized solution provides a good agreement with the previously published literature. Optimized results indicate that this novel optimization approach demonstrates a robust implementation of fault inversion for any depth-varying density distributions (Fig. 5.15).

5.3.5 Crustal and mantle structures and geodynamic model for Western Ghats

The Western Ghats (WG), with an average elevation of ~1.2 km, is one of the greatest escarpments that spans ~1500 km parallel to the west coast of India. It is a mosaic of disparate geological formations having distinct structural and physical characteristics. In this study, the lithospheric structure and deformation along and across the WG are investigated using receiver functions (RFs) at 30 broadband seismological stations. Techniques like slant-stacking, common conversion point imaging and harmonic decomposition are applied to the RFs. Results reveal a large crustal thickness of ~45 km in the central part of the WG, which decreases to ~39 km in the southern and ~37 km in the northern parts, in conformity with the geology. This variation could be due to the effect of the hotspot impingement and subsequent rifting mechanism. Moreover, a clear step in the Moho is observed across the WG, with the depths changing from ~39 km to ~44 km. This marks a distinct transition from the Granulites to the Peninsular Gneisses. Further, the RFs reveal a strong sub-Moho low velocity layer (LVL) along the WG. This observation gains support from a previous inference of a low-density zone in the uppermost mantle beneath the west coast of India. Harmonic decomposition of the RFs reveals that this LVL is anisotropic, while the Moho is dipping. The trend of the symmetry axis of anisotropy varies from 58.2° to 134.4°, almost perpendicular to the west coast of India. We postulate that the origin of this LVL can be linked to different rifting episodes along the west coast of India since LVLs are manifestations of thermal/chemical anomalies.

Further, NCESS measured the upper mantle anisotropy using shear wave splitting analysis of SK(K)S and PK(K)S waveforms recorded at 17 broadband seismological stations located along and in the vicinity of the WG. Results indicate that the fast axis polarization directions are primarily in the NE-SW direction, with delay times varying from 0.3 s to 1.8 s. This direction is parallel to the Absolute Plate Motion of the Indian sub-continent, suggesting that shear at the base of the lithosphere is the dominant mechanism for anisotropy along the WG. E-W oriented anisotropy at stations close to the west coast, especially in the northern part of the WG can be associated with lithospheric stretching along the west coast, associated with the rifting process. Further, the coast-parallel fast axis polarization directions (N-S, NNW-SSE), with delay times varying from 0.6 s to 1.2 s, at stations away from the coast, could be due to the edge flow associated with transition from a thinner to a thicker lithosphere. In addition, we model the variation in splitting parameters at station in the Southern Granulite Terran in terms of two-layer anisotropy, with an E-W orientation in the upper layer and a NE-SW one in the lower layer. The variable fast axis polarization directions from coast perpendicular to coast parallel at stations close and away from the west coast of the Indian sub-continent imply different rifting episodes. These results support the rifting model proposed for the evolution of WG.

5.3.6 Palaeofluids in the Petroliferous Basins of Western Offshore, India

NCESS developed a special wafer preparation technique for the first time in India to visualize hydrocarbon fluid inclusions (HCFIs) without background interference. Also, developed a technique to determine the American Petroleum Institute's (API) gravity- a quality parameter for the pricing of oil present in micron sized HCFIs. Identified the hydrocarbon species in HCFIs using Raman shifts and a 785 nm diode laser and it was the first of its kind effort internationally. Detected oil in the two declared dry wells in the Indian western offshore basins (Mumbai offshore and Kerala-Konkan) using the fluid inclusion technique developed at NCESS. Established the potential of fluid inclusion technique to determine the paleo temperature and hydrocarbon quality of oils in petroliferous basins.

5.3.7 Groundwater chemistry in the Attappadi CZO, southern Western Ghats

Mountainous catchments are one of the world's important water sources that sustains a major portion of global population and a rich biodiversity. The

groundwater quantity and quality of mountainous watersheds depend generally on the geologic characteristics and climate gradients. Although many studies have been carried out in the midlands and lowlands of many river basins, not enough focus has been paid to the groundwater characteristics of mountainous catchments of tropical watersheds. Therefore, a study has been undertaken to address the spatiotemporal variability and controlling factors of groundwater characteristics of the mountainous catchments of the Attappadi Critical Zone Observatory (CZO) – which is a part of the TERRAIn (Tropical Ecosystem Research ObservatoRies in PeninsulAr India) network of Critical Zone observatories setup by NCESS. A total of 88 groundwater (open and borewell) samples were during pre-monsoon, monsoon and post-monsoon seasons for assessing various physico-chemical parameters and solute contents. The results of the study revealed that higher pH and Total Dissolved Solids (TDS) are noticed in the talc-tremolite dominated central zone whereas low values are recorded in the charnockite dominated areas. The major cations in the water samples are of the order $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and the anions are of the order $HCO^{3-} > Cl^{-} > SO^{42-}$. The content of Cl^{-}, shows higher values in areas close to agricultural/settlement areas (Fig. 5.16).

An overall evaluation shows that the hydrochemistry of groundwater in the study area is influenced by both silicate and carbonate weathering. Mineral stability indices computed for the groundwater reveal that

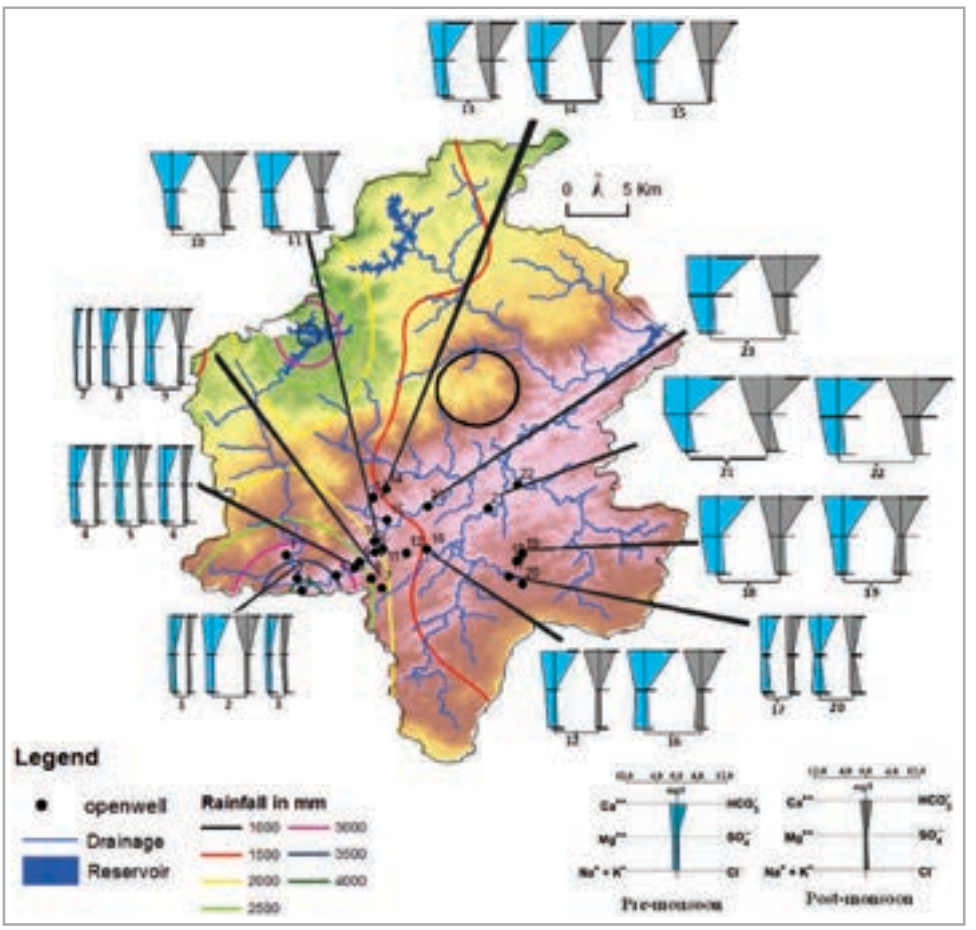

Fig. 5.17: Spatial variation of cations and anions in pre-monsoon and post-monsoon season in the open well samples of Attappadi CZO indicating the control of climatic gradient in the groundwater chemistry.

about 52% of the samples are supersaturated with carbonate minerals and often exhibit scaling due to solute overloading. Saturation Index and mineral stability diagram also support that the incongruent dissolution of aluminosilicate minerals (silicate weathering) is an important hydrochemical process controlling the chemistry of groundwater. Langelier saturation index (LSI) and Puckorius scaling index (PSI) show that a significant number of open well and borewell samples exhibit scaling tendency. Analysis of data using PCA and HCA indicated that the water quality variations are mainly due to geogenic/natural processes. However anthropogenic factors also had significant effect in the agricultural/settlement dominated areas. Among the contributing factors that determine water quality of groundwaters, chemical weathering and anthropogenic activities play a significant role. It was observed that, among the contributing factors that determine the hydrochemical characteristics of well water samples, both silicate and carbonate weathering and agricultural activities play a pivotal role in the input of ions to the groundwater in the area. Long-term monitoring of the hydrochemical characteristics of the groundwater in the region could unravel the source contribution and future trends in hydrochemical characteristics of the groundwater systems in intensely managed agricultural areas in arid and semi-arid regions.

5.3.8 Assessment of Global Environmental Changes in Sahyadri

The Isotopic signatures of moisture recycling and evaporation processes along the Western Ghats orography has been studied. This study highlights the varying nature of elevation and amount effect on the stable isotopes as a consequence of the re-evaporation processes especially in the coastal lowlands which in turn suggest the significance of establishing permanent spatially widespread monitoring stations across the Ghats. This would provide key insights into the orographic precipitation formation across the Western Ghats. Additionally, the relation between $\delta^{18}O$ and convective activities along the slopes of Western Ghats suggests the dominance of local processes along the highland station. The study is the first of its kind along the Western Ghats hotspot exploring the changes in elevation and amount effect across the PRB of Western Ghats. The tropical humid region of Western Ghats is known to have higher water vapor recycling rates thus inducing a significant amount of local moisture. This recycled moisture supplies about 25-40% of SWM rainfall to the drier Tamil Nadu State, situated along the rain shadow region of the Western Ghats. The study using the back trajectory approach has estimated the moisture recycling rate over the windward side to be a monthly maximum of 8.5% across the midlands of this mountain chain and the daily contribution reaching up to a maximum of 50.7%. Though the back trajectory analysis did not show any moisture recycling signs in the highlands, the d-excess (d-excess) and the depleted $\delta^{18}O$ in precipitation shows signatures of moisture recycling. The moisture uptakes (Fig. 5.17) recorded in the endpoints of highland back trajectories indicate the underestimation of moisture recycling using the approach, especially towards narrow mountain networks like the Western Ghats. The negative lc-excess (line-conditioned excess) of surface water bodies suggests the availability of evaporated moisture in the ambient air which could successively get recycled to form local precipitation.

5.3.9 Mid-late Holocene evolutionary history and climate reconstruction of Vellayani lake, south India

The Vellayani lake is the second largest freshwater lake in Kerala State in southwest India. A study carried out on a 10m long borehole core retrieved from the lake revealed that the lake had a marine connectivity before 2000 cal yr BP. High Sea Level with lagoonal conditions persisted during 64304390 cal yr BP followed by a gradual sea regression which led to formation of oxygen deficient conditions due to poor water ventilation during 43002600 cal yr BP. From 2600 to 440 cal yr BP the region was separated from the marine influence and transformed in to a

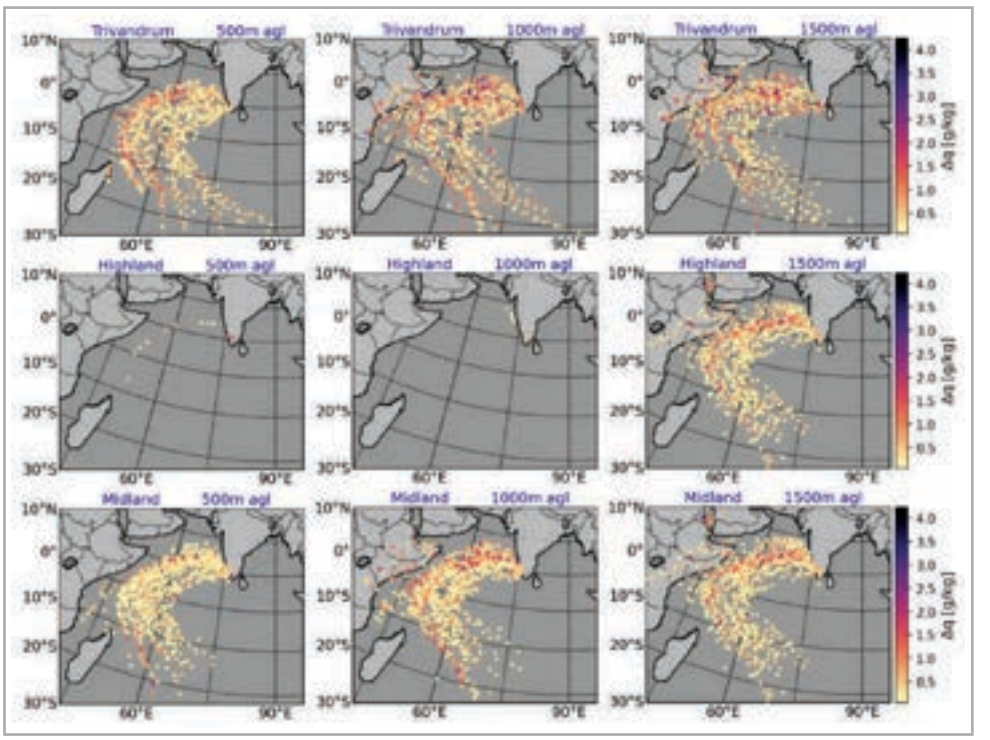

Fig. 5.18: Moisture uptake (Δq= +ve) locations along 168 hr back trajectory reaching the sampling stations at different levels (500, 1000 and 1500 m agl).

freshwater lake and the present configuration was attained during last 440 cal yr BP (Fig.5.18).

5.3.10 Export of particulate organic carbon by the mountainous tropical rivers of Western Ghats, India: Variations and controls

Global rivers transport biogeochemical fluxes from continents to the oceans realm and are connecting three large carbon pools of the planet viz. soil, atmosphere and ocean and affects the atmospheric carbon inventory over a broad range of timescales. Organic carbon (OC) transported by rivers act as one

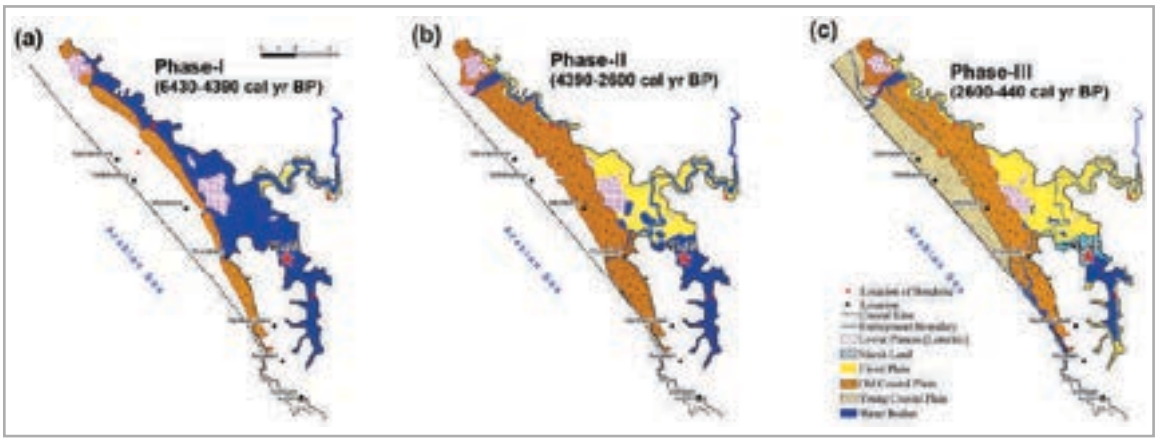

Fig. 5.19 : The schematic diagram showing the gradual sea regression since mid-Holocene period. Red star (★) depicts the core location VL-23 at Vellayani Lake.

of the primary food sources for the aquatic and marine organism and these inputs are essential for improving the scientific understanding of how terrestrial contributions influence biogeochemical cycles and food-webs in the coastal waters. Rivers transport OC both in dissolved (DOC), and particulate (POC) forms, collectively termed as total organic carbon (TOC). Most of the regional and global-scale empirical studies dealing with the POC transport face problem of the inadequate representation of data of rivers draining different climate zones and catchment sizes especially small mountainous rivers. Transport of organic carbon by small mountainous rivers is essential, but the poorly constrained component of the global carbon cycle. In the current context, an extensive seasonal sampling of 70 sizeable tropical coastal rivers, draining the Western Ghats (WG) of India was carried out to analyse the particulate organic carbon (POC) contents form these rivers. This study aimed to investigate the spatiotemporal variability in POC contents, to estimate flux and to identify environmental controls on POC sources and transport characteristics across the region. The results suggests that, WG region approximately covering 0.25% of Asia's land area exports 0.79 Tg of POC to Arabian sea and hence contributing to the 1% of Asia's riverine POC flux to the oceans. The averaged value of organic carbon (OC) in the particulate samples is 3.24%, and the mean POC concentration is 2.86 mg/L (Fig. 5.19).

For source appropriation samples were classified based on total suspended matter (TSM) and the C/N ratios of POC samples (Fig. 5.19). Among the total

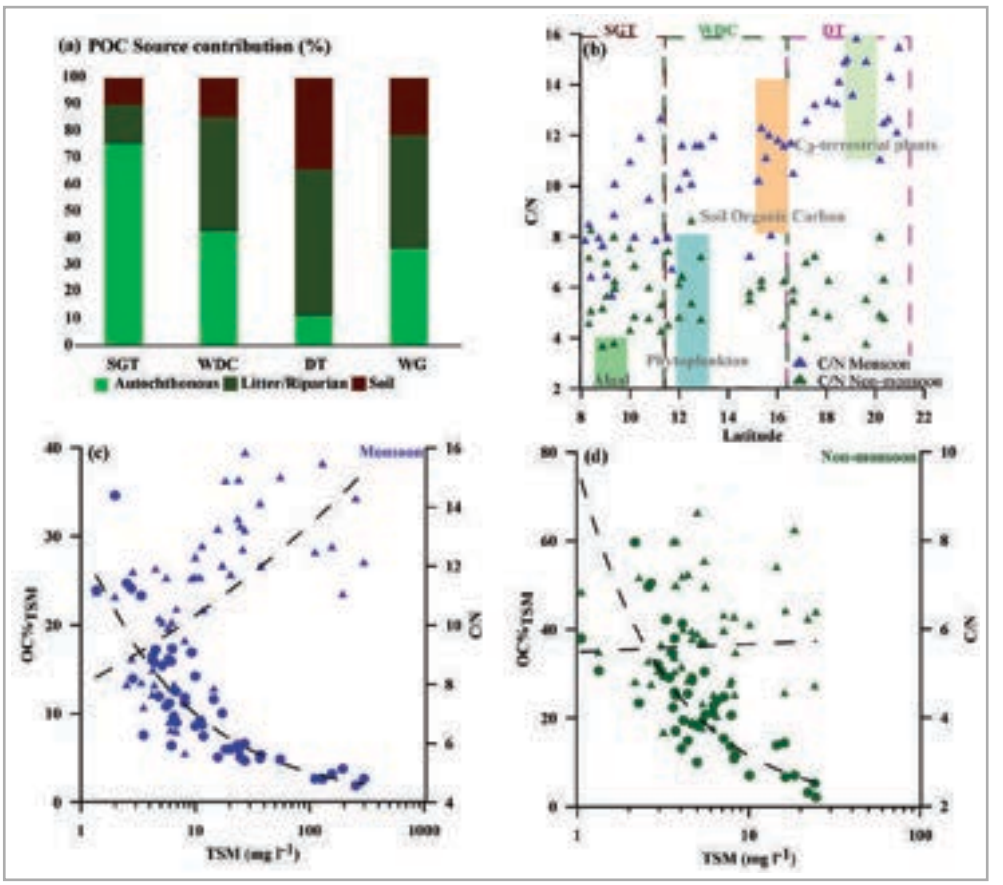

Fig. 5.20: (a) Relative distribution of source of POC pools for the SGT, WDC, DT blocks and the entire Western Ghats; Characterizing POC pools through C/N ratios, (b) distribution of C/N ratios of autochthonous to allochthonous pools; TSM vs OC%TSM and C/N plots for (c) monsoon and (d) non-monsoon seasons.

transports of POC, Litter/riparian (42.5%) pools are the largest source of organic matter, followed by autochthonous (36%) and soil (21.5%) for the WG region. However, locally autochthonous sources contribute exceptionally to POC pools, indicating a favorable environmental condition for the growth of algae and phytoplankton which is in contrast to historical studies reporting the contribution of the autochthonous sources for the global rivers to be between 8 and 28% of POC. Thus, current study highlights the dominance of primary production in the POC pool in coastal tropical environments. This study demonstrates the influence of various environmental parameters on the origin and supply of POC fluxes at catchment scales (hydrological, climatological, physical characteristics of catchment, land-use), in-stream processes (aquatic primary production, sediment deposition, and remobilization etc.). This study also highlights the need of comprehensive source to sink investigations to provide detailed descriptions of how riverine carbon dynamics affected by inputs, in-stream transformation, and deposition.

5.3.11 Unravelling of submarine ground water discharge (SGD) zones along the south west coast of India (Phase-I)

Under the Working Group-4 of this national network project, NCESS had estimated SGD flux from three coastal catchments of southwest coastal zone of India through aquifer modelling technique. There are nine critical zones with a total shore length of 106.5 km, out of 640km surveyed, in the SW coastal zone having SGD signatures. Average flux of groundwater per unit length of shoreline was calculated from 36 to 1213 m^3/y/m, wherever SGD occurs (Fig. 5.20). In other words, 4 to 6% of rainfall has been computed as leakage to sea as SGD in a year. The cliff sections composed of Tertiary sedimentary formation discharges (700 m^3/y/m) slightly lesser compared to

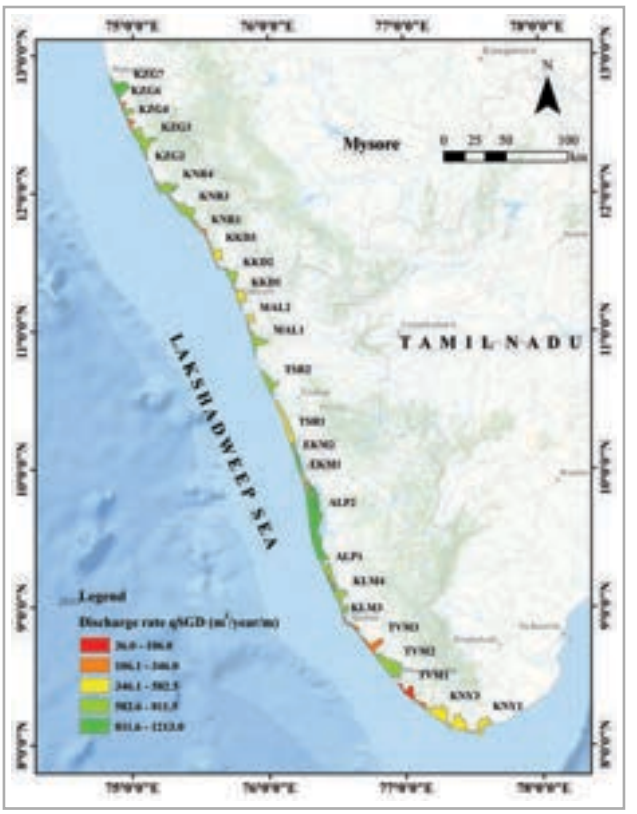

Fig. 5.21: Spatial map of estimated discharge rates in coastal catchments in SW coast

aquifers comprising coastal alluvium, weathered overburden and fractured country rocks (~900m^3/y/m). Neotectonism reportedly facilitated in generating conduits for SGD and also in maintaining higher hydraulic gradient of water table towards coastal zone.

5.3.12 Macrophysical features of tropical clouds and precipitation over heterogenous terrains

The study focuses on research in tropical clouds, rainfall and lightning using advanced instruments and numerical weather prediction models. A combined synthesis of ground and satellite-based observations make it possible to comprehend the macrophysical features of clouds vis-a-vis the associated precipitation microphysics. A study has been carried out on the precipitation mechanisms during pre- and post-monsoon seasons for the years 2017 and 2018 in two representative (1 tropical coastal and 2 high-altitude) locations on the windward side of southern Western Ghats. While, aggregated cloud layers contributed to the total precipitation at the coastal site, precipitation is evolved from the middle-level clouds contributed in the high-altitude location at Rajamallay (~1800 m above msl). Furthermore, single cloud layers contribute more than 50% of the precipitation at Rajamallay. Presence of large ice crystals and bigger cloud drops (high CER values and giant CCN by sea salt aerosols) intensify the rimming efficiency leading to the generation of higher cloud ice or graupel. While passing through the melting layer, these mixed-phase hydrometeors grow and resulted in larger Dm values at the surface pointing to the presence of deep convective clouds. In addition, the annual lightning activity in south India is increasing in recent years. A spike in lightning activity just before an active monsoon spell is identified in central India. The study indicates that observations on lightning and their analysis will be useful to predict the upcoming active monsoon that witnesses the region (Fig. 5.21).

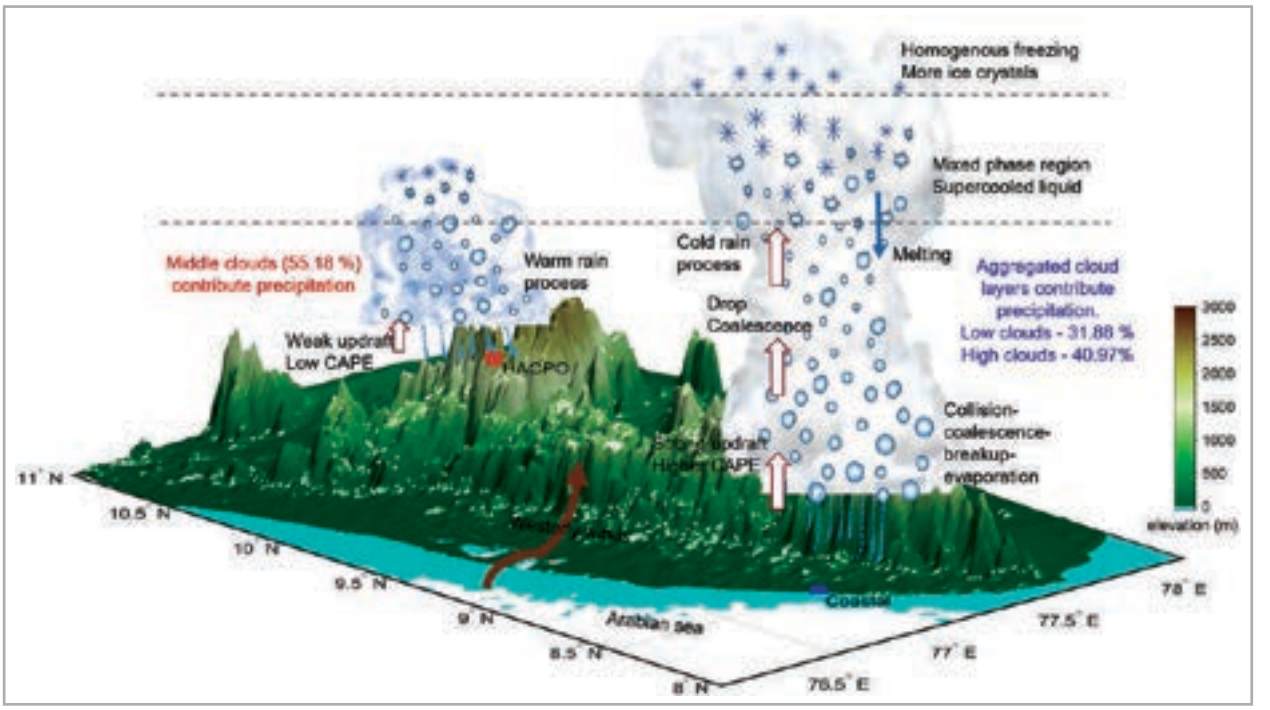

Fig. 5.22: Schematic diagram that represents the major difference in the characteristics of clouds formed over a coastal and high-altitude terrain on the windward side of Western Ghats.

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 (atmosphere, hydrosphere, geosphere, cryosphere and biosphere) as well as interactions between them and their response to the natural and human induced changes through various R&D programs. This 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. Knowledge Resource Centre Network (KRCNET)

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

6.1 RESEARCH & DEVELOPMENT IN EARTH SYSTEM SCIENCES (RDESS):

Proposals from various academic/research organizations and universities in the different fields of Earth system Science are supported with an intention that it would help in improving our understanding of the earth system. Activities which are supported include focused research in areas of national importance; Building indigenous development, Human resource development through opening of Centers of excellence, initiation of academic programmes, establishment of MoES Chairs; Setting up of specialized labs as national facilities; National and international collaboration, National coordinated projects and setting-up of Earth Science & Technology Cells (ESTCs). During the current financial year, a total number of 27 proposals have been sanctioned as shown in the table below:

Number of proposals funded during 2021-22	Atmospheric Science	Ocean Sciences	Geosciences	Seismology	Cryosphere and Hydrology
	8	5	7	6	1

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

6.1.1 Atmospheric Sciences including Climate Change

Three projects have been completed under Atmospheric Sciences The achievements under each of them are described below:

1. "**Improvement in heavy rainfall prediction over Eastern sector of India using high resolution mesoscale analysis and modeling system**" by NIT Rourkela.

The project mainly deals with the efforts to improve the mesoscale simulation of heavy rainfall activity during monsoon season. The study has contributed in improving the short-range forecast of monsoon

rainfall activity. Atmospheric data assimilation of satellite products over India reveals two important facts that Polar satellite radiances data is particularly useful to improve the analyses of 00 and 12 UTC and INSAT-based temperature and moisture profiles are better at 06 UTC analysis cycle than the 00 and 12 UTC cycles.

The outcomes and deliverables are useful to customize the operational mesoscale model at India Meteorological Department for monsoonal heavy rainfall predictions. Seven publications have been obtained during the project.

2. The project "**Investigating aerosol-cloud forced climate change over India: A multi-satellite approach"** was completed by Savitri Bai Phule University Pune.

A detailed study of the different types of aerosols derived from Cloud Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) has been carried out over the Indian region. A key finding is the identification of the presence of broad distribution of various aerosol types over India from surface to 5 km altitude during pre-monsoon and monsoon seasons.

3. The project **"Monitoring Indoor Air Pollution in Delhi University Area and Accessing its Health Impacts**" is completed by University of Delhi.

This project on Indoor air pollution generated detailed primary data base in diverse residential configuration within Delhi University campus. The generated database on indoor environment has been taken stock of the perils that how mankind has created health challenges in the form of Indoor air pollution. Simultaneous monitoring of indoor and outdoor air at household level using sensitive monitors brought out more clear understanding of the dynamics of indoor air pollution and its impact on the state of respiratory pathology.

Three publications, one chapter in book and a monograph are the major outcome of the work. Two Ph.D and three M.Tech students have been trained in the project and nine workshops have been conducted during the work.

6.1.2 Geosciences

Title of the project: Palynoflora, reptilian tetrapods and clay minerals of sediments associated with Deccan Continental Flood Basalts of the Malwa Group, Dhar District, Madhya Pradesh: A biotic response to climatic changes by RTM Nagpur University- Completed

The main aim of this multidisciplinary project was aimed to track biotic and climatic changes associated with Deccan volcanic eruptions during Late Cretaceous-Early Palaeocene and its link to global mass extinction at the Cretaceous-Palaeogene (K-Pg) boundary. The studies suggest that terrestrial ecosystem of the Indian subcontinent was affected with the advent of Deccan volcanic eruptions in C30N and biotic changes preceded the K-Pg boundary. These observations are not in conformity with the pattern of extinction recorded at K-Pg boundary in terrestrial sections of Western Interior of North American where floral and faunal changes are observed close to the boundary.

Variation of paleostress and kinematics in the schist belts and granitoids of East and West Dharwar craton: implications for gold mineralization by IIT Kharagpur- Ongoing

The Dharwar craton in southern India is a well-known gold province where gold mineralization in all the areas is dominantly in quartz veins that intrude the Precambrian rocks of the region (metavolcanic and metasedimentary rocks). It is however, a mystery that whilst some veins are mineralized, others are not. This project addresses the fundamental question that **what controls concentration of gold in certain parts of the Dharwar craton, while other parts are left relatively barren.**

India's first triple ion beam milling system for Broad Ion Beam (BIB) polishing has been set-up through this project in IIT Kharagpur.

6.1.3 Hydrology & Cryosphere:

Project Title: Advanced Research in Hydrology and Knowledge Dissemination by IISc Bangalore- Ongoing.

A SWAT (Soil Water Assessment Tool) and HEC-HMS (Hydrological Engineering Centre – Hydrologic Modeling System) models to simulate daily streamflow for the Brahmaputra river has been developed to assess changes in streamflow due to perturbations in the forcing (precipitation) for both models. This accounts for the inherent uncertainty in the observed rainfall, be it from ground-based IMD gauge network or from remote sensing (e.g., TRMM). The SWAT Model has default parameters which control the partitioning of the incoming quantum of water into surface water and subsurface water and how the accumulated water is routed through the river basin. The sensitivity of these parameters has been estimated using HEC-HMS and selective perturbation of parameters such as the Muskingum routing parameter and the channel loss coefficient have been developed. The two models were used to simulate 24 years of daily discharge (1982-2005). Their comparison suggests that the models appear to be capturing the daily and intra-seasonal ("flood pulses") variations in the Brahmaputra discharge.

2. Improved description of the water cycle in the Upper Ganga Catchment using isotopic, geochemical data and model simulations by IIT Kanpur- Ongoing

The quantification of the discharge contributions from glacier, snow, rain and ground water to the total discharge in upper Ganga basin, through measurement and analysis of isotopic composition of river water will be established. This proposed work is in continuation with the MoES scoping project which provided them with a ~5 years of data set of streamflow from various source components contributions. The hydrological model based on the information obtained from isotopic analysis, glacier, snow, rain and ground water contributions were quantified using isotope mixing model. The glacier model coupled with the VIC model was set up and run for Chandra and Dudhkoshi Basin. Modelled Discharge was used to study the climate sensitivity of discharge to precipitation, temperature changes and the control of glaciers on sensitivity. The contribution of glacier and off-glacier areas to the runoff, from the above catchments was quantified. Accordingly a 2-D SIA model was applied to model all the glaciers in the Himalayan region (> 2 km).

3. Development of remote sensing based method for the rapid reconstruction of time series of formative water discharges of the Ganga and Brahmaputra rivers in the Himalayan foreland by IISER Bhopal- **Completed.**

A generalised semi-empirical width-discharge regime curve for the Ganga and Brahmaputra river has been established from the measurement of channel geometry in the field and threshold theory. As the regime equation is generalized and independent of any specific location, this can be used to estimate the channel forming discharge of the Ganga and Brahmaputra rivers at any location in the alluvial plain by just measuring the channel width on satellite or aerial images. Thus regime equation developed in this study is independent of channel pattern. It can be used on braided as well as single thread channels. A new set of data for channel width, depth and velocity has been prepared using Acoustic Doppler Current Profiler (ADCP) and can be used in flood forecast modelling and various other hydrological and morphological modelling. A web application has been developed to automate the process of image classification to extract river channels and their width. This application will soon be launched on web for community usage. A procedure to extract channel with from CORONA photographs has been developed which can further be used to know the status of Himalayan rivers.

6.1.4 Seismology

- **Maintenance of existing permanent GPS sites for Crustal deformation and plate motion studies of Indian Subcontinent and adjoining regions** by National Geophysical Research Institute (NGRI), Hyderabad. To understand crustal deformation and earthquake occurrence processes in the inter and intra plate regions of India, NGRI has established GPS networks in Garhwal-Kumaun Himalaya (24 stations), Indo-Burmese arc (4-stations), Andaman-Nicobar

Islands (7-stations), Koyna-Warna region (6-stations) and southern India (6-staions). Data accrued under different MoES projects related to GPS has helped in understanding crustal deformation and plate motion of Indian subcontinent and the new insights was published as more than 20 papers in high impact SCI journals.

- **Near Surface Geophysical and Geotechnical Investigation for Site- specific Earthquake Hazard and Slope Stability studies in and around Gangtok via-a-via it's Vulnerability and Risk Implications** by IIT, Kharagpur. An intensive analysis was carried out for landslide hazard in and around Gangtok with geological, geophysical and geotechnical investigations. GPR survey along 67-profiles and ambient noise survey at 234- locations were conducted in and around Gangtok. Geotechnical investigation was carried out in and around Gangtok at 6 sites. Two papers have been communicated for publications in SCI journals, and one Ph.D and one Master of Science degree has been awarded so far under the project.
- **Seismicity monitoring and evaluation of active faults in Garhwal Himalaya and adjoining Shimla hills region in Himachal Pradesh** by Wadia Institute of Himalayan Geology, Dehradun. A seismic network of 7-stations in Garhwal namely, Adibadri, Tapovan, Gaurikund, Chakrata, Ghuttu and adjoining Himachal Pradesh namely, Nahan, Kotkhai was established in 2007 and the data are being acquired continuously. Recently, a refined 1-D regional velocity model estimated from ~5000 earthquake waveforms from 50 seismic stations (including the 7 from this project), depicting 4-layer velocity model upto to 20 km depth, highlighting the new crustal geometry that confirms the depth of main Himalayan thrust beneath the Lesser Himalaya. Six papers were published in SCI journals, and one Ph.D awarded so far under the project.
- **Seismotectonic analysis of the Jammu region & its adjoining areas** by Jammu University. A seismic network of 7 seismic stations is being operated by Jammu University. Out of the 7 stations, 4 were established in 2009 at Jammu, Poonch, Doru and Bani. Subsequently, one more seismic observatory at Tangdhar was established in 2013 and 2 more were established in 2015 at Bhaderwah and Rajouri. Analysis of the data showed two prominent seismic clusters (cluster-1 on the NW of the Kashmir valley near the western syntaxial bend and cluster-2 between the Panjal thrust and Kishtawar window in the Chenab valley). Three papers have been published in SCI journals, and two Ph.D awarded so far under the project.
- **Modelling of Finite Ruptures in Three Dimensionally Attenuating Medium For Detail Seismic Hazard Studies of The Kumaon Himalaya Using Strong Motion Data** by, IIT Roorkee. A good amount of data base has been generated from network of 14 SMA established in 2006 in Kumaun Himalaya and 957 accelerograms are available from 337 recorded events. 11-papers were published in SCI journals and 3 PhD were produced from the SMA data on the results of detail attenuation and site characteristics of different locations in the Kumaun Himalaya.
- **Geoelectrical mapping of the deep Subsurface along the Eastern Ghats Mobile Belt region Using Magnetotelluric Studies by** IIT, Bombay. Magnetotelluric data were collected along two profiles (i) Ongle profile and (ii) Nellore profile. A 48-electrode multi-electrode resistivity imaging survey was carried out along Nellore profile to assess the lateral and depth extent of cause of the high conductivity in the shallow subsurface in the region. The subsurface beneath Ongole and Nellore is highly resistive, with resistivities being more than 10^5 Ohm-m from ~2 km and beyond which suggest the prominent southward extension of eastern ghat mobile belt (EGMB) beyond Ongole. Three papers were published.

6.1.5 Ocean sciences

- **Bay of Bengal mesoscale eddies role on convection, rainfall, winds: A multi sensor study** by NIT, Rourkela- **Completed**.

This project investigated the role of oceanic mesoscale eddies on the atmosphere through air-sea interaction and the impact of mesoscale eddies on the atmosphere. Findings from the case study advocates the fact that variability of mesoscale eddies during summer monsoon season can be used as a proxy in delineating active and weak monsoon seasons, whereas this hypothesis needs further research in future. The scientific outputs were published in the peer reviewed journals. Publication related to eddy induced Temperature using 11420 Argo profiles in the Journal of Dynamics of Atmosphere and Oceans is being one of the most downloaded articles from the issue. One PhD and MTech students were trained under this project.

- **Exploring India's Medieval Coastline using Geospatial Analysis and Historical Records** by NIAS, Bangalore-Ongoing

  The project successfully demonstrated ability to extract spatial information of coasts from old colonial maps, hence being able to understand coastal changes in last 300-400 years in the coastal stretch along Kollam, Kochi, Chettuva, Vypin in Kerala, Tamirabharani delta in Tamil Nadau and Honavar and Basrur in Karnataka. The scientific outputs were published in the peer reviewed journals. One PhD thesis also submitted.

- **Development and Characterization of Efficient Drilling Fluid Systems to Explore Huge Natural Gas Hydrate Resources in the Offshore of India** by IISM, Dhanbad -Ongoing.

  The project aimed to design an efficient drilling fluid which can prevent hydrate decomposition and formation during drilling operation. They achieved to prepare a low-cost drilling fluid using Boron nitride (BN) nanoparticles, which has a significant influence on achieving a suitable drilling fluid to use to extract gas hydrate. BN nanoparticles significantly decrease the fluid loss volume by forming a network structure with guar gum to create a less porous and less permeable filter cake. Five research papers were published in the peer reviewed journal.

- **Isolation and characterization of potent emulsifiers from bacteria isolated from Chennai harbor waters** by Ramachandra University, Chennai. The project aimed to develop inexpensive and an eco-friendly approach using microorganisms to reduce or mitigate the oil pollution as bio emulsifiers. The recent findings include the genomic DNA isolation and molecular characterization two isolates from the Chennai harbour and identified as Pseudomonas *aeruginosa* and *Psedumomas guguanensis* respectively. The project is still ongoing with studies on ex-situ remediation of hydrocarbon contaminated waters. The technology is submitted for patent.

6.1.6 Earth System Science and Technology Cells (ESTC)

Focussed network R&D is continuing under following three ESTCs

I. ESTC on Satellite Meteorology (SM) at SRM Institute of Science & Technology, Kuttankulathur (Tamil Nadu) comprises 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'.

II. ESTC on Coastal and Ocean Technology (COT) with project entitled "Hydrodynamic performance characteristics of Caisson type Breakwater"

III. 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,

v. Isolation and identification of bioactive compounds from marine sponges for white spot syndrome virus (WSSV) control

IV. Network project/s under the theme entitled "Understanding the interaction between components of the Earth System and Human Systems at various spatial and temporal scales" is ongoing at National Institute of Advanced Studies (NIAS), IISc. Campus, Bengaluru.

Ministry's institutes, National Centre For Medium Range Weather Forecasting, Noida (NCMRWF) and Indian Institute of Tropical Meteorology (IITM) Pune are associated for projects under ESTC-SM. Further, National Centre for Coastal Research (NCCR) for ESTC-COT project; and Centre For Marine Living Resources and Ecology (CMLRE) Kochi and National Institute of Ocean Technology (NIOT) Chennai for ESTC-MBS projects for research outcome towards applications and mandate of Institutes.

Fourteen number of Ph.D. are ongoing under the network / ESTC projects. Ten papers were published in referred journals and five are under review.

6.1.7 Human Resource development & Capacity Building

- The memorandum of Understanding (MoU) between MoES and IIT Delhi was extended for five more years for the continuation of support to the MoES sponsored M.Tech and PhD programs in Atmosphere and Ocean Sciences and Technology in the Centre for Atmospheric Sciences at IIT Delhi. Five fulltime students of M. Tech and 5 fulltime students of PhD programs are supported through this MoU.
- Supported the Indo-Norwegian Fellowship Program under the MoU signed between Norwegian Polar Institute (NPI) and National Center for Polar and Oceanic Research (NCPOR). One selected student is working at NPI on the assessment of changing ice-sheet dynamical features along the margins of Dronning Maud Land (DML), East Antarctica. The student is jointly supervised by researchers at NPI, NCPOR and University of Oslo, Norway.

6.2 AWARENESS AND OUTREACH PROGRAM

The objective of the programme is to propagate and bring awareness about the activities of the Ministry among the public, student and user communities. This is ensured through participation in National and International exhibitions, sponsoring seminars, symposia, workshop in the area relevant to the programme of the Ministry. In addition, "Earth Day" and "Ozone Day" are celebrated with the participation of school, college and university students. Ministry also supports the National and International Earth Science Olympiad.

Due to the unprecedented Covid-19 pandemic conditions, Ministry supported the outreach and awareness activities in either virtual or hybrid mode, as per Government directions from time to time.

6.2.1 Seminars / Conference and Exhibitions

In order to provide a platform to scientists, engineers, technologists, experts, social scientists and user communities to interact and discuss the various aspects of Earth System Science, the Ministry supported and participated in 2 Exhibitions/Science Fairs and 5 seminars in hybrid mode during the year.

6.2.2 Earth Day Celebration-2021

An oath taking event was organized by Ministry on occasion of Earth Day (22 April 2021) to save mother Earth. More than fifty thousand students/persons participated virtually through MyGov in the event.

6.2.3 International Ozone Day:

On International Ozone day, national seminar and activities of students were supported by Ministry. Honorable Union Minister for Animal Husbandry, Fisheries and Dairying Shri Purushottam Rupala Ji graced the occasion as chief guest and delivered inaugural address on 'Importance of Ozone Layer and Ministry's Role' in the national Seminar on 16 Sept 2021. More than thousand people participated in hybrid seminar and the news circulated in Krishi Jagran was viewed by more than one lakh. Total 405 students of Govt. schools participated in the activities conducted on 16 September 2021.

6.2.4 Azadi Ka Amrit Mahotsav

Ministry celebrated Azadi Ka Amrit Mahotsav to commemorate 75th Year of independence of country during iconic week 18-24 October 2021. One day

interaction of experts (Earth Sciences disciplines) with entrepreneur/ Start-ups for applications towards societal and economic benefits was organized at Ministry Headquarters on 18th October 2021. The Honourable Minister of Earth Sciences, Dr. Jitendra Singh graced the occasion as chief guest. Ministry and institutes celebrated the week by illuminating their buildings and displaying their advisory services and visits of their labs by stake holders, public and students. Variety of competitions and activities were organized to celebrate this and an emphasis was given to differently abled and orphan students.

6.2.5 MoES Foundation Day:

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27th July 2021 in hybrid mode at Prithvi Bhavan, MoES Headquarter at New Delhi. Honourable Union Minister of State (Independent Charge), Ministry of Sciences & Technology, Earth Sciences, DoPT, DAE and Dept of Space, Dr. Jitendra, Singh was the Chief Guest. The foundation day lecture was delivered by Prof Petteri Taalas, Secretary General, World Meteorological Organization (WMO).

This year the Life Time Excellence Award was awarded to Dr. Satish Shetye for his significant contribution in the field of Ocean Sciences. National Ocean Sciences award was awarded to Dr. Sunil Kumar Singh, Director, CSIR-National Institute of Oceanography, Goa. The National Award for Atmospheric Science & technology to Dr. R. Krishnan, Scientist-G and Executive Director, Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Pune. The National award for Geoscience & technology was presented to Dr. Kalachand Sain, Director, Wadia Institute of Himalayan Geology. The National Award for Ocean Technology to Dr. M. V. Ramanamurthy, Director, National Centre for Coastal Research, Chennai.

Dr. Thara Prabhakaran, Indian Institute of Tropical Meteorology, Pune and Dr. Vandana Prasad, Director, Birbal Sahni Institute of Palaeosciences, Lucknow shared the Anna Mani award for woman scientist.

Dr. Jitendra Singh, Honourable Minister of Earth Sciences is lighting the Inaugural lamp during the occasion of Ministry's Iconic week of Azadi Ka Amrit Mahotsav

Dr. Jitendra Singh HMoES Chief Guest in Ministry's Foundation Day, 27July 2021

The young researcher award for the year was awarded to Dr. Kandula V Subrahmanyam, Space Physics Laboratory, ISRO and Dr. Waliur Rahaman, National Centre for Polar and Ocean Research, Goa. The details of other awardees are available at https://moes.gov.in /awards.

6.2.6 India International Science Festival (IISF-2021)

The 7th edition of the India International Science Festival (IISF-2021) was held during 10-13 December 2021, at Panaji, Goa. It was jointly organized by Ministry of Earth Sciences, Ministry of Science and Technology and Vijnana Bharati and executed by the National Centre for Polar and Ocean Research (NCPOR), Goa.

The IISF-2021 had 12 main programs:

i. Science Film Festival
ii. Science Literature Festival
iii. Engineering Students Festival
iv. Science Village Festival
v. Traditional Crafts and Artisan Festival
vi. Guinness Book of World Records
vii. Festival of Games and Toys
viii. Global Indian Scientists and Technocrats Meet
ix. Eco Festival
x. New Age Technology Show
xi. National Social Organizations and Institutions Meet
xii. Mega Science and Technology Expo

Nearly 8000 delegates attended the festival physically at Goa. Out of which, nearly 5000 were school children participated in science village, Guinness Book of World Records and Games and Toys program. Three Guinness World Records have been achieved by these students. Online participation was about twenty thousand, who participated through online sessions and programs. More than three lakh people from Goa visited the Mega Science and Technology Expo.

6.3 BIMSTEC- CENTER FOR WEATHER AND CLIMATE (BCWC)

BCWC was established at NCMRWF following a Memorandum of Association (MoU) signed among MoES, India and BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) Member countries. An online workshop cum training programme on 'Use of Ensemble Model Forecast Products for Weather/Climate' was conducted during 24-26 March 2021. There were about 50 participants from the NHMS of Bangladesh, Bhutan, Nepal, Myanmar, Thailand and Sri Lanka.

Deterministic and probabilistic forecast plots from global and regional models, generated at real time for the BIMSTEC member countries and displayed at NCMRWF website on daily basis. Also, on the request of National Centre for Hydrology and Meteorology, Bhutan, the forecast data and plots are being transferred daily on real time. Weekly extended range forecast products are sent to all the NHMs of the

Dr. Jitendra Singh, Honourable Minister of Earth Sciences is lighting the lamp during the Inauguration of IISF 2021.

BIMSTEC member countries through e-mail on every Thursday.

The model domain of regional ensemble prediction system of NCMRWF (NEPS-R) has been expanded to include all the BIMSTEC member countries.

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 online training mode due to the pandemic has enabled increased participation from IOR countries in the training programmes. During January - December 2021, 16 training course were conducted. A total of 1713 persons (Male: 1039, Female: 674) were trained of which 1021 are from India and 692 (Male: 448, Female: 244) from 58 other countries.

6.5 DEVELOPMENT OF SKILLED MANPOWER IN EARTH SYSTEM SCIENCES (DESK): Development of Skilled manpower in Earth System Sciences (DESK) was initiated to create a large pool of trained and dedicated multidisciplinary earth system and climate research manpower in the country. Under the MoES Research Fellow program (MRFP), first batch of 21 JRFs after completing the mandatory course work at IITM have joined various MoES Institutes. The work done by these JRFs during their first year was evaluated in an interview in November 2020. The second batch of 13 JRFs have joined under MRFP.

Five days online training Program 'Online training in AI/ML for atmosphere-ocean applications for beginners' was conducted during 15-19 Feb 2021. A total 107 participants (shortlisted from 264 applicants). Eleven Experts from IITM, IIT Gandhinagar, IIT Chennai and IISER Pune took 19 sessions during the training. Videos of the training are made available on IITM YouTube channel https://www.youtube.com/channel/UC_K_3pxWrgRCJ-RMF82IBJw

Webinars were conducted under **Azadi ka Amrut Mohatsav**, MoES Webinar Series on "Earth Sciences Popular Lectures", MoES – Hindi Webinar Series, Swachchta Pakhwada, IITM Monsoon Discussion Forum (IMDF) 2021, Prof. R. Ananthakrishnan Seminar Series, Special Days observance (viz., National Science Day, World Meteorology Day, International Day for Biological Diversity 2021, Earth Day 2021, World Environment Day 2021). All the videos are made available for public online @IITM YouTube channel.

6.6 MOES-KNOWLEDGE RESOURCE CENTRE NETWORK (KRCNET)

- The Knowledge Resources Centre Network (KRCNET) is a dynamic web portal developed by the MoES which aims to integrate all knowledge and intellectual resources of MoES and its institutes on a single digital platform. Aligned with the concept of Digital India Initiative of the Government of India, the KRCNET portal is a unique and one-of-its-kind digital system to collect, collate, catalogue, store, and retrieve knowledge products of MoES and its institutes 24X7 from around the globe.
- E-resources subscribed under DERCON (Digital Earth Sciences Consortium) in 2021 were made available to scientists and employees of MoES institutes through KRCNET.

Chapter-7

DEEP OCEAN MISSION (DOM)

7.1 Background:

Oceans are a storehouse of both living and non-living resources, modulator of global climate and habitat for ecologically significant diverse group marine organisms. The Sustainable Development Goal 14 (SDG-14) proposed by the United Nations (UN), which deals with the life below the water emphasizes the importance of ocean in modulating and sustaining the life and environment on the planet Earth. So far, considerable research initiative has been taken up by the Ministry to understand and explore our coastal seas and offshore waters but there is lack of detailed understanding of the deep Oceans. Only 5% of Deep Ocean has been explored and the rest remains unexplored.

As a Maritime nation having coastline of about 7500 km and around 30% of the country's population living in coastal areas, oceans plays an important role in Indian economy. The Government of India's Vision of New India by 2030 enunciated in February 2019 highlighted the Blue Economy as one of the ten core dimensions of growth. With a view to explore deep ocean for resources, develop deep sea technologies for sustainable use of ocean resources, and improve our understanding of deep sea, Government of India launched the "Deep Ocean Mission" at an estimated cost of Rs. 4077.0 crore for a period of 5 years implemented in phase-wise manner. The estimated cost for the 1st phase for the 3 years (2021-2024) is Rs. 2823.4 crore. This mission mode project will support various priority areas illustrated in the Blue Economy policy document of the Government of India. Ministry of Earth Sciences (MoES) will be the nodal implementing Ministry for this multi-ministerial, multi-institutional mission.

7.2 Objectives:

The major objectives of the Deep Ocean Mission are as follows:

- To develop technologies for mining of deep-sea resources like Polymetallic nodules from the Central Indian Ocean at a water depth of 5500 m.
- Design, and develop one working prototype and one final Manned Submersible rated for 6000m water depth along with technologies for underwater vehicle and underwater robotics.
- To provide the future projections or predictions on the trends in sea level along the Indian coast, cyclone intensity and frequency, storm surges, wind waves, biogeochemistry and ecosystem. To install deep ocean observations (below 2 km depth) over the Indian Ocean.
- Inventorization, archival of specimens and development of DNA bank of deep-sea fauna of Northern Indian Ocean through systematic sampling using Remotely Operated Vehicle.
- Development of technology for isolation of deep-sea piezotolerant and piezophilic microbes, symbionts and screening for novel biomolecules using culture-based and meta genomic approaches.
- Exploration of formation of life friendly molecules and organismal components in deep sea.
- To explore and identify potential sites of multi-metal hydrothermal sulphides mineralization along the Indian Ocean mid-oceanic ridges.
- To acquire a new all-weather multidisciplinary research vessel (research ship) for Indian Ocean operations.
- Detailed engineering design document for high capacity offshore OTEC powered desalination plant.
- Performance assessment of critical components such as deep-sea cold-water conduit and mooring system by demonstration in deep sea.
- Integrating the ongoing advanced basic and applied research in marine biology, marine ecology and related marine engineering through the establishment of an advanced Marine Station for Ocean Biology.
- Capacity building in Marine Biology with the help from international institutes.

- National and International collaboration in education, research and excellence in the field of ocean science and Ocean Technology.

7.3 Components of the Deep Ocean Mission

The Deep Ocean Mission consists of six major components/verticals as detailed below:

7.3.1 Development of Technologies for Deep Sea Mining, Underwater Vehicles and Underwater Robotics

A manned submersible will be developed to carry 3 people to a depth of 6000 m. in the ocean with suit of scientific sensors and tools. An Integrated Mining System will be developed for mining Polymetallic Nodules from 6000 depth over the central Indian Ocean. The exploration studies of minerals will pave way for the commercial exploitation in the near future, as and when commercial exploitation code is evolved by International Seabed Authority, the responsible UN organization. This component will help the Blue Economy priority area of exploring deep sea minerals and energy.

7.3.2 Development of Ocean Climate Change Advisory Services

A suit of observations and models will be developed to understand and provide future projections of important climate variables on seasonal to decadal time scales under this proof of concept component. This component will support the Blue Economy priority area of coastal tourism.

7.3.3 Technological innovations for exploration and conservation of deep-sea Biodiversity

The deep sea harbours the highest biodiversity on Earth with novel biomolecules having environmental, industrial and biomedical importance. Bio-prospecting of deep sea flora and fauna including microbes and studies on sustainable utilization of deep sea bio-resources will be the main focus. This component will support the Blue Economy priority area of Marine Fisheries and allied services.

7.3.4 Deep Ocean Survey and Exploration

Deep Sea mineral resources including poly-metallic hydrothermal sulphides have attained immense attraction as being considered as the future alternative of lan resources and source for global metal supply. The primary objective of this component is to explore and identify potential sites of multi-metal hydrothermal sulphides mineralization along the Indian Ocean mid-oceanic ridges. This component will additionally support the Blue Economy priority area of deep sea exploration of resources.

7.3.5 Energy and freshwater from the Ocean

Considering the growing demands of energy for the remote islands, it is essential to develop technologies to harness the energy from the seas surrounding them. Ocean Thermal Energy Conversion (OTEC) has been known for a long time but the ocean's vagaries are yet to be conquered for a continuous operation of OTEC offshore. Studies and detailed engineering design for offshore OTEC powered desalination plant are envisaged in this proof of concept proposal. This component will support the Blue Economy priority area of off-shore energy development.

7.3.6 Advanced marine station for Ocean Biology

The Deep Ocean Mission provides the right time and opportunity to bring the fundamental research and the marine engineering into a cohesive group, managed and coordinated by a nodal hub – "Advanced marine station for Ocean Biology" with a network of coastal and island research stations in India and abroad. This component is aimed as development of human capacity and enterprise in ocean biology and engineering. This component will translate research into industrial application and product development through on-site business incubator facilities. This component will support the Blue Economy priority area of Blue trade and Blue manufacturing.

Chapter 8

INTERNATIONAL COOPERATION

Ministry of Earth Sciences has a mandate to provide a reliable weather, climate and other hazard related forecast for service to society. In this effort, MoES regularly partners with national and international institutes to help broaden the scope of trans-national research through linking researchers with different skillsets and expertise in various countries. This involves joint projects on understanding processes, joint observational campaigns, joint developmental work including decision support systems. The international collaborations not only help in delivery of high-end research for societal benefits but also ensure optimum usage of infrastructure, data and manpower resources.

8.1. Cooperation with NOAA, USA

The Memorandum of Understanding (MoU) between MoES and National Ocean and Atmospheric Administration (NoAA) on Earth Sciences and Observations was renewed on 23 October 2020 for a further period of ten years. Although ten Implementation Agreements (IA) were signed, however only three among them are active. Some of the significant outcomes from these projects are mentioned below:

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

The field work and the research conducted under the RAMA IA have greatly contributed to our understanding of the importance of the Indian Ocean in the regional and global climate system. Till date, the data from **RAMA moorings have been used in 78 articles published in international journals.** India is also using RAMA data to generate ocean analysis products through the assimilation. Global ocean analysis using GODAS (Global Ocean Data Assimilation System) by assimilating all available in-situ data forms an important initial condition for seasonal monsoon prediction by coupled model. The second IA on RAMA was signed on 13 June 2018 to continue the activities of the RAMA IA.

The IA on "Technical Cooperation in Development of the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA) and the Ocean Moored buoy Network in the northern Indian ocean (OMNI) for Improving Weather and Monsoon Forecasts" was signed on 09 August 2021 in a virtual event. The Joint RAMA-OMNI Indian Ocean Data Portal was also launched by Secretary during the virtual event. The OMNI-RAMA portal will showcase the large inventory of meteorological and oceanographic data sets with direct access for data display and delivery. The data sets with frequency as high as 2 minutes to the regular transmission interval of one hour is provided with a supporting meta data information such as deployment, sensors specification, calibration, sampling strategy, data processing, quality control etc. The portal would facilitate the visualization of measured as well as estimated parameters at various frequencies along with provisions for data downloading in various formats.

8.1.2 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 sixth assessment report of the International Panel on Climate Change (IPCC). A new version of the GSI Data Assimilation was implemented. IMD GFS14 (Control Run) forecasts are now part of international model forecasts comparison carried out by NCEP and is displayed in their Environmental Modeling Center international model daily bias/AC section from May 2021 and the same was implemented by Monsoon Desk at NCEP. Global Forecast System (GFS) fixed files T1534 format are made available to IITM scientists.

8.1.3 Improving Tropical Cyclone Prediction Over the Indian Ocean :

A coupled regional mesoscale model HWRF-HYCOM was operationally employed for the forecasting of all cyclones over North Indian Ocean during 2020 and 2021. A total of 9 cyclones and 6 depressions have been predicted using the said coupled modeling system using INCOIS Tendral Ocean Prediction System – Indian ocean model (ITOPSI) ocean initial and boundary conditions. Six hourly cycling forecasts for 5 days are generated for all low-pressure system from its weaker initiation stage i.e., when the system is at its depression stage

8.2 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 on "Early Warning System for Air Quality in Delhi" with the National Center for Atmospheric Research (NCAR), a lab funded by UCAR is continuing. The system for air quality early warning system for Delhi NCR region in collaboration with NCAR at a very high spatial resolution of 400 m has been operationalized since June 2021. A public dissemination system developed for the purpose is being used operationally by IMD, Central Pollution Control Board and Delhi Pollution Control Board. In addition to the above, IITM has developed indigenous Decision Support System(DSS) for advanced air quality management for Delhi NCR region. DSS is designed to deliver quantitative information about a) the contribution of emissions from Delhi and the surrounding 19 districts to the air quality in Delhi b) the contribution of emissions from 8 different sectors in Delhi to the air-quality Delhi c) the contribution from biomass-burning activities in the neighboring states to the degradation of air quality in Delhi. Additionally, DSS also gives information about the quantitative effects of possible emission source-level interventions on the forecast air-quality event in Delhi. All this information would assist in managing the air quality in a timely manner. It will issue timely warnings for forthcoming air quality events and prediction for source contribution for next 5 days to take necessary steps as per the newly designed Graded Response Action Plan of Government of India.

8.3 Consortium Agreement with UM Partners: The UM Partnership Board meeting was held virtually on 03 November 2021 and was attended by other Board members from Met Office, UK, BoM, Australia, NIWA, New Zealand, Korea Meteorlogical Agency, South Korea and US Air Force. It was decide to include Singapore as a core partner. The operational NCUM global Data Assimilation (DA) system has been upgraded with components of UK Met Office Parallel Suite 43 (PS43) which enables assimilation of cloud-affected microwave radiances from satellites. The new global NCUM-G and regional NCUM-R model versions were operationalized with GA7.2 science configuration in NCUM-G and the "Tropical science regional atmosphere configuration version 2 (RA2T)" in NCUM-R model with improvements in moisture conservation and stochastic perturbation. As a part of the Regional Model Evaluation and Development (RMED) activities, verification statistics for total precipitation and lightning flash counts for the 2018 & 2019 Kerala Flood events were prepared. The DM-Chem 330 mts Delhi winter fog model was upgraded by incorporating EDGAR and SAFAR emission inventory and daily biomass emission from GFAS (Global Fire Assimilation System) to provide improved high resolution fog/visibility forecast for Delhi and adjoining regions during the 2020-21 winter period. A Convective Scale Working Group Meeting was held in which the ongoing activities of regional ensemble prediction system were showcased.

8.4 MoU with UK Met Office – Consequent upon extension of the Implementation Agreement on WEATHER AND CLIMATE SCIENCE FOR SERVICE PARTNERSHIP INDIA (**WCSSP India**) between MoES and UK Met Office by a year till March 2021, both sides mutually agreed for an additional extension till March 2022. The science plan has been revised to include 4 work packages as follows:

(i) Work Package 1(WP1): Seamless Coupled System Development across Scales

(ii) Work Package 2 (WP2): Evaluation and understanding of Monsoon Processes and Hazards

(iii) Work Package 3(WP3): Observations and improving hazard prediction

(iv) Work Packge 4 (WP4): Risk based forecasting & high impact weather/seasonal events

Annual Science meeting of WCSSP India program was organized virtually during 1-4 Feb 2021 with participation of over 100 scientists from India and UK. 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 global coupled ensemble data assimilation system, development of a convective scale regional coupled environment prediction system for India and neighboring seas, a sub-km scale modelling for Indian region with advanced urban surface process. In addition, joint work on model component process studies, satellite data assimilation, lightning and fog forecasting over India is underway. Under the WP2, IITM has collaborated with UK Met office to understand the role of tropical extra tropical interaction and western disturbances in modulating the weather over the Indian region especially during the monsoon season. A skill evaluation is undertaken to understand the skill in capturing the western disturbances by IITM-ERPAS and UKMO-Glosea model. As part of the activity under WP3, various lightning parameterization schemes are evaluated to simulate lightning flash counts using WRF model over India from hindcast along with real time operational forecast simulation. To develop impact based forecasting tools under WP4; a closed working group has been set up at MoES to translate model output into usable tools to be used at IMD. Under this Impact based forecasting prototype is being developed for risk based forecasting of high impact events on the weather and seasonal time scales. Flood inundation forecasting systems are being tested during the monsoon season.

8.5. Cooperation with Natural Environment Research Council (NERC): Implementation Agreement (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. Due to Covid-19 pandemic restrictions during 2020 and 2021, which adversely affected the activities of APHH projects, some of the activities under the work packages could not be completed. Therefore, the duration of the projects has been extended by 1 year. During 2017-21, APHH Secretariat has organized five science meetings and 3 observational field campaigns in Delhi (November 2017-February 2018, May-June 2018 and November 2018- January 2019). The APHH published 41 peer-reviewed papers in reputed journals including 1 in Nature Geoscience, 2 chapters in book, 38 conference papers. APHH scientifically contributed in strengthening the SAFAR framework of MoES by developing new parameterization of secondary aerosol mechanism and linking air quality with climate change in CMIP6 models. APHH led to capacity building in the area and mutual benefits to both the collaborating nations, delivered skilful products with significant potential for sustainable societal needs. The final outcome will yield an integrated framework of air quality to further strengthen application-oriented work for the benefit to society and planning mitigation strategies.

8.6 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.. The Belmont Forum annual preliminary 2021 was held in a virtual mode during 26-28 October 2021. Members from over 31 countries participated in the meeting. Some of the new CRAs introduced during the preliminary included

Migration & Mobility, Systems of Sustainable Consumption and Production, Climate, Environment, Health II and Future Leaders. 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. An Ocean Sustainability Hub, the website created specifically for the Oceans CRA project members has been launched . This is a platform that provides an opportunity for awardees and project collaborators from the Oceans CRA to showcase their project outputs, including publications, presentations, webinars, media, one-pagers, etc. The Hub also has a built-in social network to help project members connect with each other on one platform and the public will be able to access the Hub. To maintain India's significant relationships with the Belmont Partnering countries and for streamlining its future activities on recent environmental challenges, MoES scientists participated virtually in Sustainability Research & Innovation Congress 2021 (SRI2021) held in Brisbane, Australia, 12-15 June 2021. SRI was a joint initiative of Future Earth and the Belmont Forum event with more than 100 sessions on diverse themes by expert speakers from various countries.

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

The First Meeting of the BIMSTEC Expert Group on Himalayan Science Council was held virtually in New Delhi, India on 12 October 2021 with an aim to finalize the Concept Paper on 'Proposal for the Himalayan Science Council (HSC) under the BIMSTEC'. Delegations from the People's Republic of Bangladesh, the Kingdom of Bhutan, the Republic of India, the Republic of the Union of Myanmar, Nepal, the Democratic Socialist Republic of Sri Lanka and the Kingdom of Thailand attended the Meeting. Secretary, Ministry of Earth Sciences, and Head of Indian Delegation chaired the meeting. The concept note was discussed in detail and has been again circulated to all the member countries for their final comments. India will submit a draft Memorandum of Association (MoA) on the Establishment of the BIMSTEC Himalayan Science Council, once the concept note is accepted by all countries.

8.8. Cooperation with Norway

8.8.1 MoU with Research Council of Norway (RCN): Five joint Indo-Norwegian workshops/ Training prog. were held in India and 9 papers were published under the 5 projects funded under the Climate System in Polar regions and Geohazard theme. A joint Indo-Norwegian meeting was conducted on 23rd March 2021 to review the progress of projects sanctioned jointly under the MoU between MoES and RCN. Out of those 8 projects, four projects have been completed while others are in various stages of implementation. Some of the major findings include (i) The GPS traverses throughout Nivlisen shelf and three ice cores raised from the Ice rises have helped the NCPOR and NPI researchers to reconstruct climate and oceanic conditions during the late Holocene. (ii) The study of multi-proxies in the cores from IODP 355 has indicated that during the Mid Pliocene Warm Period (MPWP) when atmospheric CO_2 concentration was similar to present, stronger summer monsoon occurred with less sea ice in the Arctic.A strong evidence of teleconnection between ISM and the Arctic sea ice has been noted (iii) A reliable high-resolution (0.1 x 0.1 deg) emission inventory of eight indirect greenhouse gases and particulate matter pollutants has been developed for Indian subcontinent for base year 2018. (iv) Improved models have been developed to look at intraplate sesimicity in regions of both India and Norway.

8.8.2 Collaboration with Norwegian Ministry of Climate and Environment: A Letter of Intent was signed on February 2020 between MoES and Norwegian Environment Agency through the Norwegian Ministry of Foreign Affairs (MFA) to develop a framework for the Integrated Ocean Management and Research Initiative with a focus on Marine Spatial Planning (MSP). The first India-Norway Scoping meeting on MSP was held on 10th- 11th of December, 2020, with 40 participants from both countries. During the meeting, it was decided to take up two areas namely Puducherry (a well developed Urban area in the mainland) and Lakshadweep (an

ecologically sensitive island ecosystem) as pilot areas for study and preparation of Marine Spatial Plans. National Center for Coastal Research would take the lead from the Indian side and the Institute of Marine Research and the Norwegian Environment Agency will be the lead agencies from Norway. The first Project Steering Committee meeting of the India-Norway Integrated Ocean Management and Research Initiative, was held on 26th February, 2021.

8.9. Cooperation with Europeon Union: 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**. Four calls were selected for funding by MoES

8.10 Cooperation with UNESCO/IOC: The International Training Centre for Operational Oceanography (ITCOocean) established at INCOIS, Hyderabad a UNESCO Category 2 Centre, had trainees from 95 countries uptill now. The online training mode due to the pandemic has enabled increased participation from Indian Ocean Rim countries in the training programmes. During January 2021 - November 2021, 9 training course and 3 webinars were conducted. A total of 1526 persons (Male: 904, Female: 622) were trained of which 906 are from India and 620 (Male: 386, Female: 234) from 58 other countries.

8.11: LoI between India and UNESCO on cooperation for reducing disaster risks and capacity building in the Earth-Sciences: Second International Indian Ocean Expedition (IIOE)-2: Endorsed a total of 45 scientific projects (including 3 projects during January -December 2021) that align with the IIOE-2 objectives (https://iioe-2.incois.gov.in/IIOE-2/Endorsed_Projects.jsp). IIOE-2 meta data portal (https://iioe-2.incois.gov.in/IIOE-2/data.jsp) was created to make oceanographic data from the region is discoverable and widely accessible to the stakeholders. This metadata Portal enables search and discovery of metadata of completed & forthcoming/planned cruises under IIOE-2. The IIOE-2 Steering Committee meetings were held virtually during April 12-15, 2021 and 70 participants from 45 organizations and 14 countries have participated.

8.12. Contract with International Seabed Authority (ISA) on extraction of Polymetallic Nodule (PMN): Under the contract with ISA, MoES carried out Survey & Exploration, Environmental Impact Assessment, Technology Development (Mining), and Technology Development (Extractive Metallurgy) for polymetallic nodules through various national institutes. An expedition to the Central Indian Ocean Basin was undertaken and thirty-one stations were successfully sampled at 6.25 km x 6.25 km grid interval in the Revised First Generation Mine (RFGM) area. Nodule abundances of surveyed stations are calculated and the abundance database is updated. The resource potential of the RFGM area has been estimated. The moisture contents of the samples have been measured and chemical analysis of all the collected samples has been carried out for the five metals, Ni, Co, Cu, Mn and Fe. Towards the realization of the Integrated Mining System (IMS) for test mining polymetallic nodules (PMN) at a depth of 6000 m, seabed locomotion trials were successfully undertaken on water-saturated soft sediment soil at 3420 m. The mining machine system has been improved upon for weight and stiffness and optimised for improved hydrodynamic behaviour underwater to minimise the umbilical cable loads from the movement of the ship on the surface due to heavy swells.

8.13. Contract with ISA on extraction of Polymetallic Sulfides: The analysis of surveys carried out earlier in the exploration area resulted in the identification of new locations of hydrothermal plumes over the southern part of the Central Indian Ridge (CIR) and the eastern part of the South-West Indian Ridge (SWIR) segments. A three months cruise was undertaken to identify new plume locations, narrow down the source location of the identified plumes in the exploration area, collect geological samples and acquire baseline environmental data. Integrated multi-disciplinary scientific investigations,

including geophysics, geology, physical oceanography, and chemical oceanography, identified 11 new locations for the potential of hydrothermal activity over CIR and SWIR. Detailed studies on baseline characterization of microbe, plankton, and benthos and to understand their diversity were carried out.

India has been submitting Annual Reports regularly to the Authority indicating the progress of work pertaining to both the contracts. 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.

8.14. Cooperation with Japan: A webinar on "Marine Plastic Pollution Prevention and Management" was held on 16 February, 2021 with the aim to highlight the specific efforts of institutions in Japan and India on Marine plastic waste related issues and collaborate to address the marine waste problem. The webinar was organized by S&T Wing, Embassy of India, Tokyo in association with the Ministry of Earth Sciences (MoES), Government of India; and the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Government of Japan. The webinar was attended by scientists and academicians from both the countries and provided various valuable inputs for programmes related to marine pollution and plastics. A virtual meeting between India and Japan was held on Mar 12, 2021 to discuss opportunities to work together in the area of Arctic Research and pollution. Documents on potential collaboration research topics on (i) Coastal Vulnerability and Marine Litter and (ii) Deep Ocean technology aspects like Manned Submersibles, Ocean Mining etc., were exchanged. In addition, a round table discussion was held on 7th July 2021 on marine plastics and two working groups have been constituted to take forward the research programmes using latest technologies.

8.15. Cooperation with International Continental Scientific Drilling Programme (ICDP), Germany: The MoU on the Membership of the ICDP between MoES and the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, signed on 30th August 2016, has been extended for a further period of five years on December 8, 2021. As per the 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 and facilitates 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, plans for instrumentation of the Koyna Pilot Borehole have been firmed up and it was decided to take up the work as soon as the necessary clearances are obtained and the travel restrictions are relaxed. Also, a joint research publication is under revision. India was represented in the Executive Committee meeting held during April 19-20, 2021.

8.16. Cooperation with International Ocean Discovery Program (IODP), USA: The MoU on the Associate Membership of the IODP with National Science Foundation (NSF), USA 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. India is also represented on three panels of IODP, viz, Science Evaluation Panel (SEP), JOIDES RESOLUTION Facility Governing Board and IODP Forum. Amid COVID-19 pandemic during the current year, IODP consortium managed to complete a few scientific drilling expeditions with limited participation. Due to travel restrictions, Indian scientists participated virtually in IODP-386 (Japan Trench), IODP-395 (Reykjanes Mantle Convection and Climate) and IODP-396 (Mid-Norwegian Continental Margin) expeditions however, they would get their requested samples for further research.

8.17: Collaboration with Sweden: Under the MoU on Polar Science between MoES and the Ministry of Education & Research, Sweden signed on 2nd

December 2019, a virtual meeting was held with faculties from Stockholm University and Bolin Centre for Climate research, Sweden to identify potential areas of collaboration between India and Sweden in the areas of Polar Research, including Arctic Council working group activities. Both teams exchanged various areas of collaborations and concept notes for collaboration in the field of Ocean-atmosphere interactions, climate change, palaeo-climatology, and microbiology. A scientist from MoES participated in the 6th meeting of the India-Sweden Joint Committee led by Secretary DST wherein several areas of joint interest were discussed.

8.18. 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. Despite the COVID-19 travel restrictions, RIMES continued its efforts to provide uninterrupted services to its member and collaborating States in 2021. RIMES along with the Regional Climate Centre, Pune of India Meteorological Department, UK Met Office, and World Meteorological Organization participated in the South Asian Outlook Forum (SASCOF) during 26-28th April 2021 in a virtual mode. About 100 meteorologists from National Meteorological and Hydrological Services offices and climate experts prepared the seasonal and regional climate outlook of monsoon. The SASCOF-20 and Climate Services User Forum (CSUF) was held in September 2021 for producing a seasonal outlook for winter monsoon or Northeast monsoon season. RIMES also established a European Center for Medium ECMWF-NHMS data exchange platform and demonstrated to Member countries in September 2021.

8.19: Cooperation with United Arab Emirates (UAE) : Following the MoU signed on 23rd November 2020, between MoES and the National Center of Meteorology(NCM), Ministry of Presidential Affairs UAE, a virtual meeting was held on 10th March 2021 to understand the facilities available with each side and plan the future strategy. Both sides noted the similarities in terms of seismic & tide gauge networks, Tsunami early warning protocols, bulletins and dissemination systems which provides a way forward as common framework and opportunities for mutual collaboration and cooperation in terms of data exchange, transfer of knowledge and capacity building. As a follow up, on 29th March 2021, both sides discussed possible collaboration in Tropical Cyclonic, Storm Surge, and Marine Forecast.

8.20. Other international events

8.20.1 : Ministry of Earth Sciences and UK Research and Innovation (UKRI) jointly organized a COP26 partnership virtual event on Sustainable and Inclusive Climate Adaptation and Resilience: local leadership for a global goal on 29 September 2021 as a contribution towards the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow in November 2021, Principal Scientific Advisor (PSA) to Government of India, Prof K. Vijay Raghavan gave a high-level statement to firmly establish India's interest and commitment towards building climate change adaptation and resilience. The half a day event provided an opportunity for key stakeholders to discuss and identify future priorities for bilateral UK-India programmes that are globally relevant and aligned to the COP26 theme of adaptation and resilience. Prior to this a kick-off event was organized by the UKRI on 3rd July 2021 in which Secretary MoES highlighted the initiatives being taken by Government India towards the initiative.

8.20.2 : Virtual Conference on "Future of Natural Resources : Ministry of External Affairs and Ministry of Earth Sciences jointly organized a Virtual Conference on "Future of Natural Resources (Hydrocarbons, Rare Earth Metals and Blue Economy)" on 29th Oct 2021. Seven eminent scientists from the Indian Diaspora including one Indian speaker participated in the panel discussion and gave valuable insights and discussed the areas of probable collaboration with India. The feedback from the conference is expected to feed into the next Pravasi Bhartiya Divas Convention.

8.20.3: Intergovernmental Oceanographic Commission (IOC) of UNESCO: India participated in the 53rd session of the IOC Executive Council held online during February 01-09, 2021 and took the floor to provide its interventions on activities of IOC-UNESCO, UN Decade of Ocean Science for Sustainable Development 2021-2030, IOC medium-term strategy for 2022-2029, etc. India along with Germany, Norway, Argentina and Morocco, presented a statement supporting the draft resolution on the implementation of United Nations Decade of Ocean Science for sustainable development (2021-2030) which was adopted by the Executive Council. Indian delegation participated in the 31st Session of the IOC Assembly and 54th Session of the IOC Executive Council held online during June 14-25, 2021 .

8.20.4: UN Decade of Ocean Science for Sustainable Development (UN Ocean Decade): India submitted a proposal for establishment of Regional Decade Coordination Centre (DCC) for the Indian Ocean (IO-RDCC) at INCOIS, Hyderabad against UN Ocean Decade first 'Call for Decade Action'. India established the National Decade Coordination Committee (NDCC) under the chairman ship of Secretary, MoES and involving various national institutions and stakeholders, to coordinate existing activities and develop new programs at the national level to meet the objectives and goals of ocean decade and also to enhance national access to Decade benefits. The Kick-off meeting was held on February 03, 2021 through online mode.

8.20.5 : Indo-UK collaborations (NCCR-Cefas) Marine Litter & Microplastic studies: Under the India-UK collaboration on Marine Litter, 100nos of microplastic samples from seven beaches of Chennai and Puducherry have been given to scientists from Centre for Environment Fisheries and Aquaculture Science (CEFAS),UK for doing FTIR analysis in UK laboratories as part of joint collaboration of research activities. NCCR and CEFAS will continue working together on monitoring, mapping and modelling of microplastic at locations *Viz.*,Chilika Lagoon, Pichavaram Mangrove and Puducherry along the Indian coast in future. This will help to prepare Marine Pollution/ Plastic policies and management strategies.

8.20.6 : Bilateral Cooperation projects under IPOI, India (NCCR, MoES)-Vietnam (MONRE): Under Indo-Pacific Ocean Initiative (IPOI), a framework for cooperation between Ministry of Earth Sciences (MoES), India and Ministry of Natural Resources and Environment (MONRE), Vietnam has been established for the implementation of activities related to Ocean Resource Management that include projects on Coastal erosion and coastal protection. To initiate the activities a workshop on Coastal Erosion and Protection was held on 24th March 2021 in virtual mode to identify the existing knowledge gaps and key areas for collaboration and capacity development.

8.20.7: International Monsoons Project Office (IMPO) : An agreement has been signed between the World Meteorological Organization (WMO) and Indian Institute of Tropical Meteorology(IITM) on 30 July 2021 for a period of 5 years on establishment of a joint World Weather Research Programme(WWRP) and World Climate Research Programme(WCSP) International Monsoons Project Office (IMPO) at IITM. IMPO will pursue activities and connections related to monsoon research around the world, identified and fostered under the leadership of WCRP and WWRP, thereby deriving mutual benefits to both WMO/ WWRP/ WCRP and IITM.

Chapter-9

PUBLICATIONS, PATENTS, AWARDS AND HONOURS

9.1: Publications in peer reviewed journals:

A total number of 622 research papers were published in 2021 by MoES scientists under its various schemes, and the details of which are given below.

Table 1 : MoES Publications

	ACROSS	OSMART	PACER	SAGE	TOTAL
Total no. of Publications	310	149	110	53	**622**
Cumulative Impact Factor	**1106**	**406**	**430**	**158**	**2100**

The detailed publication list under each scheme is available at https://moes.gov.in/publications.

The number of research papers published and the total impact factor (2100) are comparatively much higher as compared to the previous years (Fig. 9.1). The average impact factor of research papers was 3.37.

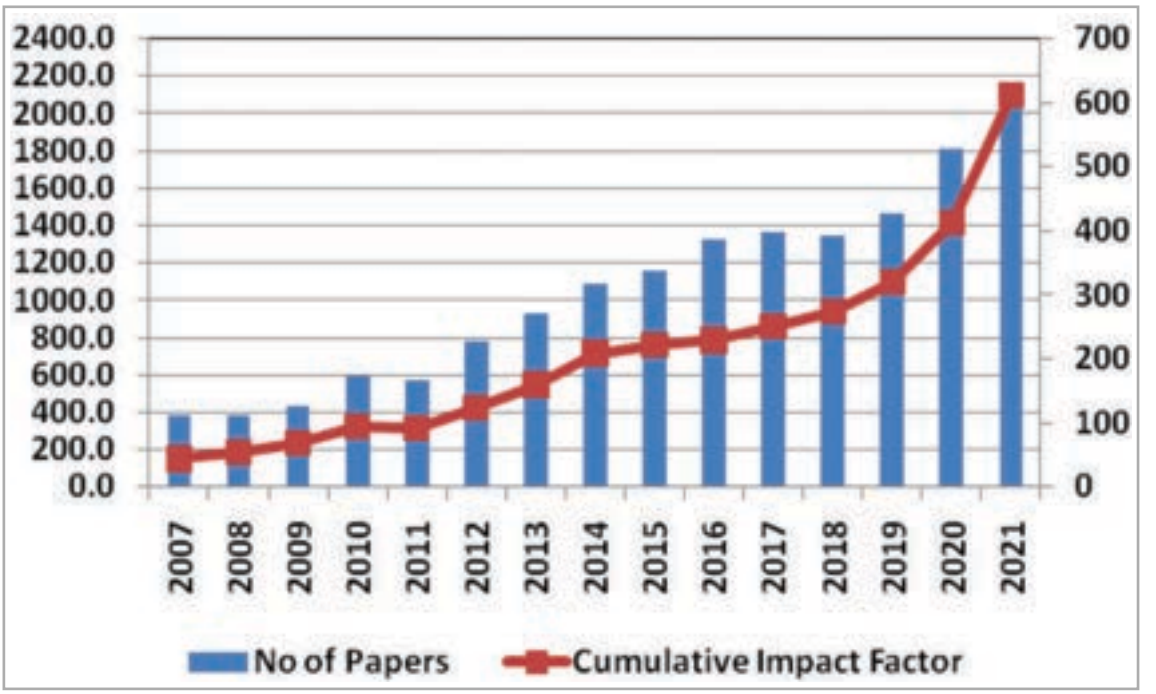

Fig. 9.1 : Number of research papers and cumulative impact factor year wise

9.2 Patents Granted

Details of Patents granted				
Sl. No.	**Innovators**	**Title**	**Country**	**Grant Reference**
1.	Tata Sudhakar, ShijoZacharia, T.Thamarai, V.Gowthaman, G.A.Ramadass, M.A.Atmanand	Tsunami Detection System "TSUNAREC"	India	352188 25.11.2020
2.	Kirubagaran R Thirupathi K Atmanand M.A Dharani G Vinithkumar N.V Mary Leema Thilagam Magesh Peter D	A Microalgal Harvesting System	India	354426 24.12.2020
3.	A. Thirunavukkarasu, G. Raguraman, G. Latha, M.C.Sanjana	An Autonomous Ambient Noise Measurement system for Acoustic Field Characterization in Shallow waters	India	357273 29.1.2021
4.	Purnima Jalihal, D.Sudha, Ashwani Vishwanath	A System for pumping cold water deploying Permanently Moored Floating Conduit from deep sea	India	365861 30.4.2021
5.	Meena B, Anburajan L, Vinithkumar N.V, Dharani G, Kirubagaran R	NIOT-*E. faecalis* Multiplex PCR detection kit – A process for detecting virulent genes of *Enterococcus faecalis* and a detection kit thereof	India	367008 19.5.2021
6.	R.Venkatesan, M.Arul Muthiah, R.Sundar K.Ramesh	Real Time Tsunami Monitoring System	India	369964 22.6.2021
7.	Sundar, R. Srinivasan, Dr. G.A. Ramadass, Dr. M.A. Atmanand	A system and method for calibrating acoustic tide gauge	India	371442 Dt.8.7.2021

In addition to the above, a provisional patent (202121016209, Intellectual property INDIA) has been granted for the invention "A detachable three-layered stainless steel filter chamber to mitigate microplastic pollution and its mobility via ballast water", developed by Ravidas Krishna Naik, Parthasarathi Chakraborty, Priya M. D'Costa, N. Anilkumar, R K Mishra, Veliton Fernandes, and M. Ravichandran from NCPOR.

9.3 Awards and Honours

The awards and honours received by the MoES Institutes/Offficials from other organizations are listed below.

Dr. Mrutyunjay Mohapatra, DG, IMD received appreciation from the Secretary General of World Meteorological Organisation for organising the WMO Tropical Cyclones Forecasters Training Workshop online during 6-18 October 2021 for Panel on Tropical Cyclones (PTC) members with focus on tropical cyclones and related storm surge and impact-based forecasting.

Dr. R. Krishnan, Sc-G, IITM was nominated as Focal Point for the 53rd BIS Session of the IPCC.

Dr. S.D. Pawar, Sc-F, IITM was nominated as a Member, WMO ad-hoc Lightning Extreme Records Committee.

Dr. Thara Prabhakaran, Sc-F, IITM was nominated as the Focal Point for Cloud Seeding Techniques for the MoU signed between the Ministry of Earth Science (MoES) and the National Centre of Meteorology (NCM), United Arab Emirates (UAE) Asia regarding the Scientific and Technical Collaboration between NCM and MoES.

Dr. S. Chakraborty, Sc-F, IITM became the Associate Editor, Frontiers in Water and Climate, and , *Member Editorial Board,* Quaternary International, 2021-2025.

Dr. (Smt.) Suvarna Fadnavis, Sc-F, IITM was nominated as Member, Scientific Steering Committee (SSC), Chemistry-Climate Model Initiative, Stratosphere-Troposphere Processes and their role in Climate (SPARC).

Dr. Roxy Mathew Koll, Sc-E, IITM chaired, 17th Annual Meeting of the CLIVAR/IOC-GOOS Indian Ocean Region Panel, 28 April 2021.

Dr Yogesh K. Tiwari, Sc-E, IITM became an Expert member at the United Nations Framework Convention on Climate Change (UNFCCC) to Technical review of GHG inventories and other annual information reported by Annex-I Parties.

Dr. J.S. Chowdary, Sc-E, IITM has been invited as Review Editor on the Editorial Board of Predictions and Projections, Frontiers in Climate from February 2021.

Dr. Mahen Konwar, Sc-E, IITM was nominated as Member, the International Commission on Clouds and Precipitation (ICCP/IMAS)

Ms. Chaitri Roy, Sc-D, IITM was awarded the Fulbright-Kalam Climate Fellowship for the academic year 2020-2021.

Shri Manmeet Singh, Sc-C, IITM was awarded Visiting Student Researcher under the Fullbright-Kalam Climate Fellowship for doctoral research 2020-2021.

Dr. Purnima Jalihal, Sc-G, NIOT elected as Vice Chair of the Ocean Energy Systems - Technology Collaboration Program (OES-TCP) under the IEA. The OES TCP consists of 24 member countries and she is part of the cabinet consisting of Chair from France and another Vice Chair from European Commission with Member Secretary from Portugal.

Dr. R. Venkatesan, Sc-G, NIOT has been registered as a Chartered Marine Technologist and is a part of an elite group of members of the Marine Technology Register at MTS, SUT, and the IMarEST and to have title "CMarTech" to his post nominal. This recognition is from a prestigious Institution in UK.

NIOT has been bestowed with the "Best Innovative Practices Award" and "Certificate of Appreciation" by Confederation of Indian Industry CII-SR EHS Excellence Awards 2020 in recognition for developing & implementing green technology solutions through Innovative ways onboard NIOT Ships.

INCOIS was conferred with CII Industrial Innovation Awards-2021 under the category "Top Innovative Research Institutions-2021" for its development of GEMINI System for dissemination of Ocean Information Services while out of mobile range.

Dr. T Srinivasa Kumar, Director, INCOIS was appointed as Vice-Chair of International Oceanographic Commission (IOC).

Dr. T Srinivasa Kumar, Director, INCOIS wass appointed as Co-Chair of World Meteorological Organization-International Oceanographic Commission (WMO-IOC) joint collaborative board.

Dr. T Srinivasa Kumar, Director, INCOIS was made member-representative of IOC to the Standing

Committee on Marine Meteorology and Oceanographic services (SCMMO).

Dr. Balakrishnan Nair, Sc-G, INCOIS have been selected as a Members on the WMO Expert Team on Metocean Requirements (ET-MOR). The Expert Team reports to the WMO Standing Committee on Marine Meteorological and Oceanographisc Services (SC-MMO) and will work to ensure the whole marine services value chain meets the needs of both the met-ocean community and the end users.

Dr. Balakrishnan Nair, Sc-G, INCOIS was selected as member of GOOS steering committee.

Dr. TVS Udaya Bhaskar, Scientist-F, INCOIS was selected as member of Ocean Decade Data Coordination Group for the period 2021 – 2023.

Dr. TVS Udaya Bhaskar, Scientist-F , INCOIS was elected as Steering Group Chair of Ocean Teacher Global Academy (OTGA) of IODE, Belgium for the intersessional period.

Dr. G.V.M Gupta, Director, CMLRE has been appointed as the Commissioner representing the country for the Convention for Conservation of Antarctic Marine Living Resources (CCMLR) from 2021 onwards.

Shri N. Saravanane, Scientist, CMLRE -F has been the Steering Group Member of the Scientific Committee of the Convention for Conservation of Antarctic Marine Living Resources (CCMLR) from 2019 onwards.

Dr. Avinash Kumar, Scientist-D, NCPOR, has received the prestigious National Award 'Atal Vagyaanika Shikhar Samman-2020' in the 7th Atal Award Ceremony on 24th December 2020 organised at Vigyan Bhawan, New Delhi.

Dr. Thamban Meloth, Scientist-G , NCPOR has been elected as a Fellow of the National Academy of Sciences India 2020 in December 2020 for his contributions to the polar cryosphere and climate change.

Dr. Sarat Chandra Tripathy, Scientist-F, NCPOR, has been selected as a Co-Chair of the Southern Ocean Indian Sector Working Group (SOIS-WG) of the Southern Ocean Observing System (SOOS).

During the 43rd Antarctica Treaty Consultative meeting 14-24 June 2021, the Committee for Environmental Protection elected Dr. Anoop Kumar Tiwari, Sc-E, NCPOR from India, as Vice-Chair for the next two years.

Chapter - 10

ADMINISTRATIVE SUPPORT

10.1 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	Timely release of weather forecast and warning to General Public and Meteorological support for Pilgrimage, tourism, mountain expedition, sports etc.	3 to 6 Hrs.
2	Providing Agro - Meteorological advisories at district Level	Agro-meteorological advisories at district Level	Twice a Week Tuesday & Friday
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	Timely disposal of applications/appeals	

10.2 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.

10.3 BUDGET AND ACCOUNTS

S. No.	Major Head of Accounts	2019-20 Actual			2020-21 Budget Estimates			2020-21 Actual		
		Revenue	Capital	Total	Revenue	Capital	Total	Revenue	Capital	Total
REVENUE SECTION										
1.	3403-Oceanographic Research	655.44	0.00	655.44	812.80	0.00	812.80	433.56	0.00	433.56
2.	3425- Other Scientific Research	72.66	0.00	72.66	98.20	0.00	98.20	45.65	0.00	45.65
3.	3451- Secretariat Economic Services	36.75	0.00	36.75	44.00	0.00	44.00	34.96	0.00	34.96
4.	3455-Meteorology	854.35	0.00	854.35	947.44	0.00	947.44	704.09	0.00	704.09
	Total (Revenue)	1619.20	0.00	1619.20	**1902.44**	**0.00**	**1902.44**	**1218.26**	**0.00**	**1218.26**
CAPITAL SECTION										
1.	5403-CapitalOutlay on Oceanographic Research	0.00	11.23	11.23	0.00	17.00	17.00	0.00	5.85	5.85

S. No.	Major Head of Accounts	2019-20 Actual			2020-21 Budget Estimates			2020-21 Actual		
		Revenue	Capital	Total	Revenue	Capital	Total	Revenue	Capital	Total
2.	5455-CapitalOutlayon Meteorology	0.00	93.98	93.98	0.00	155.00	155.00	0.00	63.85	63.85
	Total (Capital)	0.00	105.21	105.21	**0.00**	**172.00**	**172.00**	**0.00**	**69.70**	**69.70**
	Grand Total	1619.20	105.21	1724.41	**1902.44**	**172.00**	**2074.44**	**1218.26**	**69.70**	**1287.96**

10.4 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	Two (Para No. 5.1 of Report No. 27 of 2014 on National Data Buoy Project" and Para No. 5.2 of Report No. 27 of 2014 on "Irregular Payment of Gratuity NIOT, Chennai").	NIL	NIL	NIL	NIL

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	
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

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**	
6	2018	One (Para No.8.1 of Report No. 02 of 2018 on "Avoidable expenditure toward rent of bonded warehouse").	NIL	One (Para No. 8.2 of Report No. 02 of 2018 on "Irregular protection of pay NIOT, Chennai").	NIL	NIL
7	2020	One (Para No.6.1 of Report No. 06 of 2020 on "Grant of financial benefits without approval of competent authority").	NIL	NIL	NIL	NIL

10.5STAFF STRENGTH

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

S. No.	Groups of Posts	MOES + CMLRE + NCCR	NCMRWF	IMD	NIOT	NCPOR	INCOIS	IITM	NCESS	TOTAL
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	Group A	142	65	524	95	45	40	170	70	1182
2	Group B	113	15	3760	58	18	27	69	29	4089
3	Group C (including MTS)	74	17	2732	44	23	0	78	57	2947
	TOTAL	**329**	**97**	**7016**	**197**	**86**	**67**	**317**	**156**	**8187**

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

Administrative Support - MoES (Proper), CMLRE, NCCR

The sanctioned strength of the Ministry of Earth Sciences including attached offices i.e 329 during the year 2021-2022. The detailed break up is given below:

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

*Including 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 1.1.2022				Number of appointments made during the calendar year 2018											
					By Direct Recruitment				By Promotion				By Deputation			
	Total No. of employees	SCs	STs	OBCs	Total	SCs	STs	OBCs	Total	SCs	STs	OBCs	Total	SCs	STs	OBCs
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Group A	54	1	3	5	0	0	0	0	1	0	1	0	0	0	0	0
Group B	36	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Group C including MTS	45	15	3	9	0	0	0	0	0	0	0	0	0	0	0	0
Total	135	19	8	17	0	0	0	0	1	0	1	0	0	0	0	0

10.6 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 her, there is a Joint Director (OL), an Assistant Director (OL), two Senior Translation officers and one Junior translation officer along with 3 data entry operators. Hindi Section is responsible for entire translation work and Implementation of Official Language policy of the Govt. of India in the Ministry and its attached/ subordinate offices and autonomous institutes. During the year, appropriate action was taken to ensure implementation of the provisions of the Official Language Act and the Rules framed thereunder.

REVIEW

i) The Annual programme for the year 2021-2022 for implementation of the Official Language Policy of the Union, issued by the Ministry of Official Language as well as orders issued by them were circulated in the Ministry and to all the attached/ subordinate Offices/autonomous institutes for compliance. Progress made in this regard was reviewed through the quarterly reports received from them and critically discussed in the Departmental Official Language Implementation Committee under the Chairmanship of the JS (MoES).

The MoES staff taking part in the events organized during the Hindi Fortnight during 14 September to 30th September 2021.

INCENTIVE SCHEMES

i) Under *Prithvi Vigyan Maulik Pustak Lekhan Yojna*, Shri Gulab Kothari has been awarded the 2nd prize for his Book '**Prithvi:VikasKeGhav'.**

ii) The Ministry observed Hindi fortnight from 14.09.2021 to 30.9.2021. Various Hindi Competitions were conducted during the Hindi Fortnight. Officers and employees form the Ministry participated in these events and the response was tremendous.

OTHER ACTIVITIES

I) Ministry was awarded the second Rajbhasha Kirti Award for the year 2019-20 for its exemplary working in the domain of official language. This award was received by the then Secretary Dr. Shekhar C. Mande in a grand function organized at the Vigyan Bhawan on 14th September 2021.

I) Due to the posts of Hindi lying vacant its subordinate offices, the Ministry has made scientists the nodal officers for the official language related works. This year, out of such officers, two scientists were selected for the Certificate of Honours for doing commendable work.

ii) Last year, during the COVID period, the ministry organized a web lecture series called **'Jan JankeLiye Vigyan'** on topics related to earth sciences, in order to bring science to the masses, wherein the experts from other institutes and universities of the country apart from the ministry submitted their presentations in Hindi.

iii) Along with this, the Ministry of Earth Sciences has prepared a time bound **7 Point Charter** for the development and promotion of Official Language / Regional Languages with the approval of Hon'ble Minister, and about 8 Ministries / Departments led by the Hon'ble Minister have joined hands together to organize two National Conferences – the first on 10th January, 2022 and the second on February 21, 2022, on the occasion of the International Mother Language Day. The Ministry of Earth Sciences will lead both of these grand programs.

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

Dr. Shekhar C. Mande, the then Secretary, MoES receiving the 2nd Kirti Award for 2019-20 from Shri Ajay Mishra, the Hon'ble Minister of State (MHA) at Vigyan Bhavan on 14/09/2021.

v) This year the Committee of Parliament on Official Language has inspected the National Centre for Seismology, New Delhi, Meteorological Centre, Gangtok, and NCPOR, Goa.

10.7_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.

10.8_Implementation of the judgements/ orders of the CAT

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

10.9 Vigilance Activities and Achievements

Dr. Kamaljit Ray, Scientist 'G' is the Chief Vigilance Officer (CVO) of the Ministry w.e.f. 01.01.2020. Senior level Officers have been nominated as Vigilance Officers (VOs) in attached/subordinate offices and autonomous bodies of the Ministry with the approval of CVO. 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.) & ShriRakeshGoyal, IRSE (Retd.) were appointed as Independent External Monitors by the Ministry with the approval of Central Vigilance Commission (CVC) for monitoring the contracts exceeding Rs. 5 crores, in accordance with the guidelines of CVC. Vigilance Awareness Week was observed from 26th October to 1st November 2021 with the theme Independent India @75: Self Reliance with Integrity (स्वतंत्रभारत@75: सत्यनिष्ठासेआत्मनिर्भरता). During the Vigilance Awareness Week, two Workshops were organized by inviting guest speakers. A quiz competition was also conducted for the officers/officials of this Ministry and prizes were awarded to the winners.

10.10 Parliament Matters

Parliament Section which caters to the correspondence with Parliament Secretariat replied Lok Sabha (87 questions) and Rajya Sabha (43 questions) during the year 2021.

10.11 Significant Audit Points Printed in audit Reports of 2021

No audit point has appeared in the Audit Report of 2021.

Chapter-11

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. Deep Ocean Council (DOC) Chaired by Prof. K. VijayRaghavan, Principal Scientific Adviser to the Govt. of India.
2. Program Advisory and Monitoring Committee (PAMC) on Atmospheric Sciences chaired by Prof. G.S Bhat, IISc, Bengaluru.
3. PAMC on Ocean Science and Resources chaired by Dr. S. S. C. Shenoi, Former Director, INCOIS, Hyderabad.
4. PAMC on Hydrology and Cryosphere chaired by Dr. R. R. Navalgund, Vikram Sarabhai Distinguished Professor, ISRO, Bengaluru.
5. PAMC on Geosciences, chaired by Prof. Ashok Singhvi, PRL, Ahmedabad.
6. PAMC on Seismicity and Earthquake Precursors chaired by Dr. M. Ravi Kumar, DG, Institute of Seismological Research, Gandhinagar.
7. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
8. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Marine Ecology and Biology chaired by Prof Dileep Deobagkar, Former VC Goa University, Goa.
9. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Satellite Meteorology, chaired by AVM (Dr) Ajit Tyagi, Former DG, IMD.
10. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Coastal Ocean Technology, chaired by Prof. V. Sundar, IIT Madras.
11. Scientific Steering Committee for Inter-disciplinary Projects of Earth Sciences (IDES), chaired by Dr K. J. Ramesh, Former DG, IMD.
12. Research Advisory Committee of IITM chaired by Prof. J. Srinivasan, IISc, Bengaluru.
13. Research Advisory Committee of NCMRWF chaired by Prof. J. Srinivasan, IISc, Bengaluru.
14. Research Advisory Committee of INCOIS chaired by Dr. Satish Shetye, Former Director, NIO, Goa.
15. Scientific Advisory Council of NIOT chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
16. Research Advisory Committee of NCCR chaired by Dr. Shailesh Nayak, Director, NIAS.
17. Research Advisory Committee of CMLRE chaired by Prof. T. Balasubramanian, Vice Chancellor, Chettinad Academy of Research and Science, Chennai.
18. Research Advisory Council of NCPOR, chaired by Dr. Shailesh Nayak, Director, NIAS.
19. Research Advisory Council of NCESS chaired by Dr. S.K. Tandon Professor Emeritus, University of Delhi.
20. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof. Sulochana Gadgil / Prof Ravi Nanjundiah.

सत्यमेव जयते

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Ministry of Earth Sciences