सत्यमेव जयते

Government of India
Ministry of Earth Sciences

ANNUAL REPORT

2023-2024

FRONT COVER

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2023-2024

Indian station "Himadri" with northern lights - First winter expedition to Arctic

BACK COVER

Scientists in action at Arctic - Field Sampling

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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 major milestones have been accomplished under the six major programs of the MoES during the last year, which are illustrated below:

1. India's maiden Arctic Winter Expedition was launched by Hon'ble Cabinet Minister for Earth Sciences (HMoES) on December 18, 2023 details at https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1987724.
2. The 43rd Indian Scientific Expedition to Antarctica was launched in October 2023.
3. There has been 40-50% improvement in Severe Weather (cyclone, heavy rainfall, heat wave, cold wave, thunderstorms, fog) forecast with lead period of five days during last five years.
4. Impact Based Forecasting (IBF) is being issued for all severe weather events at district and city levels with inclusion of exposure and vulnerability parameters and suggested response actions.
5. Five Doppler Weather Radars (DWR) were commissioned at Landsdowne, Banihal, Murari Devi, Jot and Surkanda Devi taking the total number of DWRs to 39.
6. Four new Meteorological Centres were inaugurated at Port Blair, Imphal, Kohima and Aizawl. The new meteorological centres will make weather-related services better and more useful in these regions. With these new four additions, the country's total number of meteorological centres has risen to 26.
7. The number of Nowcast stations has increased from 1124 (2022) to 1200 and the number of city forecast stations has increased from 1181 (2022) to 1300.
8. A new website for disseminating information was released, including alerts for block-level weather forecasts and advisories to benefit our agricultural community, including farmers, fisherfolk, and livestock rearers. The website will be accessible at https://www.greenalerts.in/. The weather-related information shall be disseminated in English and Hindi and in regional languages in the future. The India Meteorological Department (IMD) will be collaborating with the Ministry of Panchayati Raj to share the real-time weather forecasts disseminated through this website with Heads and Members of the Gram Panchayats through SMS or WhatsApp. This is being done to ensure that weather-related services of the MoES effectively reach the last-mile user.
9. India secured the prestigious role of hosting the World Meteorological Organization (WMO), United Nations Economic and Social Commission for Asia and the Pacific Panel on Tropical Cyclones Secretariat for 2024-2027.
10. NCMRWF was recognized as the Indian Technical and Economic Cooperation Training Center by the Ministry of External Affairs for 2023.
11. A detailed report of the CAIPEEX IV (Cloud Aerosol Interaction and Precipitation Enhancement Experiment) by the Indian

Institute of Tropical Meteorology (IITM), Pune was released. The report elaborates results and recommendations of a scientific experiment strategy called cloud seeding used for enhancing rainfall. It finds that rainfall can be enhanced by up to 46±13 per cent at some locations and on average, and 18±2.6 per cent in 100 square kilometres area in the downwind of seeding location over the rain shadow region of Solapur, Maharashtra. The cloud seeding project contributed to 867 million litres of water, yielding a positive cost-benefit ratio. The report is freely available for download on the IITM website. It aims to benefit a variety of stakeholders, especially academia and policy-makers.

12. The NCMRWF Data Assimilation (DA) system makes continuous efforts to include new observations for improving its forecast quality. In this direction ATOVS satellite observations, Meteosat-10 Spinning Enhanced Visible and InfraRed Imager (SEVIRI) and Atmospheric Motion Vectors (AMV) observations, more Ground GPS observations, ISRO's Oceansat-3 and Microsate-2B observations and Reflectivity and radial velocity observations from more IMD Doppler Weather Radar observations have been used in assimilation from this year.

13. A very high-resolution (400) Air Quality Early Warning System (AQEWS) integrated with A Decision Support System (DSS) for air quality has been developed, showing an accuracy of 88% for predicting extreme pollution events, which is much higher than the estimates available for a similar system across the globe. This early warning system provides: (1) near real-time observations of air quality and visibility over the Delhi region and details about natural aerosols like dust (from dust storms), fire information, and satellite AOD; (2) predictions of air pollutants based on the state-of-the-art atmospheric chemistry transport models; (3) warning messages, alerts, and bulletins; and (4) forecast of the contribution of non-local fire emissions to the air quality in Delhi. The statutory body, Commission for Air Quality Management (CAQM) in the National Capital Region and the Adjoining Regions, has used AQEWS and DSS extensively.

14. INCOIS was designated as World Meteorological Organization-Regional Specialized Meteorological Centres (WMO-RSMC) for Numerical Ocean Wave Prediction and Global Numerical Ocean Prediction.

15. A new mobile application to provide comprehensive information on all ocean-related services of the Indian National Centre for Ocean Information Services (INCOIS). The mobile app named SAMUDRA (Smart Access to Marine Users for Data Resources and ocean Advisories) provides information on ocean-related services of INCOIS, including (but not limited to) potential fishing zone advisories, ocean state forecasts, and alerts on tsunamis, cyclones, storm surges, high waves, swell surges, etc. The app is designed using the latest technologies and will help disseminate information directly to users, especially coastal communities.

16. A new web portal featuring the biodiversity of our Indian Ocean EEZ (Exclusive Economic Zone) was made open to the public. The web portal is called IndOBIS and can be assessed at https://indobis.in/. The portal has been developed by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi. IndOBIS provides information on marine species of the Indian Ocean, including their occurrence and scientific classification. It serves as one of the 30 regional nodes of the OBIS (Ocean Biodiversity Information System). OBIS is an international open-access web platform for data and information on biodiversity and biogeography of global marine life. OBIS is a project under the Intergovernmental Oceanographic Commission (IOC)-UNESCO International Oceanographic Data and Information programme.

17. A detailed scientific catalogue entitled 'Systematic account of Indian deep-water Brachyuran crabs collected during the expeditions of FORV Sagar Sampada' was

released. It provides in-depth information on deep-sea crab diversity in the Indian EEZ (Exclusive Economic Zone) with pictures and maps of sampling locations.

18. A new dromiid crab species from the south-eastern Arabian Sea and southwestern Bay of Bengal, India, at depths of 107–113 m. This is the second new species of Epigodromia McLay 1993 discovered in Indian waters. One new species of the pelagic basslet fish, namely Bathysphyraenops radhae, by taxonomic studies of archived samples in the Central Indian Ocean.
19. The National Glider Operations Facility, e Classroom Facility at the International Training Centre for Operational Oceanography (ITCOO), Oceansat-3 Data Acquisition and Processing Facility, and marine heat wave service for the Indian Ocean were launched in February 2023.
20. Inauguration of desalination plants at Kalpeni and Amini islands of UT of Lakshadweep by Honourable President of India Smt Droupadi Murmu on March 18, 2023. The desalination plant at Kadamat was inaugurated by the Honourable Prime Minister on 03 January 2024.
21. NIOT handed MDART (Mooed Buoy Data Analysis and Representation Tool) to the Indian Navy.
22. NIOT exchanged two technology transfer licensing agreements for Met Ocean Buoy System-I &II Mechanical Components with M/s Next Eng Enviro Pvt Ltd, Ahmedabad.
23. NIOT transferred indigenous Acoustic Sub Bottom Profiler technology to M/s Bharat Electronics Limited, Bangalore, through the National Research Development Corporation (NRDC).
24. The 42nd Indian Scientific Expedition to Antarctica deployed ice-tethered oceanographic mooring at Prydz Bay, East Antarctica, to collect data on the physical parameters of the under-ice water column.
25. Inauguration of the ship tracking system for scientific data management system that facilitates the real-time monitoring of the ship's scientific data and movements, aligning with global maritime requirements.
26. Mega citizen-led beach clean-up drives were conducted at 79 locations in 8 coastal states and 4 UTs of the country on September 16, 2023, that continued on September 17, 2023, to mark International Coastal Clean-up Day as part of Swachh Sagar Surakshit Sagar campaign.
27. About 56 cruises were taken on Indian Ocean Research Vessels (06): Sagar Nidhi, Sagar Manjusha, Sagar Tara, Sagar Anveshika, Sagar Kanya, and Sagar Sampada.
28. The Seismological Observational Network includes 158 stations. Around 1411 earthquakes were monitored in the Indian region, out of which ~55 events (M>5) and ~31 seabed earthquakes (M>6) with a potential to generate tsunami occurred in 2023. The information was disseminated in less than 12 minutes of occurrence of the events.
29. A geochronology facility at the Inter-University Accelerator Centre (IUAC), New Delhi, is being developed to cater to the needs of the country's geoscientists. The geochronology facility is mandated to create an internationally competitive centre for geochronology and isotope geochemistry that will facilitate the generation of quality isotopic data for geochronological and isotopic fingerprinting. IUAC will have two major machines: an Accelerator Mass Spectrometry (AMS) and a High-Resolution Secondary Ionization Mass Spectrometry (HR-SIMS). HR-SIMS has been recently established and operational at IUAC, New Delhi, and will aid scientists in deciphering complex growth histories in processes that led to Earth's crust formation and continental dynamics.
30. Seismic microzonation of major Indian cities for earthquake hazard assessment and risk reduction measures is in progress. It provides the deliverables to minimise the loss of lives and property in an earthquake. Seismic microzonation has been completed for Jabalpur, Guwahati, Bengaluru, Sikkim, Ahmedabad, Gandhidham-Kandla, Kolkata and

Delhi. The field studies are nearing completion for Bhubaneswar, Chennai, Coimbatore and Mangalore.

31. The International Training Centre for Operational Oceanography (ITCOOcean) conducted 15 training programs and one seminar. A total of 850 persons were trained of which 680 (Male: 436, Female: 244) are from India and 170 (Male: 116, Female: 54) are from other Indian Ocean RIM countries.
32. The Development of Skilled Manpower in Earth System Sciences and Climate (DESK) conducted 3 training programs for about 200 scientists.
33. A number of outreach and awareness programs about the services being provided by MoES were organized throughout the country
34. **G 20 – Research and Innovation Initiative Gathering (RIIG) activities:**
    MoES and DST jointly coordinated the G 20 – Research and Innovation Initiative Gathering (RIIG) activities under the theme "Scientific Challenges and Opportunities for a Sustainable Blue Economy". The meeting included 35 foreign delegates. The key sub-thematic areas related to the Blue Economy, including (a) Blue Economy sectors and opportunities, (b) Marine Pollution, (c) Coastal and Marine Ecosystems and Biodiversity, (d) Observations. Data and Information Services, (e) Marine Spatial Planning, (f) Deep-Sea Exploration, New and Renewable Offshore Energy and (g) Blue Economy Policies and Management Strategies were discussed during the meeting. The speakers emphasised that while the global ocean and its resources hold tremendous potential for economic growth, they are under severe stress from the accelerating impacts of climate change, growing mariner pollution, over exploitation and declining biodiversity.

1.1 Scientific Publications

A total number of 502 research papers were published during 2023 by MoES scientists under various programs of the Ministry, and the total impact factor is 1943.63(Fig. 1.1). The average impact factor of research papers was 3.87.

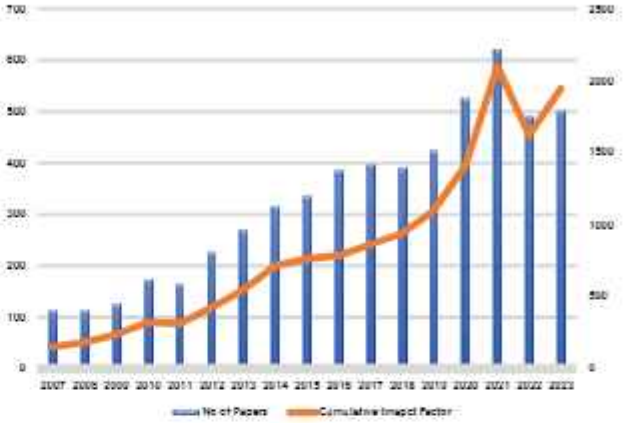


Fig. 1.1: Number of research papers and cumulative impact factor year wise

1.2 Budget Expenditure:

The total outlay for the Ministry for the year 2023-24 was Rs.2653.51 crores which was reduced to Rs. 2056.47 crores at the RE stage. The expenditure profile for the last 15 years is shown in the table below.

Year	BE	RE	Actual Expenditure
2007-08	887.95	655.85	562.03
2008-09	972.90	820.00	751.69
2009-10	1213.20	1137.20	1080.51
2010-11	1305.25	1281.06	1098.07
2011-12	1569.12	1227.01	1174.58
2012-13	1672.29	1198.66	1177.14
2013-14	1693.73	1311.12	1248.15
2014-15	1702.23	1336.88	1294.35
2015-16	1622.68	1420.98	1296.80
2016-17	1672.45	1579.11	1459.76
2017-18	1719.48	1597.89	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	2194.39
2022-23	2653.51	2056.47	1588.06
2023-24	2071.00	1575.00	882.39*

*As on 31/01/2023

Chapter–2

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

2.1 Introduction

One of the mandates of the Ministry of Earth Sciences (MoES) is to provide Weather, Climate and Hydrological Services to various users round the clock and round the year. Both operational and research aspects for these services are implemented under the Umbrella program, ACROSS by the India Meteorological Department (IMD), Indian Institute of Tropical Meteorology (IITM) and National Centre for Medium Range Weather Forecasting (NCMRWF).

During the year, many significant achievements have been made in providing weather and climate services for societal and economic benefit of the country. This entails major improvements in atmospheric and oceanic observations and data assimilation in numerical weather and climate models. Intense observational campaigns also have been taken up as special atmospheric observations help us to understand model deficiencies and to improve the skill and accuracy of models. Details of significant achievements made under the program ACROSS are given below.

2.2 Lower Atmospheric Research Using Unmanned Aerial System Facility (LARUS)

Unmanned aerial vehicles (UAV) field campaign to profile the boundary layer for measurements of meteorological and aerosol properties was organized at Osmanabad during 2-17 October 2023 (Fig. 2.1).

Fig. 2.1 Unmanned Aerial Vehicle (UAV-IITM) 2023.

In-house developed systems under LARUS: Miniaturized Radiosonde Ground Receiver (mRGR) system along with a suitable portable Ground Plane (GP) antenna has been developed in-house for meteorological data telemetry from different aerial platforms such as balloons and UAVs/ drones to ground station. The high-resolution data in the boundary layer reveal small scale features in the meteorological parameters as compared to Radiosonde balloon data. **Miniaturized Green House Gas sensor (mGHG)** system: Prototype system in-house designed and developed for making air pollution measurements on a UAV/drone platform. Vertical profiles of CO, CO_2, O_3, NO_2, SO_2 obtained at 1 sec interval showed varied concentrations at different altitudes up to 200m above the ground.

2.3 Atmospheric Research Testbed (ART) facility in central India

The ART programme is a highly focused observational and analytical research effort for understanding the physical processes of clouds and rain formation. It will help to compare the observations with modelling forecasts and simulations for accelerating improvements in both observational methodology and monsoon prediction models. A state-of-the-art aerosol measurement facility has also been established at the ART facility at Silkheda village of Madhya Pradesh testbed for continuous measurement of physical, optical and chemical properties of aerosols in conjunction with the cloud observations in the monsoon core region (Fig. 2.2a). An intense atmospheric observational campaign (coordinated radiosonde observations at ART site (2 soundings/day: 6 UTC and 18 UTC) and various other IMD locations, primarily within the monsoon core zone, was conducted during the monsoon period from 15 June-15 October 2023 (Fig. 2.2b). These unique data sets are useful for understanding the dynamical and thermodynamical structure of atmosphere and are used for data assimilation and preparation of initial conditions in the NWP models.

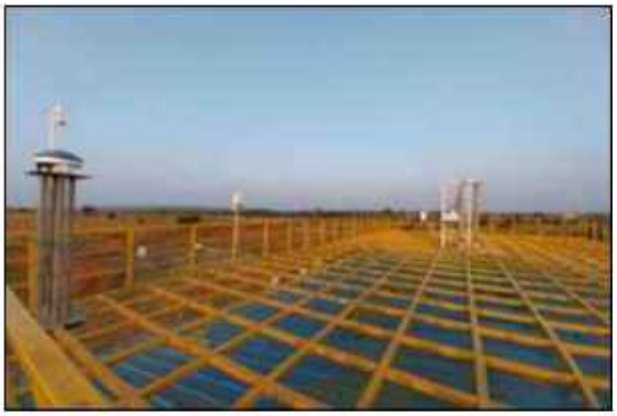


Fig. 2.2 (a) Instrumentation for measuring physical, optical and chemical properties of aerosols; (b) A radiosonde launch for measuring vertical profiles of atmospheric state parameters during the monsoon 2023 campaign at ART facility.

The GHG monitoring team at CCCR has installed a 72 m tall tower at ART site (Fig. 2.3) as a representative location in the core monsoon zone over central India. The tower is being instrumented with three levels of GHG measurements vertically, two levels of eddy covariance measurements, Photosynthetically Active Radiation (PAR) sensors, and Line PAR sensors, eight levels of multi-component weather sensors, and soil moisture measurements at ten levels below ground at one-meter depth, and radiation sensors at 2-levels. These multilevel measurements will facilitate information about the variation and mixing of GHGs within the surface layers and above. This unique facility simultaneously observes key atmospheric and land surface variables useful for climate change research in India.

2.4 High-Altitude Cloud Physics Laboratory (HACPL)

The HACPL at Mahabaleshwar was established to improve the understanding of the aerosol-cloud interactions, cloud microphysical processes so as to develop different parameterization schemes. The long-term data on hygroscopicity is utilized to develop a size-dependent hygroscopicity parameterization which is being evaluated in numerical modelling. Additionally, long term ice nuclei measurements are utilized to develop heterogeneous ice nuclei parameterization for the Indian region. The study of VOCs revealed that isoprene dominated among most of the measured VOCs indicating the contribution of biogenic emissions over the region.

Fig. 2.3 Instrumented a 72-meter tower for measuring atmospheric GHG and other meteorological variables at ART facility.

2.5 CAIPEEX Phase-IV Indian Cloud Seeding Experiment

CAIPEEX was done in four phases and the lessons learned from the first three phases were used to plan and execute the fourth phase. In the fourth phase of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX-

IV) at Solapur Maharashtra, a scientific investigation was conducted over a rain shadow region of the Western Ghats mountains in India. The experiment has contributed to 267 randomized samples of convective clouds seeding. The primary objective was to investigate the efficacy of hygroscopic seeding in convective clouds and to develop a cloud seeding protocol. CAIPEEX followed the WMO recommendations for scientific investigation of cloud seeding. The initial results of the airborne campaign in the monsoon period of 2018 and 2019 with two instrumented aircraft, a ground-based dual-polarization C-band radar, a network of rain gauges, radiosondes, and surface aerosol measurements were reported. The first physical evaluation of hygroscopic seeding through in situ microphysical observations and numerical simulations was conducted and key cloud microphysical processes in the seeding hypothesis were tracked. The formidable challenges of assessing seeding impacts in convective clouds and the results from 150 seed and 122 no-seed samples of randomized experiments were illustrated. Over 5,000 cloud passes from the campaign provided details about the convective cloud properties as the key indicators for a seeding strategy and the evaluation protocol. Advanced methods were developed: (a) Cloud seeding decision support tool for hygroscopic seeding and (b) Entrainment parameterization for large-scale models. CAIPEEX IV phase has shown that there is a relative enhancement of rainfall in the seeded samples compared to no-seed samples. The rainfall can be enhanced by up to 46±13 percent at some locations and on average based on the rain gauges 18±2.6 percent in 100 square kilometers (km^2) area in the downwind of seeding location over the rain shadow region of Solapur, Maharashtra. The experimental results suggest that cloud seeding can be approached scientifically to reduce uncertainty as an effective mitigation strategy to combat rainfall deficiencies. Lecture series on Cloud Physics were conducted and is made available on IITM YouTube channel. The CAIPEEX report, entitled "CAIPEEX Cloud Seeding Experiment Results and Recommendations" was released to the scientific community by the Hon'ble Minister for Earth Sciences, Shri. Kiren Rijiju, on the 17th Foundation Day of MoES (Fig. 2.4).

Fig. 2.4 CAIPEEX Report released by Hon'ble Minister for Earth Sciences, Shri. Kiren Rijiju on MoES Foundation Day, 27 July 2023.

2.5.1 CAIPEEX 2023 Lidar Monsoon experiments

A new intensive observational campaign was started on 30th May 2023 at Solapur to investigate aerosol vertical profiles and cloud characteristics. The experiment will focus on: a) surface and boundary layer exchange processes, b) role of low-level jet and moisture, c) aerosol transport, d) impact of clouds on the boundary layer processes, aerosols above clouds and cloud layers, and e) estimates of radiative forcing.

2.6 Modelling work at NCMRWF

2.6.1 Global observations and Data Assimilation

NCMRWF receives worldwide meteorological and oceanographic observations through Global Telecommunication System (GTS), satellite observations (NOAA/NESDIS, EUMETSAT, ISRO), etc. which are processed, quality controlled and assimilated in Data Assimilation (DA) systems to prepare initial conditions based on which numerical models are integrated forward in time to generate numerical weather forecasts of different timescales. Oceansat-3 scatterometer sea surface winds data was successfully validated and efforts are being made to incorporate wind observations into the assimilation systems (Fig. 2.5).

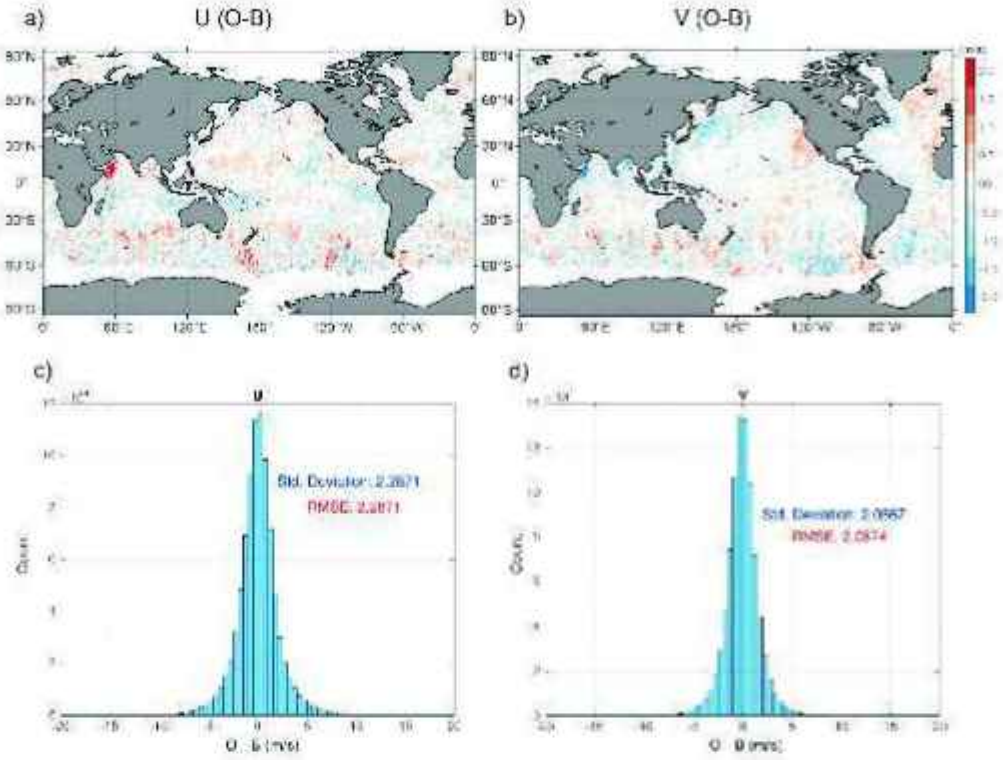


Fig. 2.5 (a, b) Difference in U & V wind component of Oceansat-3 scatterometer observations from the model background of U & V (first guess), (c, d) RMSE and Standard deviation of the observations (One month observation).

Assimilation-forecast experiment was successful for a set of sample radiances of Microsat-2B humidity sounder which helped to reduce the innovations both in the background and analysis. Other important observations added to the DA system recently are GNSS-RO data from PlanetIQ and Sentinel-6. The in-house developed DBNet data processing system from INCOIS and NRSC prepares the DBNet BUFR files and the same are disseminated through the global GTS. The quality of radiosonde data from IITM Test Bed at Bhopal and CAIPEEX experiments are analysed for their possible assimilation. Many of the GTS communication issues has been resolved and the use of IMD upper air and surface observations in the DA systems has been improved. Validation of wind profiler data from NAVY and Cochin University ST radar is ongoing. IMD Agro-AWS soil moisture and soil temperature observations are also validated for the 2023 monsoon season.

"Hybrid 4D-Var" DA method is used in the NCUM-G NWP system for the preparation of model initial condition/analysis whereas the regional assimilation system uses 4D-Var system. New observations, viz: ATOVS satellite observations directly from HRPT Hyderabad, Meteosat-10 Spinning Enhanced Visible and InfraRed Imager (SEVIRI) and Atmospheric Motion Vectors (AMV) observations, more Ground GPS observations, ISRO's Oceansat-3 and Microsate-2B observations are received and added to the NCUM-G DA system, after validation and successful assimilation-forecast experiments. Reflectivity and radial velocity observations from IMD Doppler Weather Radar observations are included in the regional atmospheric DA system. The coupled DA system of the experimental global coupled NWP system is improved with hybrid 4D-Var for atmosphere. Ocean DA system of 3D-Var method (NEMO Var) and Extended Kalman Filter (EKF) for land surface assimilations are tested for numerous cases and are also improved with the new capabilities to assimilate more observations.

The GSI analysis scheme, which provides initial

condition to IMD-GFS NWP system, has been updated for incorporating and new observations including GNSS-RO data from Grace-C & D, PlanetiQ and Sentinel-6; GNSS_IPW data from SOI-CORS network, Himawari-9 AMV and radiance observations, and Oceansat-3 Scatterometer winds. CRTM fast radiative transfer model used with GSI is incorporated with in-house generated spectral and transmittance coefficients. Coefficients for Microsat-2B Microwave sensors are successfully generated and the observation is presently in the testing phase for assimilation.

Two High Resolution Rapid Refresh (HRRR) DA systems based on WRF (1 km) and NCUM-R (1.5 km) are developed. NCUM-R HRRR system is configured over Indian region with three different domains (Mumbai, Chennai and Northeast). Indian DWR observations are assimilated in the system every 15 minutes along with satellite and convectional observations through 4D-Var DA technique. WRF based hourly updating HRRR DA system configured for North India domain also make use of Indian DWR observations. This system became operational in October 2023.

2.6.2 Global/Regional Atmospheric Model

The NCUM seamless weather prediction system based on the Unified Model (UM) system of "UM Partnership" has been upgraded periodically to adapt new scientific and technological developments for improving the global and regional model configurations. An advanced UM based global coupled NWP system (CNCUM-G) for the medium range weather prediction is being tested for many cases including the tropical cyclone forecast over the Indian region. NCUM global model with a grey scale horizontal resolution of 6 km has been developed and is being tested on Mihir HPC system. This is a prototype of the current operational NCUM global model with mass flux deep convective parameterization scheme. Science configurations of this high-resolution global model is being improved by physics such as scale aware convective parameterization scheme. Fig. 2.6 shows the spatial distribution of precipitation categorical verification skill scores of the 6km NCUM runs for July 2023.

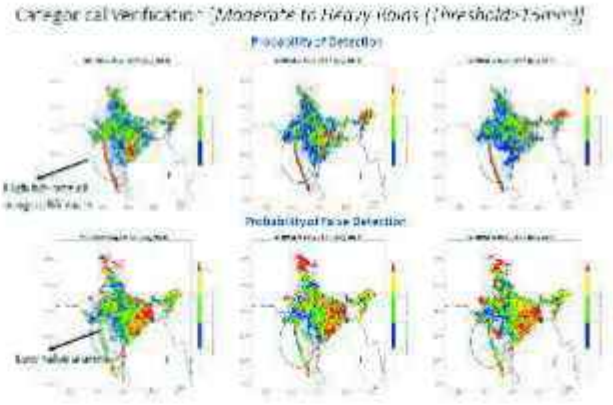


Fig. 2.6 Spatial distribution of the categorical skill scores (POD and POFD) for precipitation (mm/day) from (6 km) model runs of NCUM-G for day-1, day2 and day-3 forecast.

The NCMRWF regional UM model at 4 km resolution (NCUM-R) for the Indian region was upgraded with improved science settings (Regional Atmosphere version3, RA3) and increased vertical levels - 90 levels with top at 40 km height). The science changes include double moment cloud microphysics where particle size distribution is determined by both hydrometeor mass mixing ratio and number concentration and accounts for more physically based cloud-aerosol interactions. Another important change is the bimodal cloud scheme replacing the previous unimodal scheme to allow for more realistic mixing and exchange between the boundary layer and free troposphere. The new science settings were found to be a step change in forecast improvement with respect to precipitation distribution. The lightning scheme was also tuned to suite the new science settings with a focus on better prediction of areal coverage and extreme hot spots. Regional Data Assimilation (RDA) system based on RA3 version of NCUM-R was developed and operationalised from May, 2023.

Delhi Fog Model (DM-Chem) of very high resolution (330 m) has been upgraded with latest science version (RA3) and was used for the winter fog forecasting of 2022-23. The previous one-moment cloud microphysics scheme was replaced with double moment scheme (CASIM scheme) and the unimodal cloud fraction scheme was replaced with abi-modal scheme. The land surface model is coupled to chemistry and aerosol module through a

dry deposition scheme. Land model of the DM-Chem has been improved with more detailed treatment of urban canopy parameterization scheme (MORUSES) which employs Delhi local morphology for deriving building heights and canopies. Fig. 2.7 shows the time evolution of visibility, screen temperature and surface wind speed for January 2022 against the observed values at IGI Airport, New Delhi.

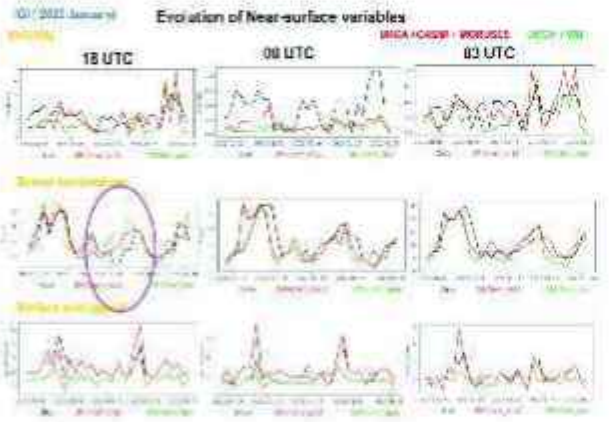


Fig. 2.7 Comparison of time series of daily visibility (m), screen temperature (°C) and wind speed at 10m above ground (ms^{-1}), simulated by DM-Chem model with its previous version (UKCA+WB: red colour contour) and the new version (UKCA+CASIM+MORUSES: green colour contour) against ground observations at IGI airport, Delhi for January 2022.

NCMRWF Seamless prediction system enables use of its coupled setup for the sub-seasonal and seasonal prediction and produces ocean and sea-ice analysis and forecast products from the operational system. Coupled system has UM atmospheric component, JULES land surface model, NEMO ocean model and Los Alamos Sea Ice Model. Weakly mean forecast products of sea ice products, SST, sea ice thickness, sea ice concentration etc are produced from the one month forecast. Seasonal forecast is prepared every month (23rd day of the month) from the 55-ensemble runs of the coupled seasonal prediction system. Fig. 2.8 shows the forecast prepared on 23rd October 2023 which suggests weakening of El-Nino by March-April 2024.

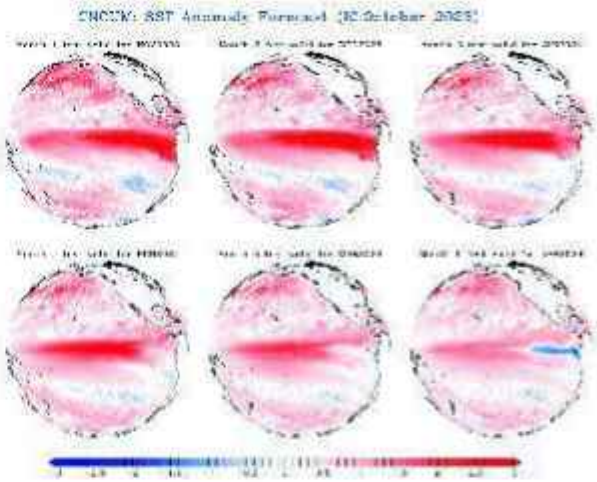


Fig. 2.8 Monthly mean SST anomalies from the NCMRWF seasonal forecast (October 2023 initial condition).

Recent studies by NCMRWF highlighted the usefulness of the monthly mean forecasts from coupled model over the homogeneous regions. Skill of rainfall averaged over homogeneous regions is generally high for monthly forecast as compared to seasonal forecast. But for all India, the skill of seasonal forecast is comparable with the monthly time scales.

2.6.3 Global Ensemble Prediction System

Ensemble prediction systems (EPSs) have become a very valuable tool in weather forecasting as it helps to quantify the uncertainty associated with weather predictions. Currently, NCMRWF is running the highest resolution global ensemble prediction system in the world of 12 km horizontal resolution. A detailed collaborative study with UK Met Office is being carried out to identify the optimal ensemble configuration. It is important to assess the value of Tropical Cyclone (TC) related products and determine at which stages the maximum benefit can be obtained, whether from a lagged ensemble or the ensembles valid at the same time. Investigations have been conducted to analyse the TC tracker and assess its performance through experiments involving cases from past three years.

2.6.4 Model Verification and Applications

The accuracy of forecast products provided by advanced Global Data Processing and Forecasting

System (GDPFS) Centres is monitored through objective verification procedures by WMO. NCUM and NEPS forecasts have been evaluated as per the WMO specified guidelines and the verification metrics are being shared with the WMO Lead Centre. This allows the intercomparison of model performance alongside the performances of other modelling centres of the world. Apart from the verification scores generated for exchange under GDPFS verification of WMO, a robust system for model verification and diagnostics is employed. Our seamless weather prediction system, spanning various timescales and spatial resolutions within the Unified Model Framework, encompasses deterministic, ensemble, and coupled models. This necessitates a comprehensive verification and diagnostics system to assess forecast quality. Utilizing the Model Evaluation Tools (MET) (https://met.readthedocs.io/) and in-house developed verification packages, many verification scores are prepared and used. Fig. 2.9 illustrates the unified forecast system verification capabilities for NCUM models and IMD GFS model.

Fig. 2.9 Comprehensive verification flow diagram for the NCMRWF seamless weather prediction system.

A novel model diagnostic was developed for analyzing the Kinetic Energy (KE) spectra computed from two operational models, namely, NCUM-Global (NCUM-G) and NCUM-Regional (NCUM-R), with spatial resolutions of approximately 12 km and 4 km, respectively. The implications of these KE spectra are for understanding and assessing the models' capabilities. The evaluation of KE spectra is conducted using the Helmholtz decomposition, which separates horizontal flow fields into rotational and divergent components. This approach allows one to assess the high-resolution capabilities of NCUM-R in resolving mesoscales relative to NCUM-G. This study holds significant implications for the future development of high-resolution models.

A detailed study was carried out to document the impact of improvements in the different model configurations with a focus on tropical cyclone forecasting of track and intensity forecasts. Three major changes in the model system during recent five years, viz., increased grid resolution from 17 km to 12 km, use of Hybrid 4D-Var DA and increased volume of data assimilated is highlighted. Besides a consistent improvement in the NCUM-G model forecasts during the pre-monsoon (April-May) and post monsoon (October –December) TC seasons, there is a reduction (27%) in the initial position error. The study reports statistically significant reduction in the Direct Position Error (DPE) and Landfall position errors, resulting in a forecast gain of 24 hours.

Model analysis and forecast products are shared with IMD and used for various applications in different sectors like agriculture, hydrology, renewable energy, tourism/adventure etc. High resolution numerical weather forecasts of near surface fields are used by renewable energy companies for power forecasting. Additionally, the reanalysis data products have helped renewable energy projects to accurately assess and update the solar and wind energy potential over India. Seasonal and Extended Range forecasts are also helping the power generators to plan the maintenance operations. There are various hydrological applications for which the model data is being used, ranging from runoff modelling over river basins to urban flooding. Forecasting for the 'Amarnath Yatra' is a unique initiative to help the authorities in planning the event and protecting the tourists in the event of landslides and flash floods.

2.7 Global and regional modelling at IMD

2.7.1. Regional Climate Centre Activities-Seasonal climate outlook for South Asia using Feb ICs, 2023

The climate research and services at IMD, Pune has

been recognized as the Regional Climate Centre (RCC) for South Asia by the World Meteorological Organization (WMO). Monsoon Mission Climate Forecast System (MMCFS) is used for the RCC long-range forecasts based on initial conditions (ICs) of Feb, Apr, May, Jul, and Aug 2023. Providing global monthly and seasonal (anomaly and probability) forecasts for temperature and rainfall, and is updated every month. Also, prepared seasonal climate outlook for temperature and rainfall for the next 2 moving 3-month season (total 4 months) with monthly update. The March-April-May (MAM) season indicates that enhanced probability of above normal temperatures is likely over most parts of north along the foothills of Himalayas and southeast region where enhanced probability of below normal temperatures is likely (Fig. 2.10). Temperature probability forecast for April-May-June (AMJ) season indicates that enhanced probability of below normal temperatures is likely over most parts of northwest and north along the west coast and enhanced probability of above normal temperatures is likely over most parts of south-central, eastern and extreme southern parts of South Asia. Monthly and seasonal El Nino-Southern Oscillation (ENSO) & Indian Ocean Dipole (IOD) bulletins with monthly update and Fig. 2.11 shows ENSO & IOD forecast for next 7 seasons.

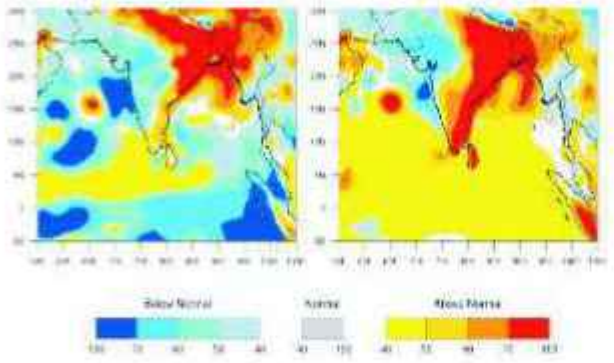


Fig. 2.10 Seasonal probability (%) forecasts of MAM & AMJ season for temperature based on initial conditions of Feb 2023 for South Asia.

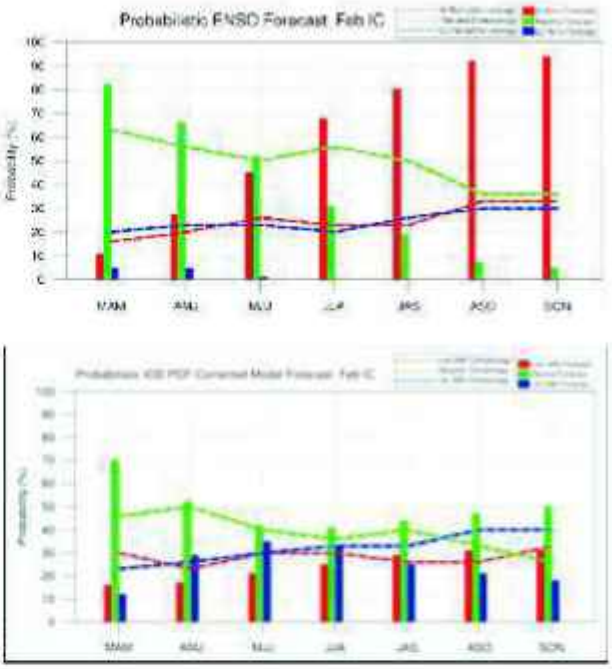


Fig. 2.11 Probabilistic forecast for ESNO (top) and IOD (bottom) prepared using MMCFS Feb ICs, 2023.

2.7.2. Seasonal climate outlook for South Asia using April ICs, 2023:

The probability forecast for precipitation for May-June-July (MJJ) and June-July-August (JJA) indicates that enhanced probability of below normal precipitation is likely over most parts of South Asia except over some parts of northwest, southeast, extreme south and northeast of peninsula where above normal precipitation is likely (Fig. 2.12). Temperature probability forecast for MJJ season indicates that enhanced probability of below normal temperatures is likely over most parts of northwest and north along the plains of Himalayas and enhanced probability of above normal temperatures is likely over most parts of west, central, eastern and extreme southern parts of South Asia. Northeast and southern region of South Asia is likely to have climatological probability. The JJA season indicates that enhanced probability of above normal temperatures is likely over most parts of South Asia except over some parts of extreme northwest, north along the foothills of Himalayas and southeast region where enhanced probability of below normal temperatures is likely (Fig. 2.13).

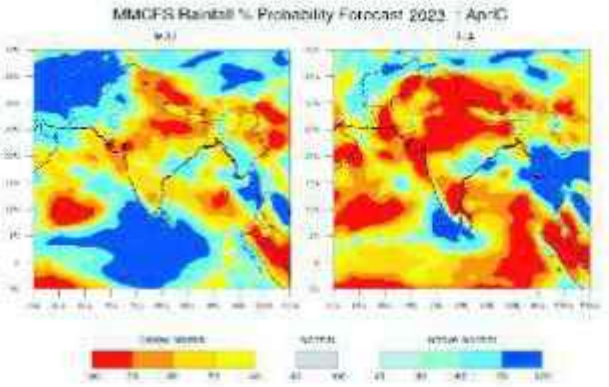


Fig. 2.12 Seasonal probability (%) forecasts of precipitation for (a) MJJ 2023 (left) and (b) JJA 2023 (right) based on initial conditions of April 2023.

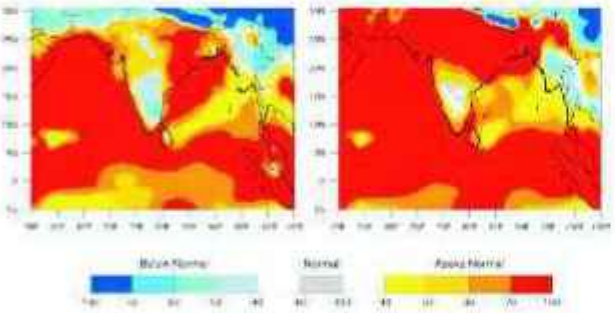


Fig. 2.13 Seasonal probability (%) forecasts of temperature for (a) MJJ 2023 (left) and (b) JJA 2023 (right) based on initial conditions of April 2023.

IMD prepares ENSO & IOD bulletin every month providing statement on the global SST anomalies and probabilities forecast with emphasis on the ENSO and IOD conditions for the next 9 months (Fig. 2.14).

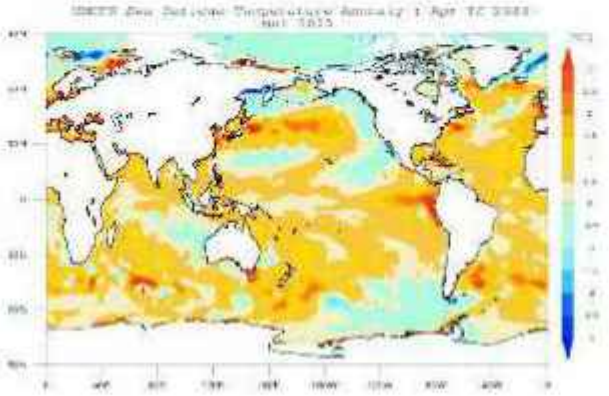


Fig. 2.14 Global sea surface temperature anomaly (top) and probability forecast (bottom) for the month of May 2023 using the April initial conditions.

2.7.3. Seasonal climate outlook for South Asia using July Ics

The probability forecast for precipitation for September-October-November (SON) indicates enhanced probability of above normal precipitation in extreme northwest, northeast and south Peninsular regions and enhanced probability of below normal precipitation in north, west, central, east and north peninsular regions of South Asia. The same for October-November-December (OND) indicates that enhanced probability of above normal precipitation is likely over most parts of South Asia except over some parts of north Peninsular regions and central parts of South Asia where enhanced probability of below normal precipitation is likely (Fig. 2.15). Temperature probability forecast for SON and OND seasons indicates that enhanced probability of above normal temperatures is likely over most parts of South Asia except over some parts of north along the Himalayan Plains where probability of below normal temperature is likely (Fig. 2.16).

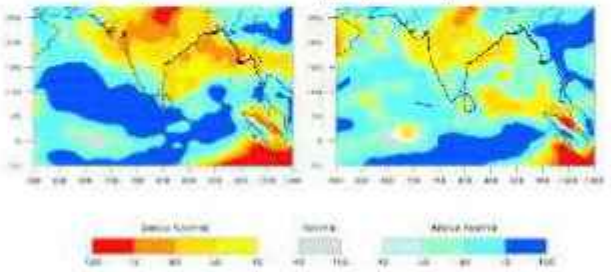


Fig. 2.15 Seasonal probability (%) forecasts of precipitation for (a) SON 2023 (left) and (b) OND 2023 (right) based on initial conditions of August 2023.

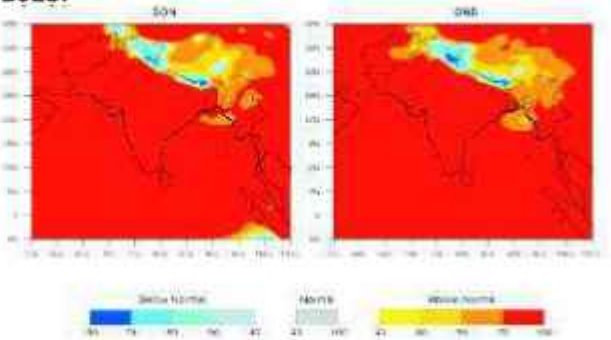


Fig. 2.16 Probability (%) forecast for the seasonal mean temperature for (a) SON 2023 (left) and (b) OND 2023 (right) based on initial conditions of August 2023.

ENSO & IOD bulletins are prepared every month providing statement on the global SST anomalies and probabilities forecast with emphasis on the ENSO and IOD conditions for the next 9 months. Fig. 2.17 gives the global sea surface temperature anomaly and probability forecast for the month of September 2023 using the August 2023 initial conditions.

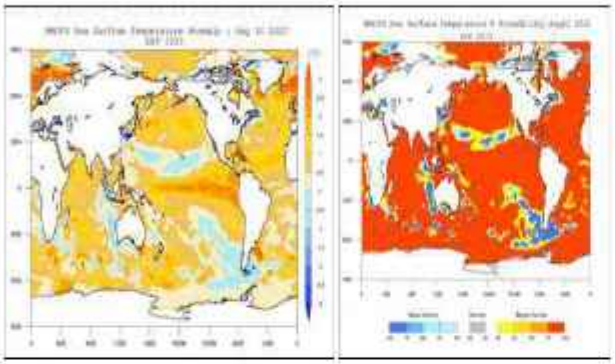


Fig. 2.17 Global sea surface temperature anomaly and probability forecast for the month of September 2023 using the August 2023 initial conditions.

2.7.4. South Asian Climate Outlook Forum support

The regional climate outlook for the southwest monsoon-2023 over South Asia has been collaboratively developed by all nine national meteorological and hydrological services (NMHSs) of South Asia with the support from "South Asian Climate Outlook Forum (SASCOF)-25". The details are as follows: normal to below normal rainfall is likely during southwest monsoon season-2023 over most parts of the South Asia. Geographically, above normal rainfall is likely over northern most parts and northwest of the region as well as parts of eastern and southern regions of South Asia. However, below normal rainfall is likely over some areas of northwest, central and north-eastern parts of the region. The seasonal rainfall is likely to be normal or climatological probabilities over the remaining areas of the region (Fig. 2.18).

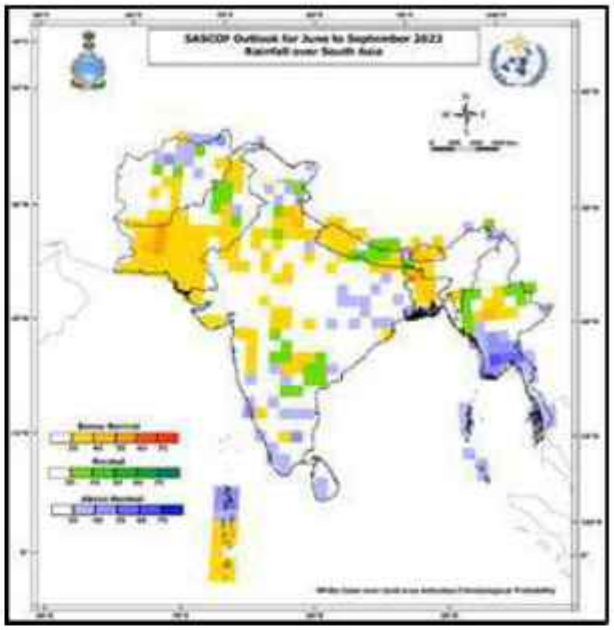


Fig. 2.18 Probability of the most likely category for southwest monsoon-2023 rainfall over South Asia.

2.7.5. State-wise Annual Climate

The India Meteorological Department (IMD) provides climate services through Climate Research and Services (CRS)-Pune. CRS has prepared "State-wise annual climate statement for the year 2022" in line with the annual climate statement prepared for the country. This report contains important information about the monthly, seasonal, and annual state averaged temperatures, rainfall, and Standardized Precipitation Index (SPI) for the year, as well as long-term trends for some of the parameters. This statement also includes state-specific information related to various extreme weather and climate events experienced during the specific year. To continue this activity every year, the CRS regularly collaborates with the state governments to obtain information on the impact of extreme weather events in the state. Spatial pattern of annual maximum, minimum and mean temperature anomalies over Uttar Pradesh during 2022 is shown in Fig. 2.19. The state-wise annual climate statements are available at the following link:https://www.imdpune.gov.in/Reports/Statewise%20annual%20climate/statewise_annual_climate.html

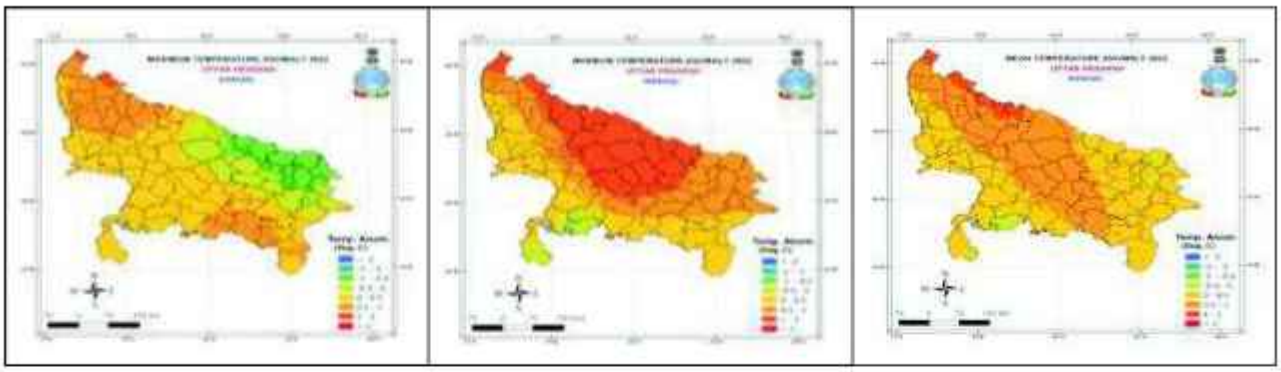


Fig. 2.19 Spatial pattern of annual maximum, minimum and mean temperature anomalies over Uttar Pradesh during 2022. The anomalies were computed from LPA for the base period of 1981-2010.

2.8 Monsoon Mission

2.8.1 Seasonal Prediction

Developed and deployed the Monsoon Mission Coupled Forecast System version 2 (MMCFSv2) model, which substantially upgrades the skill of the present operational MMCFSv1. MMCFSv2 was evaluated based on the latest 25 years (1998–2022) of retrospective coupled hindcast simulations of the Indian Summer Monsoon (ISM) with April initial conditions from Coupled Forecast System Reanalysis. MMCFSv2 captures significant features of the Indian monsoon, including the intensity and location of the maximum precipitation centres and the large-scale monsoon circulation. MMCFSv2 improves the phase skill (anomaly correlation coefficient) of the interannual variation of ISMR by 17% (Fig. 2.20) MMCFSv2 has been upgraded with the ocean model MOM6 (Modular Ocean Model version 6) as against MOM4 used in MMCFSv1.

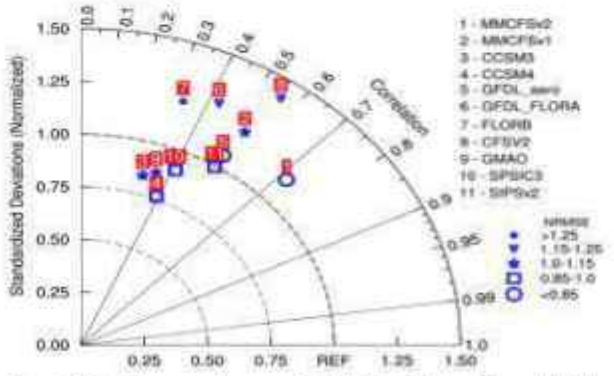


Fig. 2.20 Comparison of ISMR skill of available seasonal prediction models for the 1998-2022 period with in house developed new model MMCFSv2.

2.8.2 Unified model framework for Monsoon Variability and Predictability (UMVP)

UMVP has participated in the ILS4P project of GEWEX, to inter-compare model and understand sources of monsoon predictability associated with soil temperature and snow of elevated region on S2S time scale. The recent study pinpoints spring soil and surface temperature over Tibetan plateau as an important source of predictability of the June rainfall over several parts of the planet including the Asian Summer Monsoon Region.

2.8.3. Extended Range Prediction

The extended range ensemble prediction system developed by IITM under National Monsoon Mission Project in 2011 has been operationally implemented by India Meteorological Department in 2016. Although the first-generation version (ERPv1), has reasonable skill in predicting the onset, active/break spells and withdrawal phases of the Indian summer monsoon season, heavy rainfall events, extremes in June rainfall, heat waves, Madden-Julian Oscillation, cyclogenesis and fluctuations in northeast monsoon, the skill is limited to two weeks. Therefore, a second-generation extended range prediction system (ERPv2) has been developed with a multi physics multimodel approach. A competent set of physics pairs based on convection and microphysics schemes has been selected to formulate a physics-based ensemble. The system with only control runs has shown a great potential in the first three week leads. The experimental forecasts based on the new ERPv2 are being generated from May 2022 and are

updated every week on a real-time basis on the ERPAS website, https://www.tropmet.res.in/erpas/ of IITM. A thorough analysis on the hindcast skill of ERPv2 compared to ERPv1 in predicting the Indian summer monsoon rainfall during 2003-2018 indicates that the prediction system has remarkable skill in predicting the intraseasonal fluctuations within the season remarkably well up to 3 weeks over the monsoon zone of India as well as the four homogeneous regions of India (Fig. 2.21).

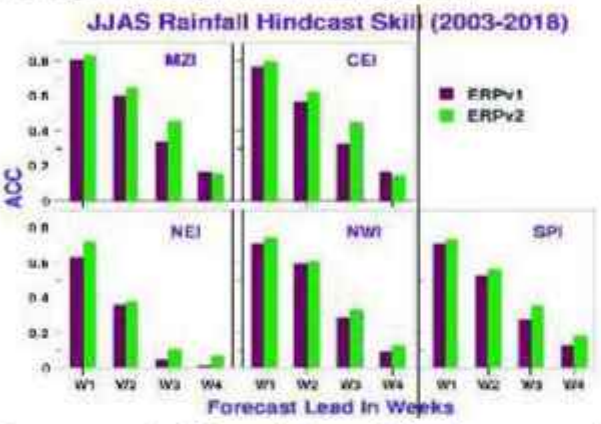


Fig. 2.21 Rainfall prediction skill of ERPv1 and ERPv2, in terms of Anomaly Correlation Coefficient (ACC), during the summer monsoon of 2003-2018 over Monsoon Zone of India (MZI), Central India (CEI), Northwest India (NWI), Northeast India (NEI) and Southern Peninsular India (SPI) for Week 1 (W1) to Week 4 (W4).

2.8.4. Short range Global Ensemble Forecast (GEFS)/ Global Forecast System (GFS)

The GEFS T1534 based ensemble forecasts provided accurate forecast of genesis, ensemble tracks, strike probability, intensity and landfall for the extremely severe cyclonic storm "MOCHA" during 9-15 May 2023 over Bay of Bengal, "BIPARJOY" cyclonic storm during June 2023, and the tropical cyclones: "TEJ" over Arabian Sea and "Hamoon" over Bay of Bengal during October 2023. The experimental forecast from the 6.5 km IITM HGFM (high resolution global forecast) (Tco1534) model also predicted the track, intensity and landfall of the systems accurately. Both the forecast products were communicated to IMD.

The Extreme Forecast Index (EFI) has been developed at IITM using the 10 years of climatology of Global Ensemble Forecast System (GEFS). The EFI was generated for 5 days lead time and was handed over to IMD for operational implementation on daily operational forecast. The Extreme Forecast Index (EFI) quantifies the difference between the ensemble forecast distribution and the model climate distribution. It enables the detection of extreme weather events without defining a threshold in either space or time. Thus, it can be applied even to observation sparse regions. The EFI ranges from -1 to +1 with magnitudes between 0.5-0.8 indicating the likelihood of unusual weather and magnitudes greater than 0.8 indicating likelihood of very unusual weather. The Shift of Tails (SOT) gives an indication of how extreme the event is with respect to the 99th quantile of the model climatology. Higher the SOT value, larger is the difference between the forecast and climatological distribution. Northern Indian region received very heavy rainfall on 9th July 2023. The indication of unusual to very unusual weather (more than the model climatology) is seen consistently from day 5 forecast of EFI. The SOT value of 4 is seen from day 2 onwards indicating the forecasted extreme is much higher than the climatological extreme (Fig. 2.22). These products are obtained from the GEFS forecast and its climatology (JJAS 2013-2022).

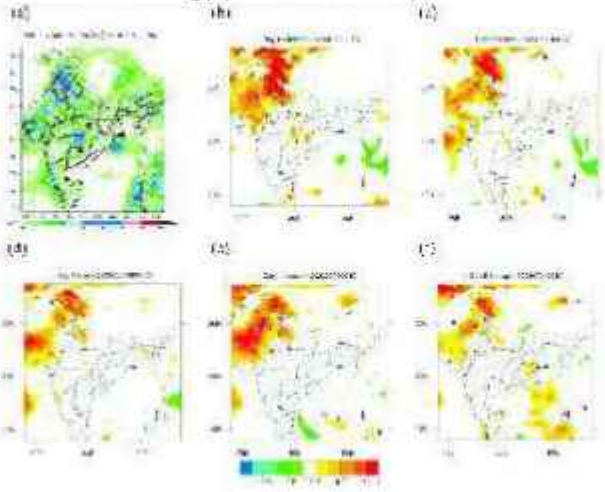


Fig. 2.22 Extreme Forecast Index based on 4th, 5th, 6th, 7th and 8th July 2023 Initial condition valid for 9th July 2023. Extreme rainfall event on 9 July 2023 observed with (a) IMD-GPM gridded data (cm/day) and its (b)-(f) day 1 to day 5 EFI (shaded) and SOT (contours) valid for 9 July 2023.

The performance of six-class weather research forecasting (WRF) single moment (WSM6) cloud microphysical scheme in the National Centre for Environmental Prediction (NCEP) Climate Forecast System version 2 (CFSv2) at T126 (~100 km) horizontal resolution in the simulation and prediction skill of the Indian summer monsoon (ISM) is investigated with 34 years of hindcast runs with 10 ensemble members. The results reveal that the revised version of CFSv2 (EXPT) shows relative improvement in summer monsoon precipitation, its variability, rainfall annual cycle, rainfall probability distribution function, synoptic and intraseasonal variance, etc. over ISM region compared to standard CFSv2 (CTRL). Robust representation of cloud hydrometeors in the WSM6 microphysics scheme leads to better large-scale precipitation distribution which resulted in realistic northward propagation of rainfall bands in the EXPT. The interannual variability of rainfall in EXPT simulation suggests improved prediction skill of summer monsoon than CTRL run and comparable to higher resolution (T382; ~ 38 km) version of CFSv2. The above improvements are attributed to better simulation of vertical and spatial distribution of cloud hydrometeors in EXPT simulation.

2.9. Centre for Climate Change Research

2.9.1 IITM Earth System Model (IITM-ESM)

The IITM-ESM, which is being developed at the Centre for Climate Change Research (CCCR), IITM, MoES, will be participating in the next phase of the Coupled Model Intercomparison Project (CMIP7) and thereby contributing to the IPCC AR7 report. A high-resolution (~70 km) global coupled model with indigenous Indian land-use land-cover changes, interactive sea-ice, ocean biogeochemistry and land-ice (Greenland contribution) is being developed. The new ocean grid developed for IITM-ESM and land-use land-cover data with 24 vegetation types implemented in IITM-ESM are shown in Fig. 2.23. The high-resolution climate projections will provide information about regional climate change over Indian region.

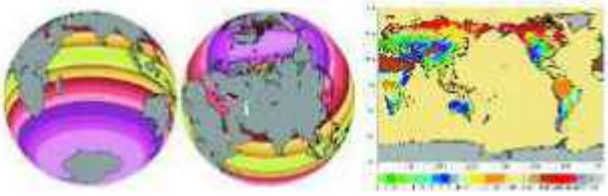


Fig. 2.23 The new ocean grid developed for IITM-ESM (left panel) and land-use land-cover data based on NRSC over Indian region with 24-type vegetation types implemented in IITM-ESM (right panel).

In addition to the development of the ESM, studies are being carried out to understand climate change using the IITM-ESM. North Atlantic teleconnection to South Asian summer monsoon is being assessed using the pi-control simulation of IITM-ESM CMIP6 and reanalysis data sets. North Tropical Atlantic Sea Surface Temperature (NTA SST) anomalies emerge as a key-driver of the El Niño Southern Oscillation–South Asian Summer Monsoon (ENSO–SASM) system. The impact of soil moisture (SM) perturbations on the characteristics of temperature extremes (ExT) based on SM observations and sensitivity experiments has been investigated for the historical period (1951–2010, HIST) and future (2051–2100, FUT) climate under the 4K warming scenario. The findings revealed that more than 70% of the Indian landmass has experienced significant changes in the characteristics of ExT due to SM perturbations. The impact of SM perturbations on the frequency and duration of ExT events over NCI becomes less prominent in the future as compared to historical climate, which is found to be associated with the increase in precipitation and consequent decrease in the temperature difference between the surface and near-surface air.

The Indian Institute of Tropical Meteorology (IITM) has established flux tower sites over several different ecosystems in collaboration with other institutes to quantify the capacity of forests and other natural ecosystems to sequester atmospheric CO_2. Since 2015, continuous measured data of ecosystem-atmosphere fluxes of CO_2, water vapour, CH_4, sensible and latent heat, momentum, etc. along with meteorological and soil parameters have been

used to develop a vegetation photosynthesis and respiration model for India. As part of the atmospheric processes and climate change impact studies in the polar regions in collaboration with NCPOR, the coupling between halogen compounds and the biogeochemical cycling of mercury, which is a global toxin, was identified using observations in ice cores from Greenland. This study has complemented ongoing work on the chemistry of halogen compounds in the Arctic, and the Indian Antarctic station, Bharati.

2.9.2 Climate Variability and Prediction: Development of IITM-Decadal Prediction System (IITM-DPS)

A Decadal Prediction System (IITM-DPS) has been developed based on IITM-Earth System Model (IITM-ESM) for near term climate prediction (Fig. 2.24). IITM-DPS differs from IITM-ESM mainly on the horizontal resolution, initial conditions, and modified soil and vegetation categories. To reduce the coupled model initial shocks due to simultaneous initialization of different components, the ocean initial conditions are first achieved through nudging of subsurface temperature and salinity from ORAS5 on ERA5 forced ocean state and then the atmosphere is initialized. This is a relatively cost-effective alternate approach for initial shock reduction, which is normally achieved only through coupled data assimilation. To complement the DPS and to enhance the extreme rainfall prediction skill, a methodology has been developed for downscaling and bias correction of decadal hindcasts, which is found to significantly enhance the prediction skill of extreme rainfall events over India.

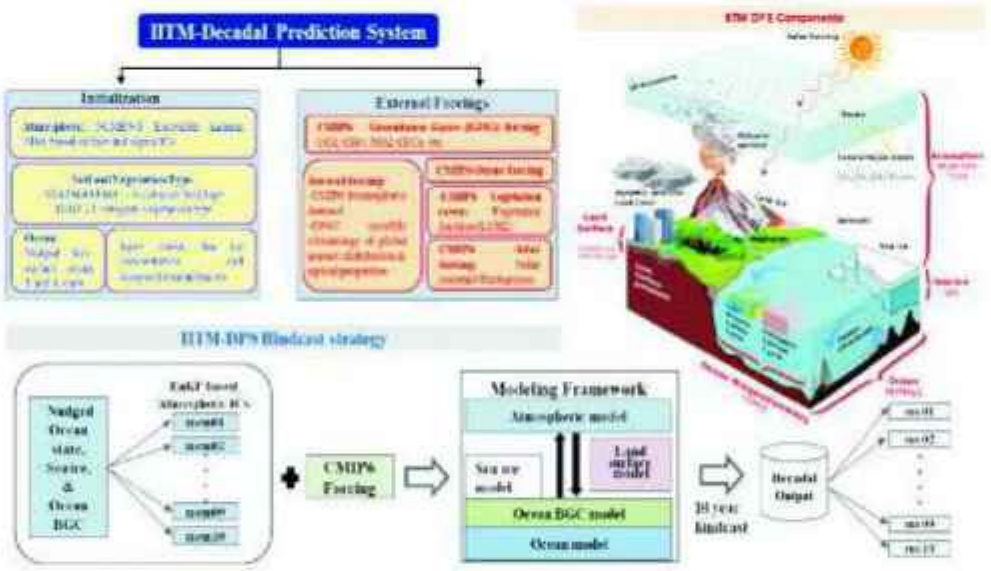


Fig. 2.24 The schematic illustrates IITM Decadal Prediction System (DPS) modelling framework, hindcast strategy and its components.

2.10. Meteorological Services

2.10.1. Tropical Cyclone Monitoring and Prediction 2023

Collaboration among the Bay of Bengal (BoB) and Arabian Sea bordered countries with India Meteorological Department (IMD) has improved the monitoring and accurate forecasts of tropical cyclones with the timely exchange of meteorological datasets. IMD's tropical cyclone advisory bulletins have helped all the countries to minimize the losses of lives with the support of satellite & radar networks and advisories based on numerical model forecasts. In India and all the boundary sharing countries with BoB and Arabian Sea, the number of casualties due to tropical cyclones have been minimized and limited to less than hundred during last 12 years when compared

against the massive ten thousand deaths due to Orissa super cyclone during 1999. With the improved skill of IMD in predicting the tropical cyclones; the extremely super cyclones namely, Phailin, Hudhud and Fani have reported minimized losses of lives 22, 47, and 64, respectively. Similarly, three thousand deaths were reported in Bangladesh due to very severe cyclonic storm 'Sidr' during 2007 while there were only 7 deaths in Bangladesh due to the cyclone 'Amphan' which crossed almost near the same area Sundarbans of West Bengal and adjoin Bangladesh in 2020. A recent progress made on tracking the tropical cyclones is as follows:

Observed track of MOCHA pronounced as "Mokha" extremely severe cyclonic storm: Observed track of extremely sever cyclonic storm 'MOCHA' over the BoB during 9th -14th May, 2023 (Fig. 2.25). The first advisory issued by IMD on formation of depression indicated landfall over North Myanmar-Southeast Bangladesh coast around 14th May noon (about 90 hours prior to landfall).

Forecast accuracy: The track forecast errors for 24, 48 and 72 hours lead period were 53, 68 and 78 km, respectively against the long period average (LPA) errors (2018-22) of 74, 112, and 153 km, respectively (Fig. 2.26). For all lead periods up to 120 hours, the operational track forecast errors were exceptionally less as compared to LPA errors. For all lead periods up to 96 hours, the landfall time errors were appreciably less than LPA errors.

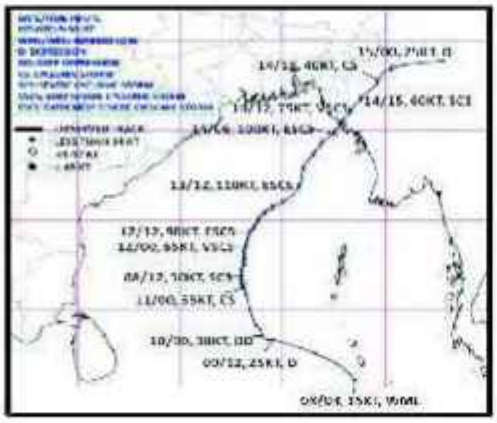


Fig. 2.25 Observed track of extremely sever cyclonic storm 'MOCHA' over the Bay of Bengal (BoB) during 9th -14th May, 2023.

Fig. 2.26 Operational track forecast errors compared to long period average (LPA) during 2018-22.

Observed track of "BIPARJOY" extremely severe cyclonic storm: Observed track of extremely sever cyclonic storm 'BIPARJOY' over the Arabian Sea during 6th -19th June, 2023 (Fig. 2.27).

Forecast accuracy: Despite various unique and diverse characteristics, Biparjoy was monitored and predicted accurately by the IMD. The landfall point forecast error for 24, 48, 72 and 96 hours lead period was 17, 23, 15 and 11 km against LPA (2018-22) of 26, 40, 76, 60 km respectively (Fig. 2.28). The track forecast errors for 24, 48, 72, 96 and 120 hours lead period were 69, 104, 152, 194 and 238 km against LPA (2018-22) of 74, 112, 153, 208, 316 km respectively.

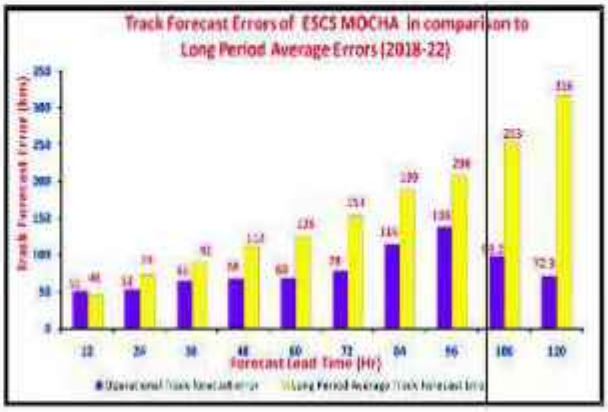


Fig. 2.27 Observed track of extremely sever cyclonic storm 'BIPARJOY' over the Arabian Sea during 6th -19th June, 2023.

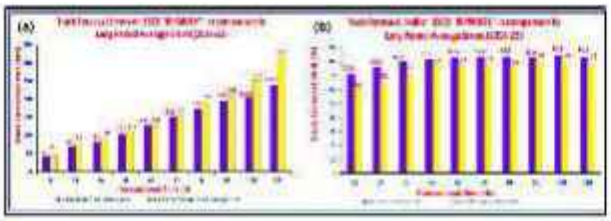


Fig. 2.28 Operational (a) track forecast accuracy and (b) track forecast skill of cyclone Biparjoy compared to long period average (LPA) during 2018-22.

2.10.2. Metropolitan Air Quality and Weather Services

Long-term trend of Pollution in Delhi: A significant declining trend was noticed for $PM_{2.5}$ in Delhi with an overall 29.0 % reduction from 2011 to 2021 (2.64 % reduction annually). Similarly, a significant declining trend was also noticed for PM_{10} with an overall 23.7 % reduction between 2011 and 2021 (2.15 % reduction annually). Role of meteorology in the decreasing trend of $PM_{2.5}$ in Delhi was delineated through sensitivity studies using the WRF-Chem model and the results show that meteorology contributed 8% of the declining trend. **Volatile organic compounds measurements in Pune:** The photochemical losses incurred by volatile organic compounds (VOCs) during transport from source to receptor site have been considered for photochemical initial concentration (PIC) estimation. Isoprene with kOH (*10− 12) value of 100 was found to be underestimated by 73% during summer period. The higher contribution of alkenes (isoprene) towards OFP (ozone formation potential) leads to significant underestimation of 32%. For the same period, secondary organic aerosol formation potential (SOAFP) was found to be underestimated by 16%. This is mainly due to dominance of aromatics in urban environments towards secondary organic aerosol formation. Since aromatics undergo photochemical degradation slower compared to alkenes (relatively lower hydroxyl reactivity), the SOAFP change (%) on PIC consideration is hence, less. The k-means clustering analysis shows that the higher ozone formation is supported under transition regime atmospheric chemistry over VOC limited and NOx limited regimes.

Black carbon trends and effects over a high altitude Central Himalayan Glacier: Transport model studies indicate a higher retention time of tracer in Uttarakhand, Punjab, Haryana, and adjacent polluted valley regions with increased biomass burning (BB) incidences. The high rate of BC influx was attributed to transport from the polluted Indo-Gangetic Plain (IGP) region, wildfires, and vehicular emissions in the valley region. Higher equivalent brown carbon (BrC) influx is linked to BB, especially wood-burning, during intense forest fires at mountain slopes. Strong correlation between BC mass and BB affirms the dominant role of BB in contributing BC to the Glacier region. Increased TOA forcing induced by surface darkening and BC atmospheric radiative heating indicate an additional warming and possible changes of natural snow cycle over the glacier depending on the characteristics and extent of debris cover.

2.10.3. Air Quality Early Warning System for Delhi

An advanced air quality early warning system (AQEWS) at a high resolution of 400 meters for the Delhi National Capital Region (NCR) was developed as part of the Smart Cities Mission (NP15) initiated by the Government of India. The forecasting system was strengthened by introducing comprehensive multi-model ensemble for $PM_{2.5}$ and PM_{10} forecasts specific to Delhi. This was a collaborative effort by integrating forecasts from various centers viz. ECMWF, NCAR, NASA, NOAA, NCMRWF, and IMD. A significant optimization milestone was achieved by fully automating the system which became operational in August 2023. The model utilizes the anthropogenic emissions inventory prepared by 'The Energy and Resources Institute' (TERI) for Delhi and the surrounding 19 districts. The system assimilates a) $PM_{2.5}$ data from the CPCB monitoring stations across the northern region of India, and b) satellite retrieved aerosol optical depth from 'Moderate Resolution Imaging Spectroradiometer' (MODIS) instrument on-board TERRA and AQUA satellites. Moreover, Decision Support System (DSS) uses the Active Fire count data from the MODIS instrument to generate near-real-time fire emissions which is critical considering the

agricultural burning activities occurring in the region post-monsoon. The DSS runs with a horizontal grid spacing of 10 km and generates the forecasts and decision-support information for the next 120 hours (i.e., five days).

The DSS assists the AQEWS by providing 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 emission sectors in Delhi to the air quality, c) the contribution from biomass-burning activities in the neighbouring states to the degradation of air quality, and d) the effects of possible emission source-level interventions on the severe air-quality events in Delhi. The DSS is actively used as an essential tool for air-quality management by the Commission for Air Quality Management (CAQM) which is the responsible parliamentary body for maintaining the air quality in NCR in Delhi. The ambient air quality and its forecast delivered by the AQEWS is actively used by CAQM in deciding the implementation or roll back of the various Graded Response Action Plan (GRAP) stages. The RASAGAM "Real-time Ambient Source Apportionment of Gases and Aerosol for Mitigation" is a joint collaboration project of IISER Mohali, IITM Pune, and IMD Delhi. The RASAGAM lab has been set up in IMD Delhi for studying the physio-chemical characteristics of aerosols and gases but also the meteorological parameter affecting air pollution in Delhi. Daily species-wise NR-PM1 time series observations over Delhi are being maintained on the dedicated air quality forecasting system website.

2.10.4. IMD collaboration with Finnish Meteorological Institute

The institutes under Ministry of Earth Sciences (MoES) are continuously striving to improve the early warning system of air quality forecasts. Air quality forecasting models are getting upgraded timely by adopting the changes in emissions inventories, land use and land cover and assimilation of observational datasets. The latest version of air quality forecasting model "System for Integrated modeLling of Atmospheric coMposition (SILAM v5.8)" has been operationalized over the Indian region. This model issues hourly air quality forecasts up to 96 hours for criteria pollutants (PM_{10}, $PM_{2.5}$, NO_x, O_3, CO, etc..) over the entire domain of South Asia. The SILAM model is coupled with India Meteorological Department-Weather Research and Forecasting model (3 km). In addition, a very high-resolution city-scale (30 meters) air quality model "Environmental information FUsionSERvice (ENFUSER)" has been operationalized and issuing 3-day forecasts for the capital city Delhi (Fig. 2.29). This model assimilates a large amount of Geographic Information System (GIS) including a detailed description of the road network, buildings, land-use information, high-resolution satellite images, ground elevation, population data, traffic density, etc. The models SILAM-v5.8 and ENFUSER were developed under the collaborative project with Finnish Meteorological Institute.

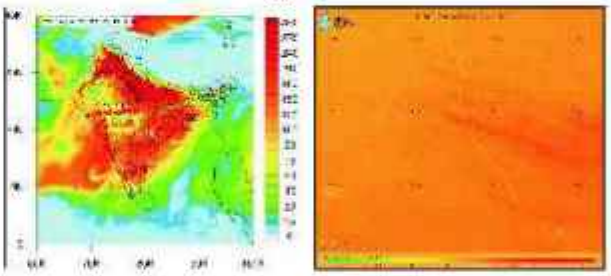


Fig. 2.29 Spatial distribution of $PM_{2.5}$ ($\mu g/m^3$) concentrations using the SILAM (3 km resolution) and ENFUSER (30 m) models over India and Delhi city, respectively.

2.10.5. Winter Fog EXperiment (WiFEX)

WiFEX is a first-of-its-kind multi-institutional initiative dealing with intensive ground-based measurement campaigns for developing a suitable fog forecasting capability under the aegis of the Smart Cities Mission of India. Measuring campaigns were conducted during the 2015–20 winters at the IGI Airport, New Delhi, covering more than 90 dense fog events. An operational modeling framework, the WRF Model, was set up to provide fog predictions during the measurement campaign. Four scientific objectives were pursued: (i) the life cycle of optically thin and thick fog, (ii) microphysical properties in the polluted boundary layer, (iii) fog water chemistry, gas–aerosol partitioning during the fog life cycle, and (iv) numerical prediction of fog. A cutting-edge Ensemble Probability Forecast System (EPFS),

comprising 21 ensemble members, was devised and operationalised from the winter of 2021. This EPFS leverages a state-of-the-art numerical model, which undergoes 21 parallel runs, each initialized with slightly perturbed initial conditions. The final outcomes of these 21 models runs collectively yield a spatially and statistically generated ensemble probability forecast of visibility. In addition, the EPFS offers a probability forecast of visibility within four distinct categories (CAT2, CAT3A, CAT3B, and CAT3C) for six major airports within the Indo-Gangetic Plain (IGP) region. Furthermore, the EPFS system provides a spatial probability forecast for the occurrence of dense fog, defined as visibility less than 200 meters, across the expansive IGP region. The real time- fog forecast verification using the field capping data has been also done on daily basis to improve model forecast skill (Fig. 2.30).

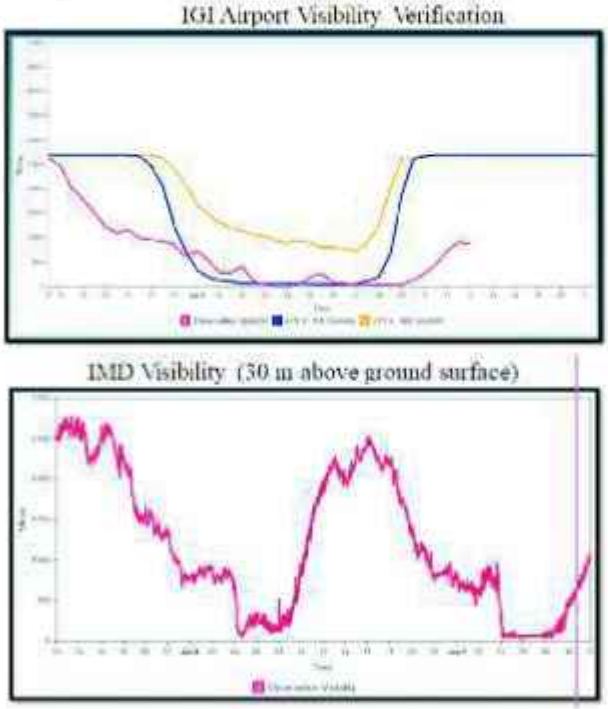


Fig. 2.30 Real-time skill verification of EPFS for 2022-23.

2.10.6. IITM deep learning Model for forecasting fire-burning locations and unveiling $PM_{2.5}$ emissions

Climate change and human activity have increased fires in India. Fine particulate matter ($PM_{2.5}$) is released into the atmosphere by stubble burning in Punjab and Haryana and forest fires in the north-eastern and central areas of the country. Air quality forecasts are prone to inaccuracies and biases due to fire emissions' dynamic nature. This study employs spatiotemporal deep learning techniques, specifically ConvLSTM and ConvGRU, to forecast fire emission locations up to three days in advance. Through evaluation, it is found that ConvLSTM outperforms ConvGRU in terms of prediction accuracy and performance. The chosen model provides a very good correlation coefficient (≈ 0.8) for the 1st day forecast and a moderate value (0.5–0.55) for subsequent 2nd and 3rd days forecasts. This deep learning model can improve air quality forecasts by revealing the complex interactions of components and reflecting fire emissions' dynamic nature.

2.10.7 Conferences and collaborations

The International Conference on Regional Climate – Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX-2023) was organized jointly by Centre for Climate Change Research (IITM), the Abdus Salam International Centre for Theoretical Physics (ICTP, Italy), the Swedish Meteorological and Hydrological Institute (SMHI), and the World Climate Research Program (WCRP) with physical hubs in Pune, India and Trieste, Italy in hybrid mode during 25-29 September 2023 (Fig. 2.31).

Fig. 2.31 ICRC-CORDEX 2023 conference participants at IITM Hub.

An MoU was signed between the Rajasthan SPCB and IITM, Pune on 26th September 2023. The project

entitled, "Early warning and decision support system for air quality management in Jaipur" has been awarded to IITM, which aims to give early warning and decision support for air quality management in Jaipur. A project under the MoU with Kalinga Institute of Industrial Technology (KIIT) on "Inter-comparison campaign of NH_3 measurements over Delhi and Chemical Transport Modelling (CTM) for NH_3 over South-East Asia using both baseline and NH_3 emission scenario" has commenced at the South Asian Nitrogen Hub (SANH) of KIIT at IITM, Pune. IITM signed two MoUs with Tezpur University, Tezpur, Assam and Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, Uttarakhand for Metflux Project of CCCR to promote collaborative research on biosphere-atmosphere exchange of Greenhouse Gases and Energy Fluxes being monitored at the Kaziranga National Park, Assam and Devasthal, near Nainital in Uttarakhand, respectively.

Chapter–3

Ocean Services, Modelling, Application, Resource and Technology (O-SMART)

The oceanographic services, research and technology development activities of the ministry are largely carried out under OSMART scheme. The major objectives of the scheme are related to 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 related to the scheme are being executed by the 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. The oceanographic and coastal research vessels of the Ministry are operated and maintained under the scheme to carry out required survey and technical demonstration support.

3.1 Ocean Sciences and Services implemented by INCOIS

3.1.1 Tsunami Early Warnings

Indian Tsunami Early Warning Centre (ITEWC) monitored 26 earthquakes of magnitude ≥ 6.5 but not Tsunamigenic **(Fig. 3.1)**, during the reporting period out of which only one earthquake occurred in the Indian Ocean region. Being the Tsunami Service Provider (TSP) for the Indian Ocean, the necessary bulletins were also sent to 25 Indian Ocean rim countries.

Communications (COMMs) test of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) was conducted on 07 June 2023 to validate the TSPs dissemination process to NTWCs (National tsunami Warning Centres) & national disaster management contacts.

Tsunami Mock Exercise was conducted in Andaman & Nicobar Islands in coordination with NDMA and Andaman administration on 09 February 2023. IOC-UNESCO conducted the Indian Ocean wide (IOWave23) Tsunami mock exercise during October 2023. India participated in the exercise in collaboration with NDMA for two scenarios like an earthquake at Nicobar Islands on 04 October 2023and at Off the coast of Iran on 11 October 2023. All coastal states/UTs participated in the exercise and over 40,000 people from 42 coastal villages of Tamil Nadu, Odisha, Puducherry, and Andaman Islands participated in the mock drill and were evacuated.

Fig.3.1: Locations of earthquakes with magnitude ≥6.5 Mw occurred during reporting period.

3.1.2: Potential Fishing Zones (PFZ), Coral Bleaching Alert and Algal Bloom Information services

Multilingual PFZ advisories and Yellowfin Tuna advisories were provided for 283 and 102 days respectively. Coral Bleaching Alert System (CBAS) provided 101 advisories comprising of HotSpots (HS) and Degree of Heating Weeks (DHWs) on Coral Bleaching Alerts. Besides, 8 warnings and 12 watch alerts of hotspots observed for five locations of Andaman, Nicobar, Gulf of Kutch, Gulf of Mannar and Lakshadweep. Near-real time status of algal bloom in the North Indian Ocean waters in four

identified bloom hotspots (North-eastern Arabian Sea, Kerala Coast, Gulf of Mannar and Coast of Gopalpur) are being monitored. Bloom information services generated for 303 days and alerts issued for 33 days.

3.1.3: Ocean State Forecast (OSF) and related services

Ocean state forecast and warnings were issued to the public along the east and west coast of India during deep depressions and depressions. A total of 1465 High Wave/Swell Alerts/Warnings and rough sea alerts were issued. INCOIS-IMD Jointly issued 159 bulletins for cyclones; two Extreme Severe Cyclonic Storms (ESCS) (Mocha during 9-14 adjoining Northeast Bay of Bengal, and Biparjoy during 6-16 June 2023 over Northeast Arabian Sea) and one very severe cyclonic storm Hamoon over Northeast Bay Bengal during 20-25 October 2023. Numerical models of INCOIS reasonably matched well with observations for both cyclones (Fig. 3.2). INCOIS issued a total of 59 timely storm surge and inundation advisories in collaboration with (IMD).

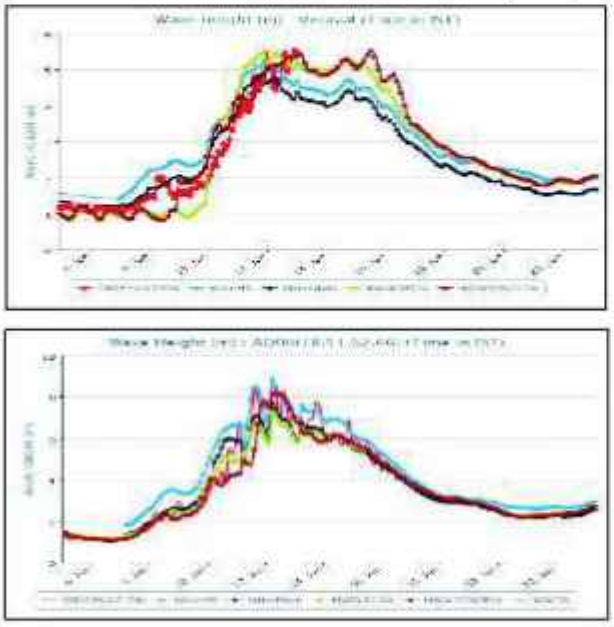


Fig. 3.2: Observations (coastal and open ocean buoys) vs numerical model forecast for the ESCS Biparjoy.

3.1.4: Other services

One oil-spill trajectory pattern was provided for Nagore Beach, Nagapattinam due to pipeline rupture. Search And Rescue Aid Tool (SARAT) advisories were provided to Indian Coast Guards and to Maritime Rescue Coordination Centre Mumbai. Daily Marine Heat Wave Advisory service are provided for different basins and sectors over the Indian Ocean through the web interface for users.

3.1.5 Data services:

Data services is for providing heterogeneous oceanographic data to various stakeholders in the country. The data centre sustained and strengthened the real-time data reception, processing, and quality control of in-situ and remote sensing data from multiple ocean observing platforms like Argo floats, moored buoys, drifting buoys , wave rider buoys , tide gauges , tsunami buoys , ship-mounted autonomous weather stations , coastal water quality buoys , HF radars, XBT/XCTD , ADCP moorings along with data from dedicated scientific cruises. Three ground stations have been established to meet the in-house operational advisory services and acquired data from AVHRR (VIIRS, MODIS & OCM sensors. Digital Ocean for visualisation , analysis of oceanographic data, and downloading available data (in-situ and spatial) is maintained. Digital Ocean users have now increased to 904, with 176 new registrations this year.

3.1.6 Information & Communication Technology (ICT) Services

This activity supports operational ocean services and research with robust computing services, including a resilient data center housing over 150 servers and 2 Peta Bytes of storage. INCOIS website (https://www.incois.gov.in/) is a key platform for disseminating important ocean information, offering a responsive, multilingual interface with WebGIS capabilities for various advisory services. The up-gradation of ground station has been successfully completed to receive the Oceansat-3 (EOS-06) satellite passes (Fig. 3.3). The EOS-06 satellite passes are being tracked by INCOIS ground station since its launch.

Fig. 3.3: Inauguration of the upgraded OCEANSAT-3 ground station.

3.1.7 Ocean Observations, Modeling and Applied Research

I. **Ocean Observation Network (OON)**

Various ocean observation platforms have been deployed and maintained in the Indian Ocean to meet the need for operational forecast and predictive understandings of our oceans. 19 Argo floats with CTD sensors are deployed to maintain the strength of 61 operational Argo floats including 13 floats with biogeochemical sensors. As acontribution to the Global drifting buoy program, four drifters, equipped with sea surface temperature and barometric pressure have been deployed in the north Indian Ocean. 17 ADCP moorings (13 slope moorings and 04 shelf moorings) along the entire Indian coast and 03 ADCP moorings along the equator are maintained. The XBT transects along commercial shipping routes were restarted in February 2023 and 95 XBT profiles and 174 sea surface salinity (SSS) samples were collected. A network of 16 Wave Rider Buoys (WRB) to monitor ocean wave characteristics along Indian coastline waters in near-real-time are maintained. A network of 34 Automatic Weather Stations (AWS) are maintained in ships to measure near-surface meteorological parameters in the Indian Ocean. A tide gauge network at 36 locations around the coasts of the Indian mainland and islands are maintained to measure sea level. Four tsunami buoys with Bottom Pressure Recorder (BPR) deployed close to the tsunamigenic source regions in the Bay of Bengal and the Arabian Sea are maintained. A National Glider Operations Facility (NGOF) was inaugurated to maintain a fleet of upcoming gliders and it is operational now (Fig. 3.4). The facility fosters simultaneous piloting of the glider fleet along with its testing, ballasting and routine maintenance.

Fig. 3.4: Inauguration of NGOF on 3 February 2023 by Dr M. Ravichandran, the Secretary of the MoES and (bottom panels) inside view of NGOF at INCOIS.

II. Other Observation and measurements

Two 'Coastal Observatories' in the form of moored buoys equipped with physical and water quality sensors at Kochi and Vishakapattanam are deployed and are in operation. A bow mast onboard RV Sagar Nidhi equipped with meteorological instruments Eddy Covariance Flux System (ECFS) was installed and is in operation for ship based Eddy covariance flux observation. In line with Enhancing Knowledge of the Arabian Sea Marine Environment through Science and Advanced Training" (EKAMSAT) program, one scientific cruise was conducted in the

Arabian Sea during June- July, 2023 in collaboration USA onboard Sagar Nidhi (Fig. 3.5).

Fig. 3.5: The scientific team onboard ORV Sagar Nidhi during the EKAMSAT expedition

3.1.8 Ocean Modelling and Data assimilation:

High-resolution Operational Ocean Forecast and reanalysis System (HOOFS) consisting of Regional Ocean Modelling System (ROMS) coupled with marine ecosystem models and integrated with the data assimilation scheme, known as the Local Ensemble Transform Kalman Filter (LETKF) has been successfully maintained. A coastal Finite Volume Community Ocean Model (FVCOM) for the coastal waters off Cochin has been configured for experimenting with different mixing schemes to fine tune the model. The current operational data assimilation system RAIN (Regional Analysis of Indian Ocean) is augmented with assimilation of satellite track data of sea level anomaly. which particularly showed enhancement in eddy estimation. A high-resolution wave model was set up for the global ocean using WAVEWATCH III 6.07. The wave parameters such as significant wave height, wave periods, wave directions as well as wind speed were validated with available moored buoy and wave rider buoy data for the global ocean.

3.1.9 Coastal Multi-Hazard Vulnerability Atlas

Multi-Hazard Vulnerability Mapping (MHVM) on a 1:25000 scale for the entire Indian mainland and Andaman and Nicobar Islands has been formulated. The MHVM is a holistic approach to estimating the composite hazard zone based on the synthesis of Extreme Water Levels, Sea-level Change, Shoreline Change Rate, and High-Resolution Topography in a GIS environment. The Atlas, comprising 1054 maps covering the Indian mainland and Andaman & Nicobar Islands, was released during the 24th INCOIS Foundation Day held on 3rd February 2023 (fig. 3.6). The maps presented in this Atlas provide vital inputs for coastal zone management and planning.

Fig. 3.6: The cover page of MHVM Atlas (a), MHVM overview map (b) showing multi-hazard zoned and release photo (c).

3.1.8 International Training Centre for Operational Oceanography (ITCOO) and other events

The International Training Centre for Operational Oceanography (ITCOocean) conducted 15 training programs and 1 seminar during the reported period. A total of 850 persons were trained of which 680 (Male: 436, Female: 244) are from India and 170 (Male: 116, Female: 54) are from other Indian Ocean RIM countries. Mega Awareness Campaigns on Ocean Information and Advisory Services conducted at Machilipatnam, Andhra Pradesh (07 July), Veraval, Gujarat (13 July), Mumbai, Maharashtra (03 August), Digha, West Bengal (08 August), and Chennai, Tamil Nadu (11 August). Megha awareness programs were highly successful with the active participation of 200-800 fishermen.

Shri Kiren Rijju, Hon'ble Union Minister of Ministry of Earth Sciences had graced the first Megha awareness campaign at Machilipatnam on 07 July 2023 (Fig. 3.7 a). Dr. Tamilisai Soundararajan, Hon'ble Lt. Governor, Puducherry and Governor, Telangana graced the last Megha awareness program at Chennai on 11 August 2023 (Fig. 3.7 b).

Fig. 3.7 a & b: Megha awareness campaigns graced by Shri Kiren Rijju, HMoESat Machilipatnam and Dr. Tamilisai Soundararajan, Hon'ble Lt. Governor, Puducherry at Chennai

3.2 Studies in Marine Living Resources (MLR)

The activities of this component are carried out by Centre for Marine Living Resources and Ecology (CMLRE), Kochi.

3.2.1 Ecosystem Processes & Ocean Acidification

I. Studies on ocean acidification

To understand the impact of ocean acidification on marine biota, 11 microcosm experiments (six in the Arabian Sea and five in the Bay of Bengal)–was conducted for seven days duration by mimicking the seawater pH to a drop of 0.2 and 0.4 from the ambient value through CO_2 bubbling (natural) or by mixing various anthropogenic sources appropriately with seawater.

These experiments revealed significant inferences that acidification impacts/changes the (i) oceanic carbon system towards the high $CO_{2(aq.)}$ side, (ii) abundance and composition of plankton (Phyto & Zoo), (iii) primary production to enhanced levels as identified by isotopic signals, (iv) buffering capacity of coastal waters which seems to be higher than acidification by local drivers (anthropogenic loads and groundwater seepage), and (v) enhanced export production rates through Transparent Exopolymer (TEP) production.

II. Phytoplankton size responses to the nutrient enrichment events in the eastern Arabian Sea

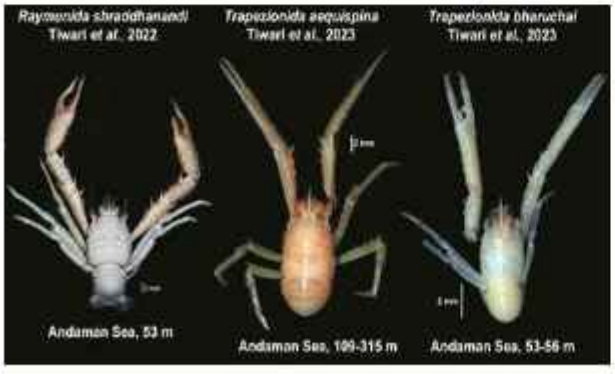
A comprehensive study examined how different size classes of phytoplankton responded to seasonal nutrient enrichment events in the eastern Arabian Sea (EAS) during the Northeast Monsoon (NEM, winter convection) and Southwest Monsoon (SWM, upwelling). During NEM, convective mixing in the northern EAS eroded the upper part of the thermocline (50–120 m), thus mixing subsurface nutrients into the mixed layer. It resulted in moderately high phytoplankton biomass and primary production in the region, with nano-phytoplankton prevalence (64.8%). In contrast, the southern EAS experienced oligotrophy during the same period due to strong surface stratification, resulting in the dominance of nano and pico-phytoplankton in the available biomass. Upwelling drives the intermediate waters (75–150 m) during SWM into the shelf-mixed layer, causing a significant increase in nutrients and primary production. This, in turn, favours the proliferation of larger micro and meso-phytoplankton (65.9%). These larger plankton sizes contribute to the high stocks of commercially important fish species during SWM, such as oil sardines, mackerel, and anchovy. However, nutrient concentrations in offshore waters throughout the entire EAS are low during this period, with nano-phytoplankton dominating. This highlights the substantial contribution of nano-phytoplankton to the overall phytoplankton biomass throughout the EAS, emphasizing their ecological significance in both nitrogen-limited and nitrogen-enriched environments.

3.2.2 Biodiversity and Ecology

Inventorisation and documentation of marine living resources of the Indian EEZ and assessing their diversity by innovative approaches such as eDNA

studies are being continued. Taxonomic studies of marine (reef-associated and deep-sea) organisms collected on-board FORV Sagar Sampada within the Indian EEZ during the period yielded seven new species of decapod crustaceans (Galathea nicobarica, Galathea tirmiziae, Raymunida shraddhanandi, Trapezionida aequispina, Trapezionida bharuchai, Munidopsis bengala, and Munidopsis kadal), one new species of fish (Bathysphyraenops radhae) and one species of peanut worm (Aspidosiphon (Akrikos) carnicobarensis) (Fig. 3.8). In addition, five decapod crustaceans (Allomunida magnicheles, Raymunida vittata, Cycloachelous levigatus, Monomia rubromarginata and Thalamita malaccensis) were documented as new zoo-geographical records from the Indian EEZ (Fig. 3.9).

Around 120,000 marine species occurrence records are documented in IndOBIS, which can be accessed through the OBIS portal (https://obis.org/). Similarly, a total of 3,374 voucher specimens categorized under 23 faunal groups representing 8 animal phyla (Arthropoda – 937, Annelida – 923, Chordata – 733, Echinodermata – 520, Mollusca – 120, Nematoda – 100, Platyhelminthes – 36 and Cnidaria – 5) have been deposited at the CMLRE repository and the digital data has been disseminated through IndOBIS data portal.



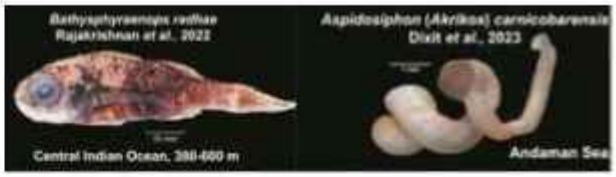


Fig. 3.8. Species new to science

Fig. 3.9. New geographical records

3.2.3 Fisheries Resource Habitat Assessment Studies

The investigations were carried out in the surface water (3 m) during three non-monsoon seasons (fall intermonsoon, winter and spring intermonsoon) from coastal locations of 20 m depth to offshore locations of 1000 m depth to identify the spawning ground of pelagic fishes such anchovies, Indian scads, lizard fishes (Fig. 3.10).

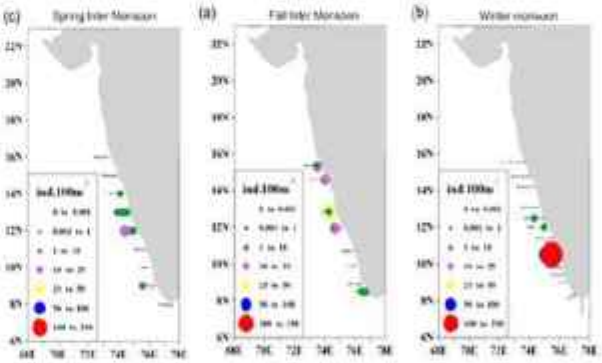


Fig. 3.10 Spawning ground of Indian Scad Decapterus russelli during non-monsoon periods

Acoustic observation showed mesopelagic fishes, dominated by myctophids, are a non-conventional fishery resources, account for a large part of the biomass, are found in the deeper layers (300-600m) during day time, and migrate to surface layers (0-150m) during night. Exploratory surveys in the Eastern Arabian Sea show significant variations between the north (NEAS) and south (SEAS) in terms of diversity, biomass, and diel vertical variations of

myctophids. Data from EK60 Echo-sounder frequencies (38, 120, and 200 kHz) along with meso-pelagic trawl data & information were made use to characterize the fishes in the Deep Scattering Layer (DSL). The selected species of Myctophid fishes are detected acoustically and the acoustic signals are processed and analysed for various filters.

3.2.4 Living resource enhancement through community farming – a societal development initiative

To achieve the large-scale production of marine ornamental fishes for the benefit of coastal fishers without affecting natural fish stocks, an experimental hatchery (Fig. 3.11) has been successfully developed at CMLRE. This pilot hatchery is dedicated to the development of non-invasive fish propagation strategies using a Recirculatory Aquaculture System (RAS) with synthetic seawater and the ability to control environmental parameters. The hatchery currently hosts five species of clownfish, namely Amphiprion clarkii, A. percula, A. ocellaris, A. nigripes, and A. sebae. Pair formation of A. clarkii, A. percula, A. nigripes, and A. sebae has been successfully achieved, representing a significant step towards breeding and propagation.

Fig. 3.11:

3.3 COASTAL RESEARCH done by National Centre for Coastal Research (NCCR)

3.3.1 Marine and Coastal Pollution

Seawater Quality Monitoring program (SWQM) assesses the spatial and temporal variations of physical, chemical, microbiological, and biological parameters in the coastal waters of India at around fifty locations along the Indian coast, encompassing the Andaman and Nicobar Islands and Lakshadweep. Three new record of Polychaeta species were reported from the Gulf of Mannar . Additionally, two rare hyaline tintinnid ciliates were reported from the coastal waters of off-Kanyakumari and its vicinity.

For real-time monitoring of coastal waters, 3 buoys equipped with water quality and meteorological sensors are placed at a depth of 10 to 12 meters along Visakhapatnam, Chennai, and Puducherry as part of the prediction of water quality program (Fig.3.12). The regional water quality model for these locations was set up to provide a 3-day advance forecast to the coastal stakeholders on water quality parameters, which is being disseminated through an in-house mobile app "Clean Coast".

Fig. 3.12 Automated sensor-based water quality Buoy at Chennai

Marine Outfall Monitoring programme across the Indian coastal waters are being implemented involving CPCB, SPCBs and PCCs . Two marine outfall locations from each coastal State and UTs were identified by SPCBs and PCCs. A total of 19 marine outfall locations were monitored and assessed for the compliance status of existing and proposed primary water quality standards for the seawater use classes SW-III and class SW-V.

Under the Marine Litter and Microplastics (MLMP) program the baseline data on microplastic pollution in the coastal water and sediment was generated through sampling along the West (30 transects) and East (45 transects) coast of India at various depths.

As a part of the World Oceans Day celebration and Swachh Sagar, Surakshit Sagar / ICC day campaign. Hon'able Minister inaugurated this event at Chennai (Fig.3.13), NCCR has organized the beach clean-up and awareness programs at more than 40 beaches during 2023-24 in association with various institutes to assess the level of plastics pollution and created mass awareness to the public on ill-effects of the litter, particularly plastics, in the marine environment. About 17,000 kg of litter were collected in a single day from Pan India beaches and disposed off from the beaches of India.

Fig. 3.13 : Hon'ble Minister and Secretary, MoES inaugurating beach clean up event at Elliot's beach, Chennai.

3.3.1 Coastal Processes and Hazards

As a part of shoreline management study, shoreline change maps for Indian coast and Islands of Lakshadweep has been prepared using satellite Imageries with time frame of 1990 to 2018 (Fig.3.14a). Shoreline Management Plan (SMP) has been prepared and released for the Tamil Nadu state. Similar plans for the Kerala, Puducherry, and Andhra Pradesh have been taken up. The development of Integrated Flood Warning Systems (IFLOWS) for the urban city of Kolkata in co-ordination with IMD, NCMRWF and the Kolkata Municipal Corporation (KMC) is in progress. The Atlas provides Coastal Inundation Risk Maps on 1:25000 scales for the coastal regions of Tamil Nadu (~1076 Km coastline) using the multi-hazard inundation line already developed by INCOIS (Fig.4).

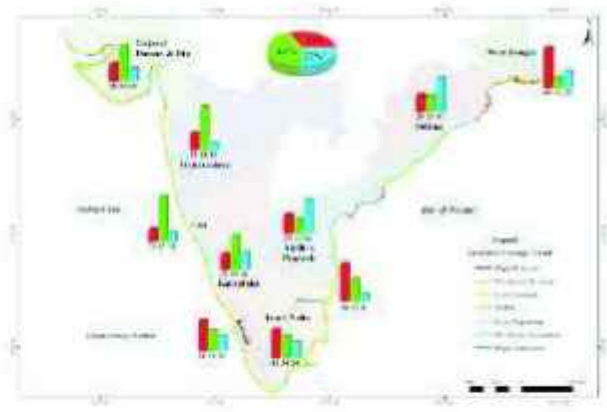


Fig. 3.14 (a) Shore line change (in percentage) map for 1998-2018 (b) IFlows dash board for Urbana

3.3.3 Coastal Habitats and Ecosystems

A comprehensive assessment of Ecosystem services provided by the Coringa mangrove ecosystem is being carried out in terms of provisional, regulatory and cultural services following the Common International Classification of Ecosystem Services (CICES) v5.1 framework. The Met-flux tower is being installed in Coringa mangroves to study the continuous GHG emissions and their importance in global climate change. A hydro-ecological model setup has been made for Coringa ecosystems to analyze the effect of nearshore circulation, transport, dispersion and biogeochemical processes. The model simulation revealed that the nutrient concentration in the bay is high during monsoon and post-monsoon season which leads to rich diversity in the phytoplankton distribution and the spatial distribution.

The Coastal Resources Assessment and

Management (CRAM) program by Monitoring, evaluating, and restoring coral reefs is undergoing in various regions like,Palk Bay and Gulf of Mannar in Tamil Nadu, Coromandel Coast in Tamil Nadu and Pondicherry, Malvan Coast in Maharashtra, and Grande Island off Goa. As part of Coral restoration studies, transplanted corals are cultivated on cement slabs in Palk Bay. 150 colonies of well-grown restored corals (Acropora muricata, A. hyacinthus) have been outplanted from Munaikadu-a restoration site in Palk Bay (Fig.8). Acropora sp. grows here at an average rate of 0.98 cm/month, reaching a maximum of 1.27cm/month. A new coral reef has been identified off Rameswaram and two new polyclad species were identified (Pseudobiceros murinus and P. stimpsoni), two polyclad species were identified as new records from the East Coast of India (Pseudoceros indicus and Maritigrella fuscopunctata).

3.3.4 Integrated Coastal Zone Management

Formulation of Marine Spatial Plans (MSPs) for Puducherry and Lakshadweep is in progress through Indo-Norwegian Collaboration. In February 2023, a beta version of these plans was unveiled on the dedicated GIS-based dashboard called "SAHAV" (derived from SAgar – Indian and HAV – Norwegian, symbolizing OCEAN) (Fig.3.15). SAHAV is intricately designed to provide decision-makers with comprehensive project details and data stored in a geo-database.

Fig. 3.15 Marine Spatial planning dash board being inaugurated at Puducherry and Lakshadweep.

3.3.5 Capacity Building and Training

Several training programmes were conducted including one day workshop on Marine Spatial Planning for Tamilnadu on 10th January, 2023 jointly with Govt. of Tamilnadu, three days training for fishermen community on Mapping our Coast towards Marine Spatial planning for Tamilnadu during 19th to 21st January, 2023 at Tuticorin, Tamilnadu. A hands-on training programme on "Seaweed Cultivation - An alternative livelihood for Fisher-Women Communities" was held at Munaikadu, Mandapam on 29th May 2023.

3.4 Ocean Technology

The activities related to ocean technology stated in the following sub sections are primarily conducted by the National Institute of Ocean Technology (NIOT), Chennai.

3.4.1 Energy and Fresh Water

Detailed design document and drawings for the Ocean Thermal Energy Conversion (OTEC) powered desalination plant equipment has been completed, civil works such as sump construction has commenced and the entire set of High Density Poly Ethylene (HDPE) pipes required for the project have been supplied to the project site and welding of these pipes has also commenced. Subtasks on Ocean Energy Powered Desalination and OTEC Economics led by NIOT have been taken up currently at Ocean Energy Systems (OES), a Technology Collaboration Program under the International Energy Agency (IEA). NIOT-MoES and the United States Trade Development Agency (USTDA) have signed a Grant Agreement for the Engineering Design of a high capacity OTEC power plant for Andaman & Nicobar Islands through the US and Indian industry (Fig. 3. 16a). A low-cost saline water lantern ROSHNI (Renewable Ocean System for Harnessing Novel Illumination) was developed in-house and the technology has been transferred to various industries (Fig. 3.16b). The saline water lantern predominantly is meant to be used as a lamp and emergency mobile charging device particularly useful in disaster-prone areas.

On 18th of March, 2023, the Honorable President of India, Smt. Droupadi Murmu, inaugurated two 1.5 LPD (Lakhs Per Day) Low-Temperature Thermal Desalination (LTTD) plants at Kalpeni and Amini Islands of Union Territory (UT) Lakshadweep (Fig. 3. 17).

(a) (b)

Fig. 3.16. (a) Photograph during Grant Agreement with USTDA for the design of OTEC plant (b) Picture of ROSHNI

3.4.2. COASTAL AND ENVIRONMENTAL ENGINEERING

The Indian Coastal Inlets Restoration Programme (ICIRP) is being conducted by NIOT aimed to keep the inlets sustainably open to ensure higher dilution, improved water quality, flood water discharge, navigation, tourism, fishing, etc. The web portal for the "Indian Coastal Inlets Restoration Program" has been launched for web portal. The studies related to restoration of 17 inlets in the Cauvery basin has been taken up on the request of Tamilnadu Water Resources Department (TNWRD). The work for sustainable mouth openings for the Cooum **(Fig. 3.18a)**, Ennore and Adayar river mouths is in process of implementing by TNWRD based on the recommendation by NIOT. A wave atlas for the north Indian Ocean including Islands is being developed by simulating wind generated waves using 28 years (1995 to 2022) high-resolution wind data (Fig. 3. 18 b). A North Indian Ocean Tide (N.I.O.T) mobile app has been developed and maintained based on observed tides along the Indian Ocean.

Fig. 3.17. Inauguration of Kalpeni and Amini LTTD Plant by Hon'ble President of India

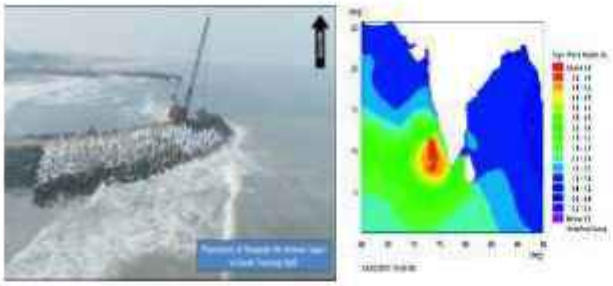


Fig. 3.18. (a) Cooum Mouth Restoration Works in progress (b) Wave atlas for the north Indian Ocean

3.4.3. OCEAN SCIENCE AND TECHNOLOGY FOR ISLANDS

Mass culture of Spirulina major was optimized in raceway ponds using customized media and a maximum biomass production of 660.00 g/m^3 and C-phycocyanin – 69.91 mg/g(dry weight basis) was achieved. Bio-oil was extracted from mass cultured Chlorella sorokiniana using microwave assisted hydrothermal liquefaction (MW-HTL) pilot scale cultivation of native seaweed Gracilaria edulis was carried out at Chidiatappu Andaman for the production of liquid fertilizer. A novel marine isolate Halomonas sp NIOT-EQR_J248 capable of mineralizing 70% Hg II was isolated from equatorial waters. A new pathway of Isooctyl thioglycolate mediated bioremediation of mercury Hg II was confirmed by GC MS, ICP MS analysis, mer gene amplification and molecular docking studies.

Training and demonstration of open sea cage culture of sea bass were carried to fishermen self-help group at Kumta Karnataka (Fig. 3. 19a) & 3.19b). Sea bass attained an average weight of 114 g in 92 days of culture from an initial weight of 10 g with formulated pellet feed.

(a)

(b)

Fig. 3.19. (a) Training on the cage fabrication (b) Cage culture sea bass in Kumta

3.4.4. MARINE SENSOR SYSTEMS

Design of an indigenous Underwater Acoustic Telephone (UAT) to be used in manned submersibles up to 6000 m depth has been completed. Stand-alone Digital Signal Processor (DSP) based Military Standard (MIL) grade Acoustic Telephone Hardware units suitable for marine environment up to 500 m operating depth has been designed and developed. The indigenous acoustic sub-bottom profiler technology for commercial production has been transferred to M/s. BEL (Bharat Electronic Limited) Bangalore.

3.4.5. OCEAN ELECTRONICS

A spar type 10m dia. fish cage culture system is fabricated and its functionality is demonstrated Off Ennore during August 2023. Development of Deep Sea Autonomous Underwater Profiler (DAUPD - operable up to 4000 m) is progressing with indigenized 1000 cubic capacity variable buoyancy engine. Two units were produced in house and carried out performance test in Bay of Bengal trials up to 500 m operations. Customized a small category heavy lift type Drone for marine applications (Fig. 3. 20 a)and was used for Ocean data collections at Pamanji – Nellore and observation of Air Quality Index parameter up to 120 m vertical height near East Coast Road (ECR), Tamil Nadu coast – Mahapalipuram **(Fig. 3. 20 b)**.

(a)

(b)

Fig. 3.20. (a) Heavy Lift – Hexacopter Drone capable of lifting 10kg instrumentation payload (b) Endurance test carried out with payload weighing from 5 to 10kg

3.4.6. OCEAN ACOUSTICS

An independent Acoustic mooring has been deployed at a water depth of 70 m at Kongsfjorden, Svalbard during Sep 16-18, 2023 to capture the dynamics of glaciers and icebergs (Fig. 3.21 a & 3.21 b). The system consists of a pair of hydrophones, connected to data acquisition modules, Conductivity Temperature Depth (CTD) and Tilt sensors configured for duty-cycled time series acquisition for a year. Central Arctic Ocean Data Analysis as part of Coordinated Arctic Acoustic Thermometry Experiment (CAATEX) Experiment recorded acoustic observations of continuous 1 hr of walrus signals in the Central Arctic Ocean during the autumn and winter of 2019. Identification of these signals revealed the presence of rhythmic knock sequences having metallic bell-like sounds consisting of short repetitious pulses lasting continuously for an hour. The vector sensor array system deployed as a bottom mounted unit in the shallow waters of South-West Bay of Bengal to measure the noise from boats/ships and localize the source. The acoustic data is analysed and the Direction of Arrival (DoA) is estimated using Multiple Signal Classification (MUSIC) algorithm for source localization.

(a)

(b)

Fig. 3.21 (a) System deployment at Kongsfjorden (b) Field Team

3.4.7 Shallow water bathymetry:

The shallow water bathymetry (0-30 m water depths) for West Bengal and Andhra Pradesh coasts have been completed successfully. Shallow water bathymetry surveys along Tamil Nadu and Odisha have been completed to an extent of 49% and 58% respectively.

3.4.8 Ocean Observation system (OOS)

Three cruises in the Bay of Bengal and one Arabian Sea was carried out onboard Operation Research Vessel (ORV) Sagar Nidhi for the maintenance of moored buoys. Imported Tsunami buoy systems

were replaced with NIOT Indigenous Tsunami buoy systems in the Bay of Bengal. Operational support was provided to various agencies for data observations.

The signals of cyclones like Extremely Severe Cyclonic Storm Mocha (May 2023), and Biparjoy (June 2023) in the north Indian Ocean were captured through real-time observations. Based on those observations, critical information on Tropical Cyclone Heat Potential (TCHP) was provided to IMD which helped in issuing cyclone warnings. An Oceanographic tool named "Moored Buoy Data Analysis and Representation Tool (M-DART)" developed for naval applications were released on 24th July 2023 by Vice Admiral Tarun Sobti, Indian Navy.

3.4.8 Coastal Ocean HF Radar network:

As part of the Indian Coastal Ocean Radar Network, a total of 10 numbers of High Frequency (HF) radar systems have been operated along the coast of India since 2008. HF radar measures surface current and waves along the coast about 200 km range.

3.5 Ocean Survey and Mineral resources:

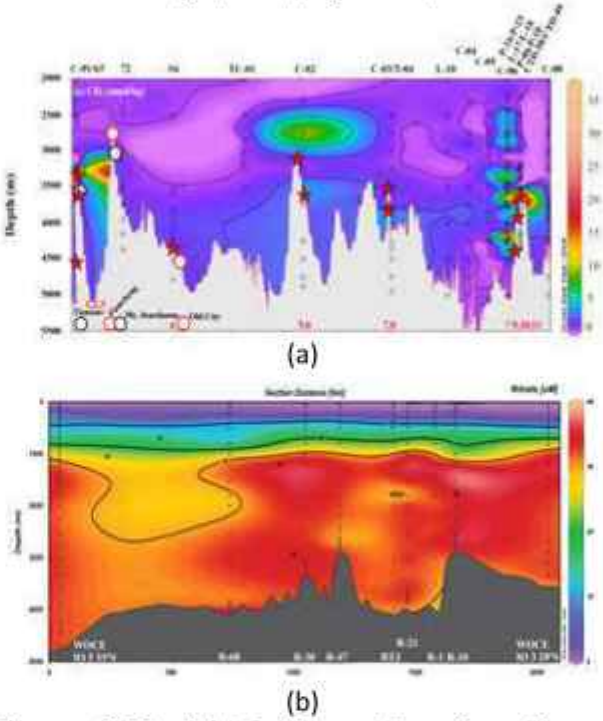
The activities of this component are carried out by National Centre for Polar and Ocean Research (NCPOR), Goa in collaboration with other national institutes.

3.5.1 Geoscientific studies in the Exclusive Economic Zone (EEZ):

Geomorphological analysis of the collected geophysical data revealed a large-scale submarine landslide in the Cochin offshore region, the southwestern continental margin of India. This massive submarine landslide named as "Cochin slide". Multibeam bathymetry data in the outer shelf of Visakhapatnam showed two discrete, NE-SW trending features, which coincide with the 90 m and 105 depth contours. These linear features are analogous to the morphology of a paleo-shoreline and are considered to be the markers of sea-level changes during the last glacial-interglacial transgression-regression.

3.5.2 Hydrothermal sulphide exploration program:

Several CTD operations in the South West India Ridge (SWIR) (67°E to 68°E), identified turbidity signatures for plume between the depths of 2300 to 4500 m. High methane concentrations ranging from 1.0-37.8 nmol/kg were observed in these plume layers (Fig. 3.22a). Baseline data collection for contract area in nutrient data in the water column in the clusters of Central Indian Ridge (CIR) and South West Indian Ridge (SWIR) (Fig. 3. 22b).



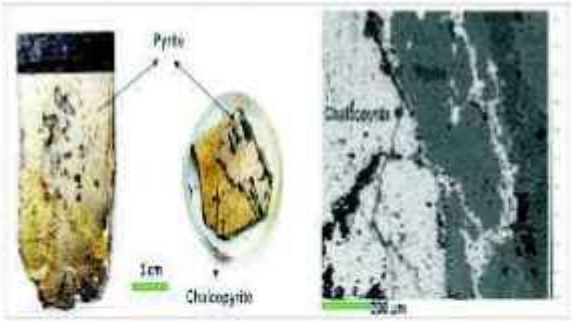
(a)

(b)

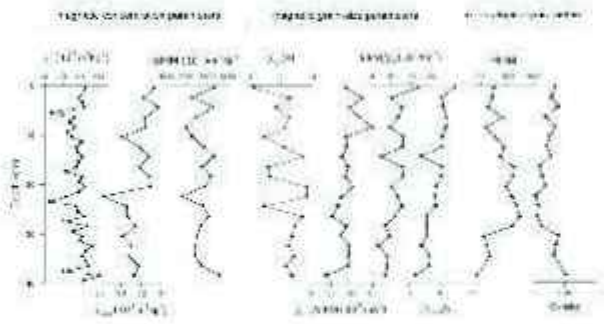
Figure 3.22: (a) Section plots of methane concentrations in nmol/kg in the SWIR (b) 2D section plot of Nitrate in water column in clusters of CIR and SWIR within the Indian contract area

Polymetallic sulphide samples were recovered from the vicinity of the SWIR field and studied for petrography and mineralogical investigations. Pyrite and chalcopyrite are dominant sulphide bearing phases along with iron oxide in the sulphide (Fig. 3.23a). Geochemical studies of surface sediments from eSWIR shows enrichment of Cu against both Fe and Mn suggesting to be sulfidic in origin. Mineral magnetic investigations on a sediment core from the SWIR, indicates that the region's sediments comprise a mixture of biogenic, detrital aeolian, local mafic and ultramafic debris, and hydrothermal components. They also suggest

that the sections between 0 and 15 cm and 30 and 40 cm have higher contributions from hydrothermal components, while the part between 15 and 30 cm has higher contributions from detrital components (Fig. 3. 23b).



(a)



(b)

Figure 3.23 (a) View of Polished section and BSE image of Sea-floor massive sulphides from Southwest Indian Ridge, showing the presence of pyrite and chalcopyrite (b) Down-core variation of mineral magnetic parameters in BC-10 indicating the concentration, grain size, and mineralogy of the magnetic minerals. The dashed lines represent the average value of the parameters in the core.

A total of 7,850,205 archaeal sequences were obtained from the CIR and SWIR. The analysis of archaeal phyla revealed the presence of Crenarchaeota, Nanoarchaeota, Thermoplasmatota, and Halobacterota. Crenarchaeota was the dominant group, while Nanoarchaeota had the lowest distribution. Thermoplasmatota and Halobacterota were more abundant in hydrothermal plume waters and bottom waters, indicating their potential as marker archaea for active hydrothermal vents. Seven new species have been described so far – four sponges (Fibuliaocciensis, Fibuliaocciensis, Asbestoplumaindiyansis, and Chondrocladiasagari), two corals (Telestularidgensis (Fig. 3. 24a) and Adinisis oblonga sp. nov.) and two squat lobsters (Munidopsisparavatee and Typhlonidamilindi). A new deep-sea Lobster species, Typhlonida milindi sp. nov. (Fig. 3. 24b) was found on ferromanganese (Fe–Mn) covered basalt rock collected from a seamount on the Southwest Indian Ridge, at water depths of 2070–2404m. The species is named in memory of late Dr. Milind Wakdikar (Scientist-G & Advisor to the Ministry of Earth Sciences), in honour of his contribution to deep-sea exploration in India.

(a)

(b)

Fig. 3.24 (a) Telestularidgensis a new species of deep-sea octocoral collected from a seamount on the Central Indian Ridge (1917–2053m depth) (b) New deep-sea Lobster species, Typhlonida milindi sp. Nov. found on ferromanganese (Fe–Mn) covered basalt rock collected from a seamount on the Southwest Indian Ridge, at water depths of 2070–2404m

3.5.3 Polymetallic Nodules (PMN) program (Survey & Exploration, Environmental Impact assessment studies (EIA) and metallurgy):

The part of the activities related to Survey & Exploration and EIA studies are being carried out by CSIR- National Institute of Oceanography (NIO), Goa. The near seabed bathymetry using Autonomous Underwater Vehicle (AUV) was carried out in parts of Impact Reference Zone (IRZ) at Central Indian Ocean Basin (CIOB). High resolution seabed maps of the area have been generated. The presence of nodules in the seabed and benthic organisms were clearly recorded. The analysis of biological (benthic organisms, planktonic forms, and metagenome assemblies) and geochemical parameters (water and sediment quality) in the contract area has been undertaken. The demarcated Impact Reference Zone (IRZ) in the contract area recorded higher density and biomass of benthic macrofauna compared to the Preservation Reference Zone (PRZ) area. However, PRZ showed more phytoplankton abundance as compared to IRZ. Within the plankton, diatoms were more dominant group followed by dinoflagellates and other planktonic forms. It was observed that Proteobacteria was the most abundant microbial group in the area.

The development of technology for extractive metallurgy of polymetallic nodules under PMN Programme is carried out at CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar. The following processing routes were studied.

I. Development of integrated ammoniacal-acid leaching process for the recovery of Cu, Ni, Co and Mn bearing products from PMN

Iron removal from the acid leach liquor is important to minimize lost targeted metals and the same was carried out by hydrothermal precipitation (Fig. 3. 25a) followed by polishing stage. The iron removal efficiency of 99.8% Fe was confirmed through hydrothermal precipitation and polishing operation while minimizing the metal losses in the iron residue with Mn-0.8%, Ni-1.1%, Co-3% and Cu-6.3%. Subsequently, the iron-free liquor was processed for solvent extraction of precious metals (Fig. 3. 25b).

II. Development of critical process parameters stage wise including reagent consumptions for reduction roasting process followed by metal/metal compound recovery

In the gaseous reduction process, the focus was directed on the downstream processing of Cu-Ni-Co-Fe-Mn alloy generated through gaseous reduction of Polymetallic nodules followed its melting for subsequent recovery of metal values and examining the suitability of the Mn-bearing slag for the recovery of Mn as Fe-Si-Mn alloy.

(a)

(b)

Fig. 3.25. (a) Hydrothermal Precipitation (b) Cu metal produced from PMN

3.6 Research Vessels:

The Ministry has six research vessels undertaking scientific research activities in the Arabian Sea, Bay of Bengal and the Indian Ocean. A total number of 66 research cruises were successfully undertaken by Sagar Nidhi, Sagar Manjusha, Sagar Tara and Sagar Anveshika. These vessels provided enormous support to the activities of the Ministry being a total number 1056 days in the Sea. Sagar Nidhi, Sagar Manjusha, Sagar Anveshika has completed dry dock

and afloat repair work. On 8th June 2023, Shri. Kiren Rijiju, Hon'ble Union Minister of Earth Sciences visited Research vessels Sagar Nidhi & Sagar Anveshika and launched the Ship Tracking System for Scientific Data Management [STSSDM] developed & customised by NIOT team onboard Sagar Nidhi **(Fig. 3.26)**. This advanced system facilitates the real-time monitoring of the ship's scientific data & movements aligning with global maritime requirements.

Fig. 3.26 : Honourable Minister visiting Sagar Anveshika at Chennai Port

Chapter–4

Polar and Cryosphere Research (PACER)

4.1 Scientific Studies in Antarctica

4.1.1 Spatio-temporal Investigations of Polar Lacustrine Systems (STAPLES)

High-resolution insights of physical properties of water columns of lakes at the Larsemann Hills, East Antarctica

During the Austral summer of 2022, a study investigated the physical properties of six lakes viz. LH57 (Progress), LH72 (Nella), LH51 (Cameron), LH74 (Discussion), LH04 and LH14 in the Larsemann Hills, East Antarctica (Fig. 4.1). The lake water column's key properties, viz. temperature, salinity, density, fluorescence, and depth, were examined using a Conductivity, temperature, and depth (CTD) profiler to establish a high-resolution description of their variations and identify the factors influencing intra and inter-lake variations. The results indicated that the water column of shallow lakes LH14, LH04 (Fig 4.1) and Discussions were well mixed from the homogenous profiles of the measured parameters. These lakes on Stornes were also affected by salinity, likely sea spray. In contrast, the deeper lakes, namely Nella, Cameron and Progress, were primarily influenced by temperature and density dynamics. The hydrological characteristics of Cameron and Progress lakes were notably impacted by their proximity to the ice sheet, while Lake Nella was influenced by the presence of a partial lake ice cover. Lake depth, location, and ice cover significantly affected temperature and salinity variations. Deep lakes may be more sensitive to temperature and density changes compared to shallow lakes and could potentially affect other physical lake parameters. This baseline information is a valuable reference for future investigations on these lakes and similar environments.

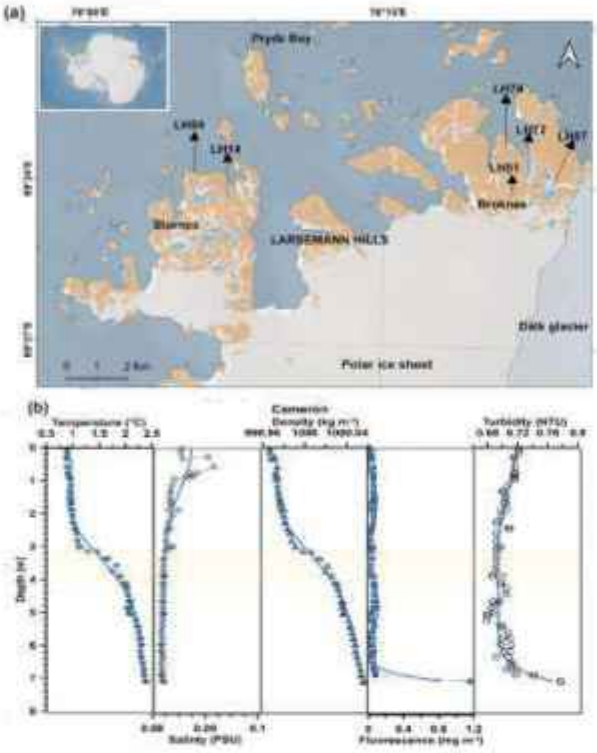


Figure 4.1. (a) Location of lakes under study in the Larsemann Hills, East Antarctica(Map); b) Vertical profiles of temperature, Salinity, Density, Fluorescence, and turbidity for deep lake LH51 (Cameron) showing inverse thermal stratification with thermocline (orange bar) at 3-4 m water depth. It is likely that such deep lakes have a different physical environment than shallow coastal lakes and possibly a different response to environmental factors.

4.1.2 Rapid Warming Over East Antarctica Since the 1940s Caused by Increasing Influence of El Niño Southern Oscillation and Southern Annular Mode

This study reconstructed a 200-year surface air temperature record in Dronning Maud Land (DML) using high-resolution ice core $\delta^{18}O$ data. Combining this with ERA5 reanalysis data (1994-2019 CE), we investigated the long-term temperature trends and their relationship with climate modes, emphasizing the Southern Annular Mode (SAM), El Niño-Southern Oscillation (ENSO), and the Interdecadal

Pacific Oscillation (IPO). Results revealed a cooling trend of about -0.164 ± 0.045 °C per decade (1809-1907 CE), succeeded by significant warming at +0.452 ± 0.056 °C per decade (1942-2019 CE)

Elizabeth Land (PEL) regions of East Antarctica has yielded significant findings regarding the influence of different factors on variations in snow accumulation and stable isotopic composition in these areas. Notably, in the DML region, the

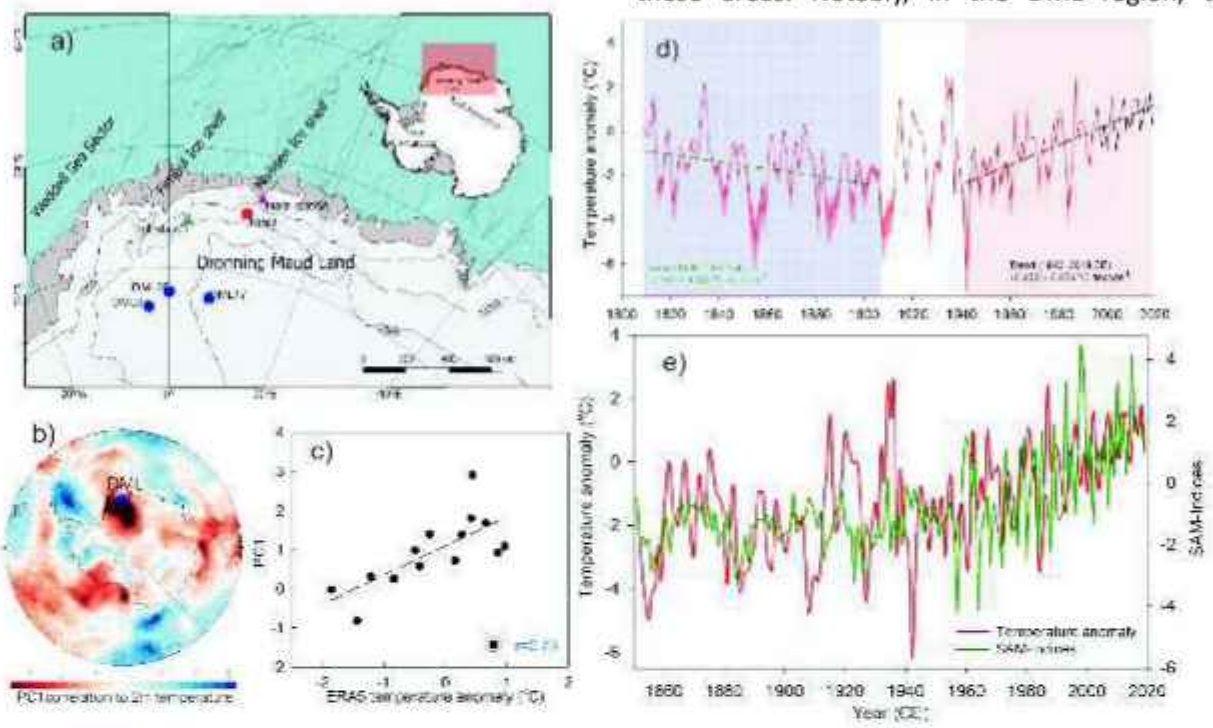


Figure 4.2. (a) Location map of Dronning Maud Land, East Antarctica, showing the ice core sites. (b) Principal component 1 (PC1) was correlated with seasonal (Nov-Dec-Jan) ERA5 surface air temperature record for the period of 19791993 CE. (c) PC1 shows a significant correlation with seasonal (Nov-Dec-Jan) ERA5 2m temperature anomaly averaged over the DML region (r= 0.73, p<0.05, 19791993 CE). (d) Trend analysis of the reconstructed surface air temperature anomaly record of the DML region, East Antarctica. (e) The Marshall SAM Index combined with the long-term 20CRV2c SAM record is compared with the DML temperature anomaly record.

(Fig 4.2). ENSO and SAM were identified as primary drivers, with recent SAM positive phase and heightened ENSO influence contributing to substantial DML warming, offering insights into broader climate dynamics.

4.1.3 Spatial variability and post-depositional diffusion of stable isotopes in high accumulation regions of East Antarctica

Stable isotopic analysis of Antarctic ice cores is a valuable tool for gaining insights into past climatic conditions. A recent scientific investigation carried out in the Dronning Maud Land (DML) and Princess

predominant driver of variations in $\delta^{18}O$ and δD is snow accumulation, while in the PEL region, temperature assumes primary importance as interpreted from the firn diffusion model output (Fig 4.3). Furthermore, this study involved a comparative analysis of $\delta^{18}O$ records derived from snow cores in relation to those obtained from ice cores, revealing a signal attenuation ranging from 55% to 70%. Importantly, the research underscores that, although isotope diffusion is present even in high accumulation regions, its impact on the dating and interpretation of paleoclimatic data is not substantial when compared to low accumulation areas.

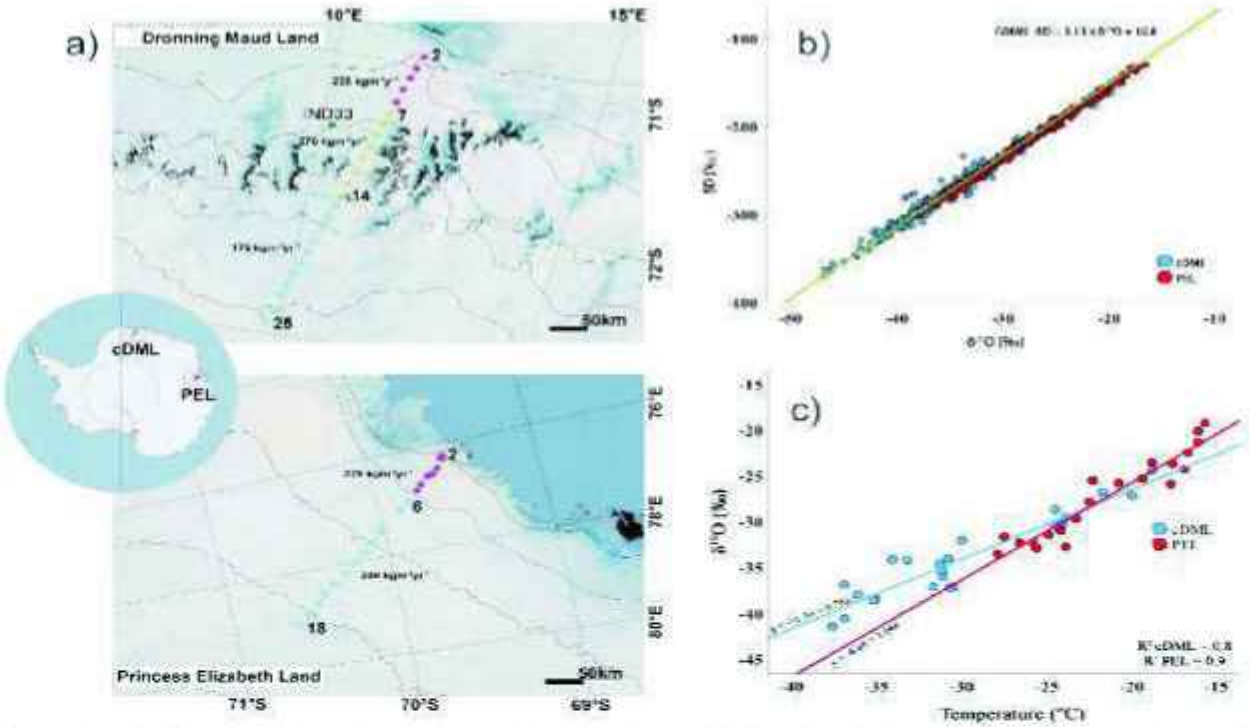


Figure 4.3. (a) Study region showing sampling locations. (b) The firn diffusion model output shows the diffusion length rapidly increasing from the surface layer before attaining its maximum at deeper layers. The diffusion length for the year 2008 was 6 cm (c) Differences in seasonal amplitudes of $\delta^{18}O$ records of IND-33 and the average snow core profile from the DML transect. Stacked profiles from which the average snow core profile is on the right. The signal attenuation in the ice core layer ranged between 55 and 70%.

4.1.4. Synthesis of field and satellite data to elucidate recent mass balance of five ice rises in Dronning Maud Land, Antarctica

This study examined the recent mass balance changes of five ice rises in central Dronning Maud Land, Antarctica. The research combined field-based geophysical measurements, such as GNSS surveys, radar profiling, and firn coring, with satellite altimetry data from ICESat, ICESat-2, and CryoSat-2. Results indicated that until 2010, three ice rises were thickening at a rate of 0.4 to 0.2 meters of ice equivalent per year, while the other two were in a balanced state. However, in the last decade, the previously thickening ice rises began thinning at a rate of -0.2 to -0.6 meters of ice equivalent per year (Fig 4.4). The observed variability is likely influenced by regional surface mass balance trends, with each ice rise exhibiting distinct characteristics based on its specific glaciological conditions.

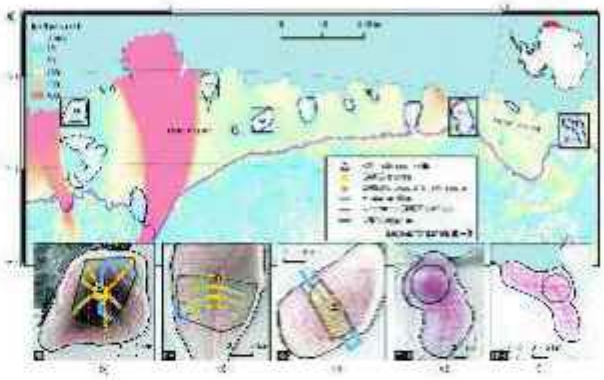


Figure 4.4. Panel (a) shows ice rises outlined in black over a flow speed map in Dronning Muad Land, east Antarctica. The inset shows the coverage of this map. Black boxes show the extent of sub-panels (b–f) of ice rises investigated in this study. Panels (B–F) show close-up views of ice rises and the various field data collected and discussed in this study.

4.1.5 Environmental Studies in Antarctica Multi index assessment of major and trace elements in the surface water of the lacustrine system of Schirmacher Hills, East Antarctica

This study evaluates the spatiotemporal variations in the water quality, major and trace element concentrations, and potential ecological risks associated with the lacustrine systems of Schirmacher Hills, East Antarctica. Water sampling was carried out under XLI and XLII Indian Scientific Expeditions to Antarctica (ISEA) during the austral summer of the year 2021-2022 and 2022-2023. Ninety water samples from 15 lakes were collected in three consecutive months, each year to determine the concentration of major and trace elements. Concurrently, in-situ measurements of physico-chemical parameters such as pH, temperature, electrical conductivity, and TDS were also measured using a Multi-parameter probe (HANNA Instruments). The mean concentration of studied major and trace elements in the lacustrine system of Schirmacher Hills. The results of trace element analysis indicated that most parameters were within the background values endorsed by World Health Organization (WHO). Elevated trace element concentrations were recorded at the sampling areas where potential human activities were observed.

4.1.6 Morphological changes and future projections of the Getz Ice shelf, western Antarctica

Moderate Resolution Imaging Spectroradiometer (MODIS) Satellite data from 2003 to 2022 assessed the 505 km extent of Getz Ice Shelf, divided into sectors I, II, III, each further split into transects at 5 km intervals. Ice shelf change rates were determined using average of rates (AOR), end point rate (EPR), and linear regression (LR) methods, cross-validated via correlation coefficients and RMSE. EPR and LR showed better correlation than AOR. During 2003–2019, LR indicated a 42 m/year shrinkage rate, validated by 2020-2023 data. 60% of transects receded, 40% prograded over 17 years. LR predicted 2024, 2029 extents: Sector I prograded, Sectors II, III receded (Fig. 4.5). Ocean-atmosphere analysis attributed changes to SAM, temperature, revealing the complex dynamics impacting ice shelf extent.

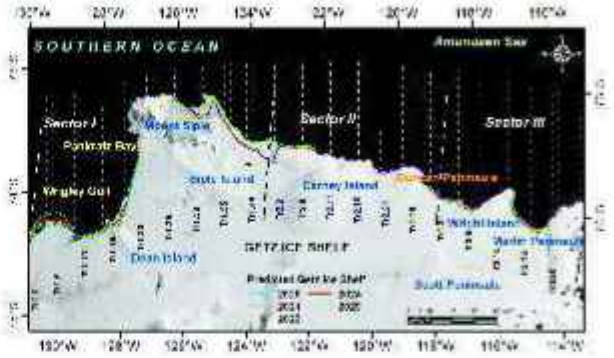


Figure 4.5. The projected extent of the Getz ice shelf for the 5- and 10-year periods (2024 and 2029) was determined using 2019 as the base year. To verify the accuracy of these predictions, data from 2020, 2021, and 2022 were overlaid and compared with the projected trends.

4.2 Operations and Management of Indian Antarctic Stations

The summer component of the 42nd Indian Scientific Expedition to Antarctica successfully concluded after the return of the expedition vessel, MV Vasiliy Golovnin to Cape Town, South Africa on 4 April 2023. A total of 104 persons comprising 37 scientists from 19 organizations and 67 operational staff from 8 organizations, including doctors, engineers, and helicopter crew, were deployed in 6 batches during the austral summer. Scientists involved in the multi-institutional scientific project, geological exploration of Amery Iceshelf (GeoEAIS), successfully carried out field surveys and sampling at several surrounding islands such as Reinbolt, Gillock Island, Munro Island, Vestfold Hills, Rour Group, including Bever Lakes.

The Sandhi outpost, established in 2018-19 at Reinbolt Hill, was resupplied with resources and a multi-sensor automatic weather station (AWS) was installed by Space Application Centre, Ahmedabad for year-round observations. Several participating scientific institutions and universities, such as Physical Research Laboratory, Geological Survey of India, Indian Institute of Geomagnetism, Indian Meteorological Department, National Centre for

Polar and Ocean Research, Pondicherry University, etc., carried out fieldwork, sea-floor sampling and observations at and around Maitri and Bharati stations. Out of the 49 members, 25 at stayed at Maitri and 24 at Bharati in Antarctica for the winter.

In the wake of the heightened risk of the spread of Avian Flu in Antarctica, the Committee on Infectious Diseases in Antarctica formulated guidelines and protocols for the Indian Antarctic Programme.

On 27 October 2023, the 43rd ISEA was launched with the first batch of 19 members and leader - Bharati, Shri Rivertis Pariong, IMD. The high-level delegation, including the Secretary, MoES, Additional Secretary & Financial Advisor, MoES, and the Director, NCPOR, joined for the maiden Cape Town to Bharati flight at Zenith Runway.

4.3 Himalayan Cryospheric Studies

4.3.1. Field work and data collections

During the period from June to October 2023, extensive glaciological field work was conducted over selected benchmark glaciers (i.e. Sutri Dhaka, Batal, Bara Shigri, Samudra Tapu, Kunzam and Bara Shigri) in the Chandra Basin, western Himalaya, encompassing a total glacierized area of approximately 300 km^2 (Fig. 4.6). The specific fieldwork activities undertaken during these periods are:

- Winter snow accumulation using snow pits and snow corer performed over the glaciers at various locations. All automated instruments, including AWS (Automatic Weather Stations) and WL (Water Level) were reinstalled, and winter data was retrieved.
- Ablation stakes were revisited, and their height differences were measured to assess winter melting. further summer ablation data was collected.
- Water level data collection, flow velocity and river cross section was performed at the three-discharge site location in the Chandra River.
- Differential global positioning survey (DGPS) was conducted for glacier surface displacements over the five (Sutri Dhaka, Batal, Samudra Tapu, gepang, and Bara Shigri) glaciers using stakes marker.

Figure 4.6. (a) The map of the Chandra basin (solid red color). The discharge and AWS sites are denoted with solid stars and circles, respectively. A solid blue color denotes the boundary of the selected glaciers for the field survey. Different field activities over the Chandra basin are also shown here. (b) Accumulation measurements on the Sutri Dhaka Glacier. (c) AWS data download near the snout of Samudra Tapu Glacier. (d) Ablation measurements using stake at Batal Glacier.

4.3.2. Differential surface melting of a debris-covered glacier and its geomorphological control

The debris thickness estimation and sub-debris ablation rate are relative to fully debris-covered area with mean debris-thickness of ~27 cm. This leads to comprehensive melt reduction as no clean ice area belongs to the same elevation band. Our rational fit (Østrem curve) results indicate 80 % of melt reduction between 2 and 72 cm debris thickness with a band between 95 % confidence interval (Fig. 4.7a). Fig. 4.7b shows the mean annual ablation under similar debris thickness over six consecutive years (2013-2019). The maximum ablation for any measurement year varied from 1.7 to 3.0 m w.e. a^{-1} with thin debris covers (2–10 cm). In contrast, the ice ablation was about 1.0 to 1.5 m w.e. a^{-1} under thicker debris (30–60 cm).

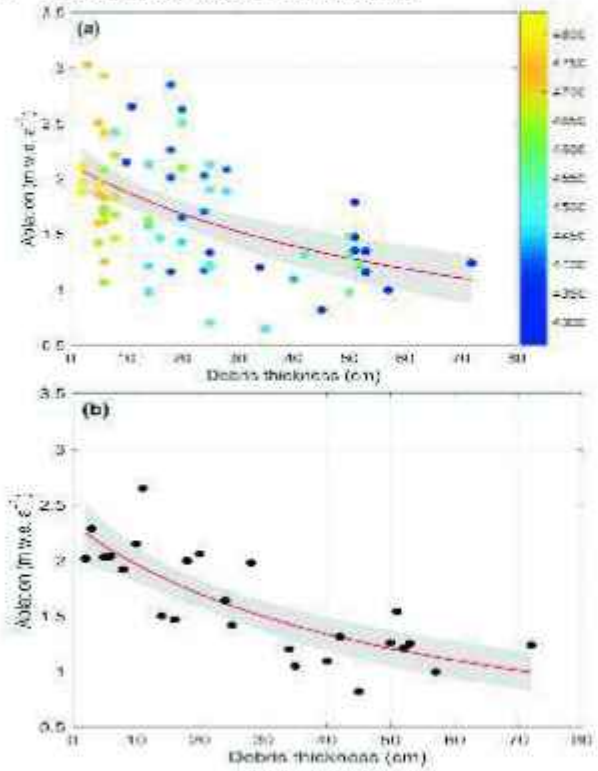


Figure 4.7. Østrem curves along with the shaded 95% confidence intervals displayed as rational fits of (a) all data sets (n=68) observed during 2013-2019. The colour shades of the circles depict the elevation bands. (b) mean annual ablation rates corresponding to the similar debris thickness distribution.

4.4 Scientific Studies in Arctic

4.4.1. Paleoclimate Research in the Arctic: Insights from fieldwork in coastal Greenland and western Svalbard.

NCPOR participated in International Ocean Discovery Program (IODP) Expedition 400 to North West Greenland during Aug-Oct 2023 (Fig. 4.8). IODP Expedition 400 focused on investigating the onset and development of glacial expansion in North West Greenland and the historical response of the Greenland Ice Sheet to past climatic changes. The expedition drilled six sites along a transect from the deep Baffin Bay basin to the glaciated margin of North West Greenland. Over 2000 meters of sediment core were recovered, providing a geological history from the Oligocene to the Holocene. Complementing this work, recent expedition in Kongsfjorden, Arctic, have successfully retrieved sediment cores for the purpose of reconstructing the region's paleoclimatic history and investigating global climate teleconnections. The fieldwork was conducted in collaboration with the Italian Institute of Marine Sciences (ISMAR) where two sediment cores were obtained using gravity coring methods during September 2023. The research aims to analyze geochemical proxies within these cores to investigate past climate changes and evaluate the Arctic-Indian monsoon teleconnection during Holocene.

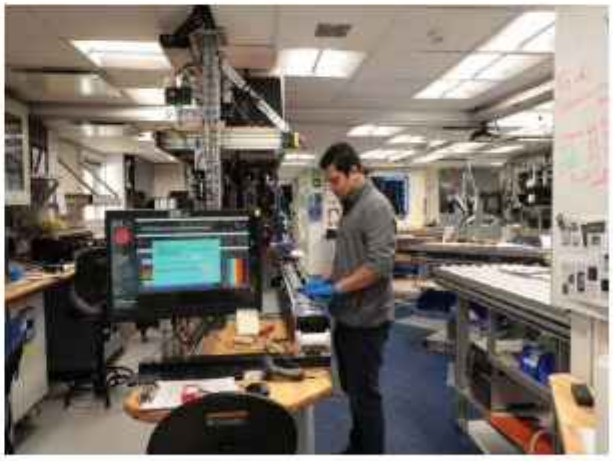


Figure 4.8. NCPOR participated in IODP Expedition 400 to North west Greenland.

4.5 Southern Ocean Studies

4.5.1. Prydz Bay Air-Ice-Sea Exchange (PRAISE) Program

The Prydz bay Air-Ice-Sea Exchange (PRAISE) program was initiated in 2021 to understand processes in the Antarctic shelf that govern the transport and exchange of heat, mass, and momentum; biogeochemical cycles/greenhouse gas exchanges; and fully coupled system behavior. As part of this program, India has established its first ice-tethered mooring system in Quilty bay, an embayment in Prydz Bay, East Antarctica in July 2022, which was later recovered in December 2022. Initial data analysis showed that the collected dataset is of good quality and provides a base data for the understanding of hydrography and the biogeochemistry of the Quilty bay, a sea-ice covered region for most of the year. In continuation of this program, the wintering team of 42nd Indian scientific Expedition to Antarctica (ISEA 42) has again successfully deployed the ice-tethered ocean mooring near Bharati Station, Prydz Bay, in July 2023 (Fig. 4.9). This is the second winter season observation carried out using this observatory.

Figure 4.9. Deployment of ice-tethered mooring near Bharati Station (69°24'S, 76°12'E), Prydz Bay in July 2023. This mooring system will measure temperature, salinity and ocean currents in a water column of 120 m depth during the austral winter.

4.5.2. Recent change in Southern Ocean sea ice extent from 2016 to 2022

The sea ice cover is an important indicator of global environmental change that modulates the albedo, ocean-atmospheric circulation, cryosphere ecosystems, and biogeochemical cycle. In a warming climate, the Southern Ocean Sea ice extent (SIE) has observed an overall increasing trend of 1.95%/decade from 1979 to 2015, of which the period from 2000 to 2014 observed higher ice extents with record high value in September 2014 (Fig. 4.10). However, this trend has recently dropped five times, to 0.11%/decade from 1979 to 2022. Out of 12 record low values, nine monthly low SIE were observed between 2016 to 2022. Recently, the SIE reached a record low condition in June 2022, July 2022, August 2022, January 2023, and February 2023, which were 13.67%, 9.91%, 6.79%, 39.29%, and 39.56% below the long-term mean values (1979-2015). The unusual variability in SIE from 2016 to 2022 occurred due to the combined influence of the intensification of the atmospheric zonal waves and anomalous warming of the atmosphere and ocean mixed layer. The SIE simulated by various CMIP6 model outputs were used as a representative tool to complement the recently observed declining trend in ice extent (Fig. 4.10). The ensemble-mean SIE showed a consistent decrease from 1979 to 2022. It has been observed

that the pattern of SIE change in satellite observations was closer to the model mean values from 2016 to 2022, hinting a possible shift towards a warmer climate.

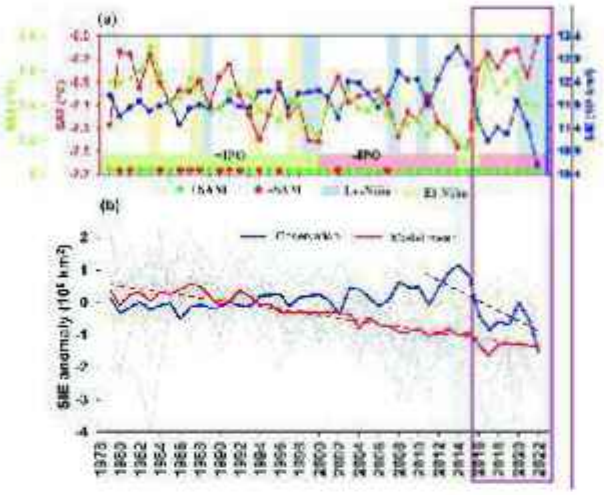


Figure 4.10. (a) The annual mean SIE from 1979 to 2022, the corresponding anomalous SAT, and sea surface temperature (SST) are represented in the blue, red, and green line plots. The green (red) shading represents the dominant positive (negative) IPO phases, while green (red) dots represent the annual mean positive (negative) SAM index. The blue (yellow) shading highlights the strong La-Niña (El-Niño) years. (b) The annual SIE anomalies for observational (blue) and the Coupled Model Intercomparison Project Phase 6 (CMIP6) (red) simulated for the entire Southern Ocean.

4.5.3. Concurrent Measurements of Phytoplankton Productivity and Light Absorption from a Global Carbon Hotspot: Variability, Features, and Causes

Plausible reasons for variability in phytoplankton carbon uptake rate and underwater light absorption capacity of phytoplankton were explained in the sparsely sampled Indian Sector of the Southern Ocean. Carbon uptake rates estimated by stable (^{13}C) and radioactive-tracer (^{14}C) based methods to show that the stable isotope can be a suitable alternative for its radioactive tracer counterpart, which some countries have banned due to contamination issues. This study also showed that phytoplankton size structure could be classified based on their light-absorption efficiency, which is controlled by the arrangements or packaging of the pigments inside the phytoplankton. The larger the phytoplankton, the smaller the packaging effect, and the more efficient the light absorption.

4.5.4. Cross frontal variability in bio-optical characteristics in the Indian sector of the Southern Ocean during an austral summer

Bio-optical properties, which play a crucial role in the understanding of the radiation budget of optical active substances (OAS), phytoplankton community, biological pump, and detection of algal blooms, have been sparsely studied in the Southern Ocean (SO). Bio-optical characteristics change across the frontal regions and during phytoplankton bloom and non-bloom domains in the Indian sector of the SO (ISSO) during the austral summer of 2011 were investigated. Using the vertical distribution of CDOM and its relationships with slope and Chlorophyll-a, multiple sources of CDOM could be identified. The percent abundance of OAS in the Polar Front-1 (PF-1) exhibited lower a_{ph}, lower detrital absorption (a_d), and higher a_{CDOM}, indicating its low productivity compared to other fronts.

4.5.5. Regional Ocean Modelling System (ROMS) for Prydz Bay, East Antarctica

To study the interaction of coastal and open ocean waters in Prydz Bay region of East Antarctica, a realistic regional scale ROMSv3.6 ocean model coupled with a sea-ice model has been set up. The model was incorporated with the mechanical and thermodynamic effects of the Amery Ice Shelf and West Ice Shelf. This model will help to understand the contribution of ocean circulation and water mass to the basal melting of the ice shelf in Prydz Bay. The model comparison with the satellite showed the better performance of the ROMS in the Prydz Bay region.

4.5.6. Participation in GO-SHIP Cruise

Ms Nirmala J., JRF, NCPOR has participated in the GO-SHIP IO5_2023 cruise aboard the Scripps Institution of Oceanography research vessel Roger Revelle from Fremantle, Australia to Cape Town

South Africa for 55 days (22 July-14 September 2023) of hydrographic operations along 32°S in the Indian Ocean (Fig. 4.11).

Figure 4.11. Ms. Nirmala, JRF, NCPOR onboard Research Vessel Roger Revelle. She was part of the scientific team to conduct CTD measurements along a zonal section (~32°S) between Fremantle, Australia, and Cape Town, South Africa. During this cruise, she was actively involved in CTD operations and water sampling at various hydrographic stations.

Chapter–5

Seismology and Geosciences (SAGE)

5.1 Observational Seismology, Earthquake Monitoring and Services

The National Seismological Network (NSN) consisting of 158 observatories as shown in Figure 5.1, continues to operate successfully. The 24x7 operational center at NCS headquarter located in IMD campus at New Delhi, maintains round-the-clock monitoring of earthquake activity in and around the country. It disseminates the earthquake information promptly after the earthquake occurrence to all the concerned agencies and stakeholders through social media to deal with the post-disaster relief and rehabilitation related matters leading to mitigative measures.

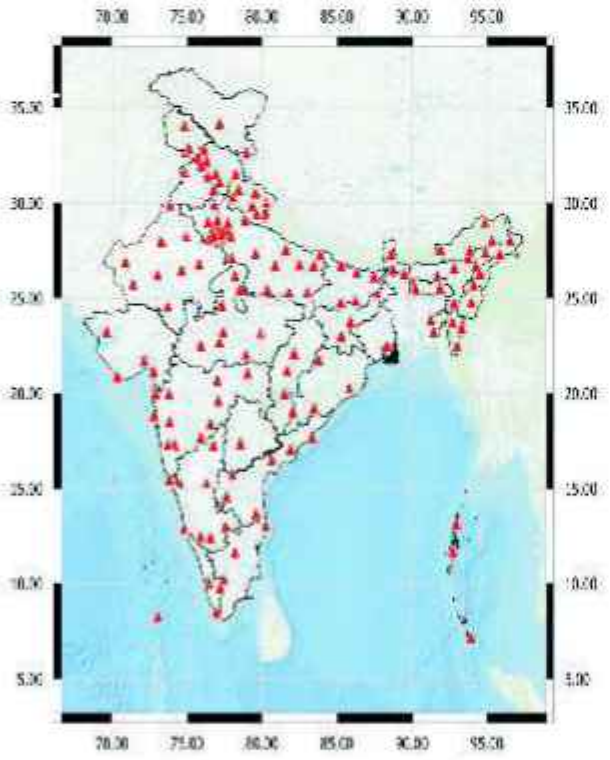


Fig. 5.1: National Seismological Network, comprising of 158 Seismological Observatories distributed throughout the country.

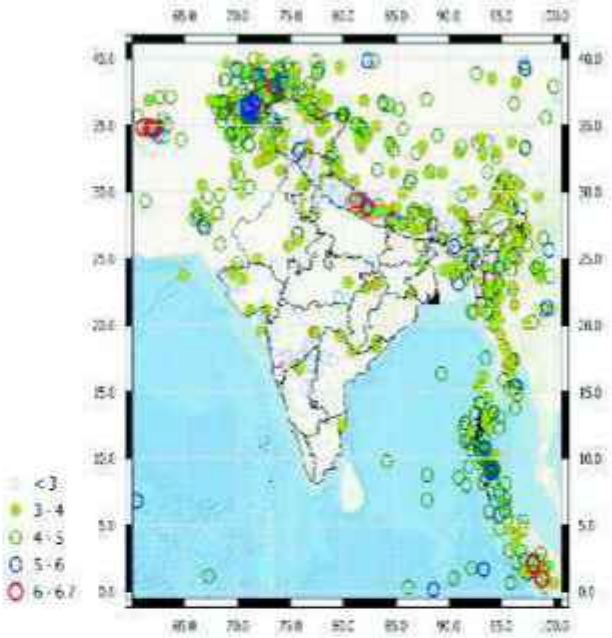


Fig. 5.2: Location of earthquakes disseminated by National Seismological Network of NCS during 01st January 2023 to 15th December 2023.

All the observatories of NSN are equipped with state-of-the-art Broadband and Strong Motion digital recorders, connected online to the operational centre for near real-time earthquake monitoring. This online integration of field observatories with the operational centre has contributed significantly for quick analysis and subsequent dissemination of the earthquake information within 4 minutes and enhanced the minimum magnitude detection. Presently, NSN is capable to detect every earthquake of magnitude 3.0 and above nationwide, while the densely networked regions of Delhi NCR and NE India can detect magnitudes below 3.0 as well. Recently, two new seismological observatories were commissioned, one at Madhubani (Bihar) on 6th May, 2023, another at Bomdilla (Arunachal Pradesh) on 10th December 2023, and two in Koyna region.

Additionally, it is planned to increase the strength of NSN by adding 100 more seismological

observatories and to upgrade Central Receiving Station in the coming years for enhancing the detectability of lower magnitude of earthquakes and improve the processing of in-coming ground motion data.

A total of 1624 earthquakes occurred in and around neighbouring region of the country (0°-40° N and 60°-100°E) were located and disseminated during the period January 2023 to 15th December 2023 (Fig. 5.2). Out of these, 65 events (4% of total earthquakes) are of magnitude 5.0 and above. Out of 1624; 599 earthquakes occurred within Indian territory. During the same period, 65 earthquakes occurred in the Andaman Sea, 80 in Uttarakhand and 53 in Assam. Table 5.1 provide the list of significantly felt earthquakes within the Indian territory during the last one year. Detailed information about all earthquakes and monthly reports of significant earthquakes have also been disseminated to various stakeholders through NCS website (https://seismo.gov.in) during the reporting period. Distribution of earthquakes occurred during 01st January 2023 to 15th December 2023, in different magnitude ranges in India and in its neighbourhood are shown in Fig.5.3.

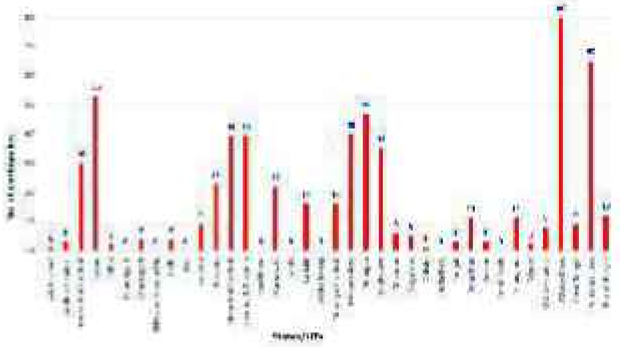


Fig. 5.3: Distribution of earthquakes occurred during 01st January 2023 to 15th December 2023, in different magnitude ranges in India and in its neighbourhood.

A series of moderate earthquakes occurred within one year in western Nepal of magnitudes M 6.3 (03rd Oct, 2022), M 6.2 (9th Nov, 2022), M 5.8 (05th Jan, 2023), and 6.3 (03rd Nov, 2023). All these events originated at shallow focal depths ranging between 5 to 15 km and therefore felt widely in northern parts of the country. Their approximate epicentral distances were 302km E of Haridwar, 206km SE of Joshimath, 296km E-SE of Rishikesh, and 434km NW of Kathmandu respectively. The NSN recorded above earthquakes as well as subsequent numerous aftershocks quite well associated with these earthquakes.

Table 5.1: Significantly felt Earthquakes within Indian territory during 2023 (with a separate weblink to the concerned earthquake.)

SN	Date	Time (IST)	Lat(°N)	Long(°E)	D (KM)	M	Region
1	2023-01-16	03:59:58	2.05	97.94	10	6.1	Northern Sumatra, Indonesia
	https://riseq.seismo.gov.in/riseq/earthquake/event/WkwOU1OeFBqQjM0TkluVVhZK2xyQT09/Reviewed						
2	2023-01-24	14:28:31	29.41	81.68	10	5.8	Nepal
	https://riseq.seismo.gov.in/riseq/earthquake/event/d2dqd0hUQU9WZmIvVHUySmlpdUZpdz09/Reviewed						
3	2023-02-23	06:07:44	37.88	73.39	25	6.7	Tajikistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/VFBmd290YkY1YXZYMnMxaUgcb2RYdz09/Reviewed						
4	2023-03-21	22:17:27	36.09	71.35	156	6.6	Hindu Kush, Afghanistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/VUxWQnEvTkJ4MzU3OS91YTdyWGhvUT09/Reviewed						
5	2023-05-31	16:50:20	25.20	96.08	15	5.7	Myanmar
	https://riseq.seismo.gov.in/riseq/earthquake/event/R3Q2K3pQWkt2TDY0NkxySTJNUTNvUT09/Reviewed						
6	2023-08-14	20:19:47	25.02	92.13	16	5.4	Bangladesh
	https://riseq.seismo.gov.in/riseq/earthquake/event/cTFIcjdsdU82TIYrOGV5STlTcl9YZz09/Reviewed						
7	2023-09-11	23:01:49	24.40	94.77	20	5.1	Myanmar
	https://riseq.seismo.gov.in/riseq/earthquake/event/T0VkK0RFb25FS3FuMVJRekllWERPZz09/Reviewed						
8	2023-10-03	14:51:04	29.39	81.23	5	6.2	Nepal
	https://riseq.seismo.gov.in/riseq/earthquake/event/K2YzOU9wOGZ6SXlTdUppYWhnoDFtdz09/Reviewed						
9	2023-10-07	12:11:02	34.78	61.81	21	6.1	Afghanistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/b0RNdGNsZXl3UnJLMU9pN24xMkl4Zz09/Reviewed						
10	2023-10-07	12:42:50	34.83	61.12	34	6.2	Afghanistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/VFA5ZDVPd384Nm4rTUwrQ0s5Q395dz09/Reviewed						
11	2023-10-11	06:11:56	34.71	62.13	10	6.1	Afghanistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/NWQ2aE1UallJeEtuWTdKdm1URHdKZz09/Reviewed						
12	2023-10-15	09:06:03	34.76	62.02	70	6.2	Afghanistan
	https://riseq.seismo.gov.in/riseq/earthquake/event/UFRNZ3ovc2ZPRlAxa3hLcGt3bktxZz09/Reviewed						
13	2023-11-03	23:32:54	28.84	82.19	10	6.4	Nepal
	https://riseq.seismo.gov.in/riseq/earthquake/event/RC9tRm8rd1hMaXNFghKUjd1bWFwUT09/Reviewed						
14	2023-11-06	16:16:40	28.89	82.36	10	5.6	Nepal
	https://riseq.seismo.gov.in/riseq/earthquake/event/UWpoekR5Qk2YY1VC3UFPd0hNVnlIUT09/Reviewed						
15	2023-12-02	09:05:31	23.15	90.89	55	5.6	Bangladesh
	https://riseq.seismo.gov.in/riseq/earthquake/event/Y0lucDNPTW4zZnVkUXJtUldOZnh0UT09/Reviewed						

Analysis of seismic data shows that these events occurred on the Main Central Thrust (MCT) and North Almora Thrust (NAT) which provide a very apt location for triggering the mainshock due to the appreciable structural heterogeneity in and around the surrounding region. The preliminary fault plane solution derived from moment tensor inversion indicates a thrust fault mechanism. These earthquakes were widely felt across the northern part of India, including the Delhi-NCR region and neighbouring states. Numerous felt reports were received from Delhi-NCR, Bihar, Uttar Pradesh, and Uttarakhand through the NCS website and mobile app within an hour, with calculated intensities ranging from II to III on the Modified Mercalli Intensity (MMI) Scale.

Several earthquakes with low to moderate magnitudes have occurred in the Afghanistan region over the past one year. Among these, two moderate earthquakes of magnitude M:5.8 (August 5, 2023) and M:5.2 (August 6, 2023) occurred at focal depths of 181 km and 85 km, respectively. The earthquakes were widely felt in the North and North-Western parts of India, including Jammu and Kashmir, Punjab, Himachal Pradesh, Delhi-NCR, and neighbouring states. The source area of these earthquakes is seismically very active and represents one of the deepest and most active intracontinental subduction zones on earth. These earthquakes originated due to the collision between the Indian and Eurasian lithospheric plates at the western Himalayan margin.

A moderate earthquake of magnitude M:5.8 occurred in the Andaman Sea at 00:53:47 IST on July 29, 2023, with a focal depth of 69 km. The earthquake was reportedly felt throughout the Andaman and Nicobar Islands.

5.1.1 Seismic Hazard and Risk Assessment study

Seismic microzonation studies play a crucial role in comprehending the diverse levels of earthquake risk across different regions, by considering multiple factors such as soil types, geological conditions, and local topography to evaluate the potential behaviour of seismic waves in specific locations. This information is essential for urban planning and designing structures which are vital for building an earthquake risk resilient society. In the Ist phase, seismic microzonation work of 4 cities (Bhubaneswar, Chennai, Coimbatore, and Mangalore) have been completed. The comprehensive reports for these cities are currently undergoing review by the Expert Committee, and are planned to be released very soon, making them accessible to all stakeholders involved.

Under 2nd phase, work related to seismic microzonation initiated in the 08-priority cities (Agra, Amritsar, Dhanbad, Kanpur, Lucknow, Meerut, Patna and Varanasi) are currently in progress and the multi-disciplinary field investigations like geophysical and geotechnical have been completed. The status of the investigations of these cities is provided in Table 5.2. In addition, the special laboratory tests comprising of Resonant Column test (RCT) and Cyclic Tri-axial tests (CTT) which are required to assess the dynamic behavior of soils under varying loading conditions for assessing the potential for liquefaction in the cities are currently in progress.

The local site-effect on the ground motion is considered the most significant factor in zoning of ground motions. The local site-effect can be estimated using various methodologies, depending to the level of accuracy required and studying zoning level. Among others, microtremor survey (Fig. 5.4) the horizontal-to-vertical spectral ratio (HVSR) (Fig. 5.5) and array data analysis methods are most popular techniques to retrieve site response parameters using micro-tremors. Microtremor survey at around 5712 locations in all the 08-cities and the data processing for the same has been completed successfully.

Table 5.2: Status of the investigations under Seismic Microzonation in 08-cities

<table>
<tr><th></th><th colspan="3">Geophysical Surveys</th><th colspan="2">Geotechnical Surveys</th></tr>
<tr><th>City</th><td>Microtremor</td><td>MASW</td><td>DHT</td><td>Field Investigations</td><td>Lab Investigations</td></tr>
<tr><td>Agra</td><td rowspan="6">Completed</td><td colspan="3" rowspan="8">Field Investigations & Data Processing Completed - Data Analysis in progress</td><td rowspan="8">Mechanical Tests completed. Special lab tests in-progress</td></tr>
<tr><td>Amritsar</td></tr>
<tr><td>Dhanbad</td></tr>
<tr><td>Patna</td></tr>
<tr><td>Lucknow</td></tr>
<tr><td>Varanasi</td></tr>
<tr><td>Kanpur</td><td rowspan="2">Few sites Pending*</td></tr>
<tr><td>Meerut</td></tr>
<tr><td colspan="6">* Required permissions from the cantonment areas are awaited for the survey to be completed.</td></tr>
</table>

Assessing site effects begins with establishing the shear-wave velocity structure, which acts as a key indicator of the resilience of formations near the surface. The complete MASW process involves collecting multi-channel surface-wave data, constructing a dispersion curve (Fig. 5.6), and employing inversion techniques to generate a profile of shear-wave velocities (Fig. 5.7). The Shear-wave velocity structure at 107 locations have been estimated through MASW in the 08-cities.

Figure 5.4: Typical Microtremor Survey Instrumentation set-up at Agra city

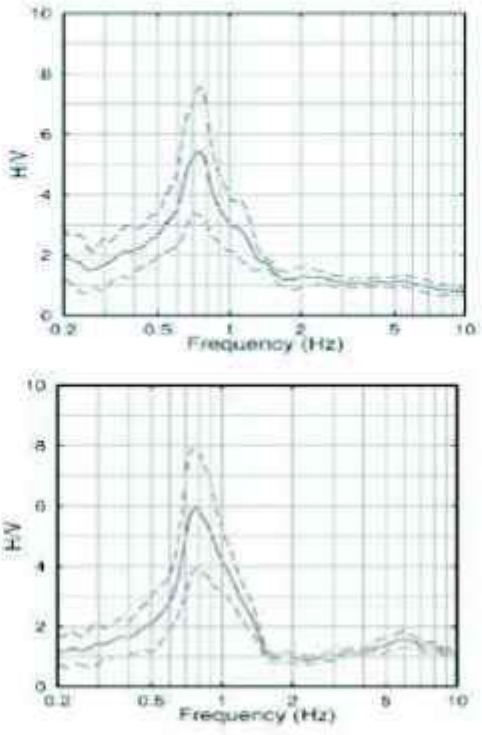


Figure 5.5: Examples of HVSR curves obtained in one location of Agra city

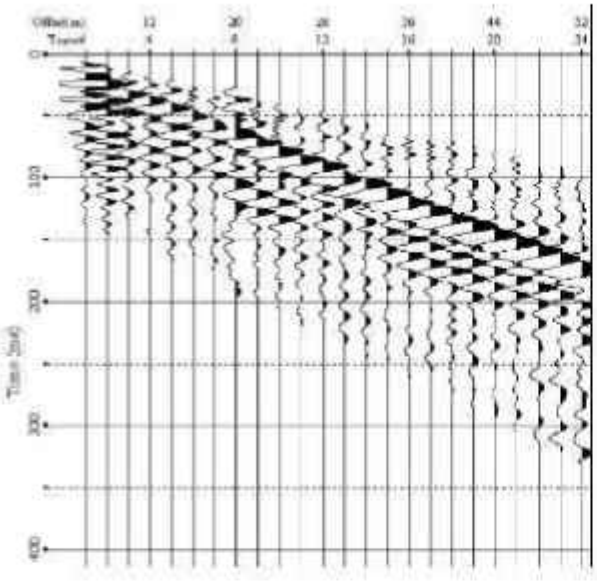


Fig. 5.6: Shot-gather data at one of the MASW locations for city of Agra.

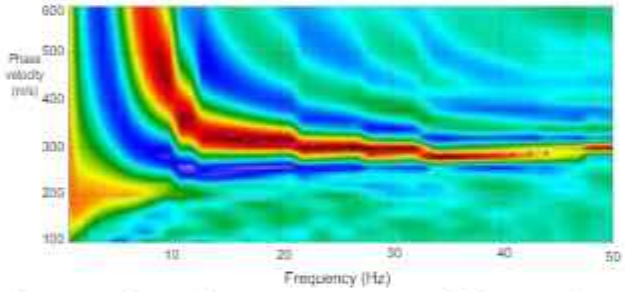


Fig.5.7: Dispersion curve at one of the MASW locations for city of Agra.

Due to the anticipated low strength of the soil at specific depths, geotechnical investigations are imperative to assess soil strength at various locations and depths. A comprehensive understanding of past seismic events requires a meticulous examination of the engineering properties of the soil through geotechnical investigations. During drilling of boreholes, disturbed and undisturbed sample were collected, for field and laboratory soil tests to providing the data needed to assess seismic hazards, understand soil behavior during earthquakes, and design structures that can withstand seismic forces. A lithological cross section derived from compiling the information collected from few Geotechnical boreholes drilled in one of the 08-cities is shown in Fig. 5.8.

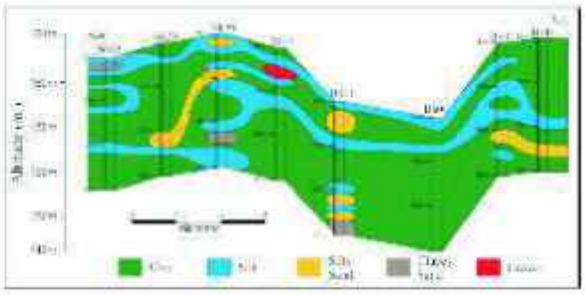


Fig. 5.8: Lithological Section across a traverse line in one of the 08-cities derived from the Field & Laboratory Geotechnical Investigations.

Across the eight cities, 256 geotechnical Boreholes upto a depth of 30m, 41 downhole tests (DHT) upto a depth of 100m, 28 nos. each of seismic cone penetration tests (SCPT) and dynamic cone penetration tests (DCPT) have been conducted to determine the resistance of the soil strata to penetration.

The downhole method is employed to acquire profiles of shear wave and compression-wave velocities in the subsurface for geotechnical design purposes. It is frequently utilized in the determination of shear velocity, assessment of liquefaction potential, and calculation of geotechnical design parameters. The configuration layout of the typical DHT survey is shown in **Fig. 5.9** and an example of the shear-wave path collected at one of the 08-cities in shown in **Fig. 5.10**.

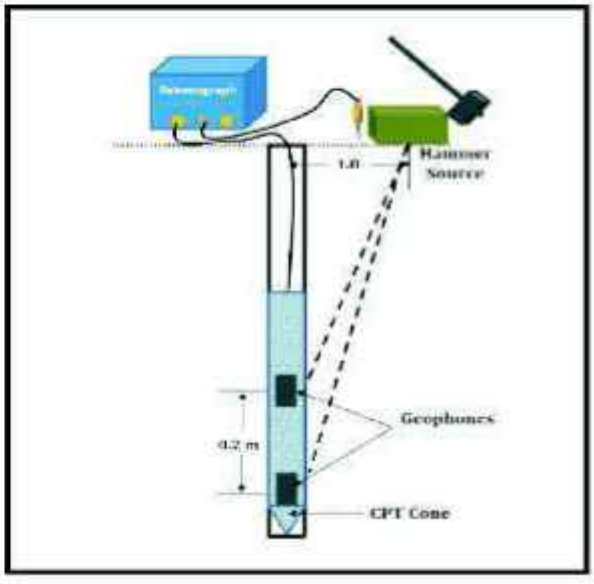


Figure 5.9: Configuration Layout of DHT

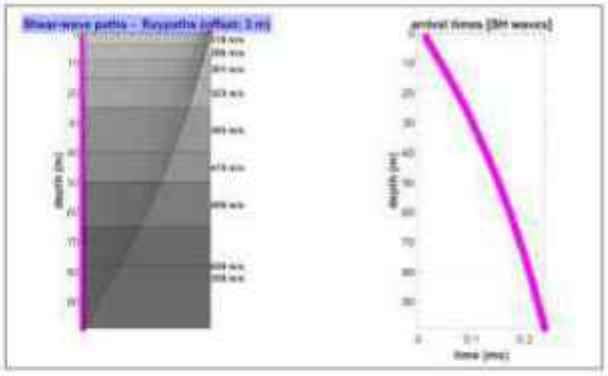


Figure 5.10: Ray-path of SH waves at one of the DHT locations

5.1.3 Pilot study on Earthquake Early Warning

NCS has initiated a pilot study on earthquake early warning (EEW) system. It is planned to cover a 200 x 200 km area under seismic Zone V in Himachal Pradesh initially for the installation of the EEW sensors **(Fig. 5.11)**.

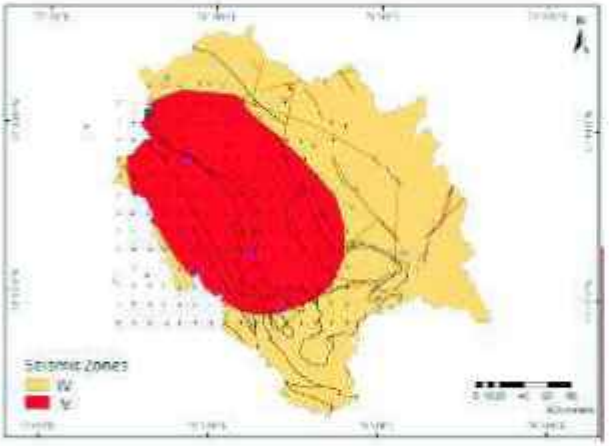


Fig. 5.11: Plan of EEW system in Himachal Himalaya under Seismic zone V

5.2 Seismological studies in the Koyna seismic zone

(I) Seismic monitoring in the Koyna region

A local surface broadband seismic (BBS) network consisting of 5 stations is being operated since January 2022 to monitor microearthquake activities surrounding the Koyna pilot borehole (KFD1) site (Fig. 5.12). The stations are distributed within a radius of 5-7 km from the KFD1 site. A total of 2058 events with magnitude range M0 to M3.8 and depth range 0 to 12 km have been recorded by the network until September 2023 (Fig.5.13). The seismicity in Koyna region trends along NNE - SSW direction, consistent with the trend of the Donachiwadi surface rupture zone, a surface manifestation of the causative fault deeper in the crust.

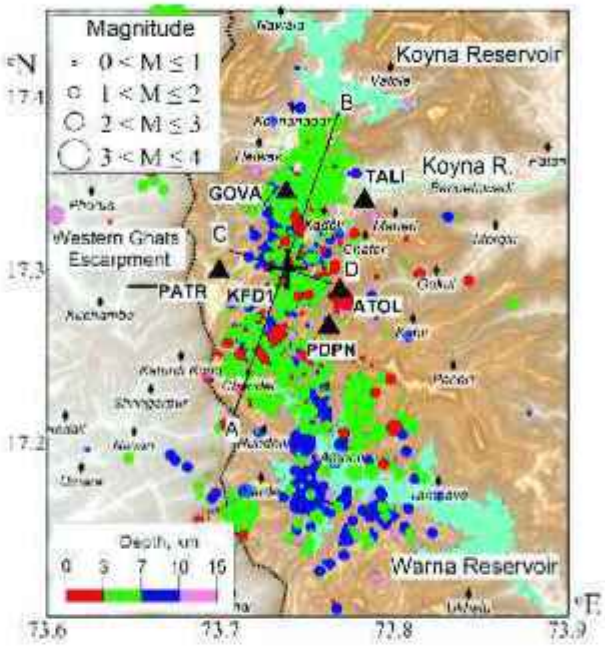


Fig. 5.12: The seismicity map of Koyna region superposed over the topographical map. Circles with different sizes and colours represent the magnitude and depth variation of the earthquake events. Triangles represent our broadband seismic stations (TALI, ATOL, PDPN, PATR and GOVA); black cross denotes the location of 3 km deep Koyna pilot borehole (KFD1); diamonds represent major localities. Two profiles AB and CD marked on the map are used to study the depth variation of earthquakes surrounding the Donichawadi fissure zone in Fig. 5.13.

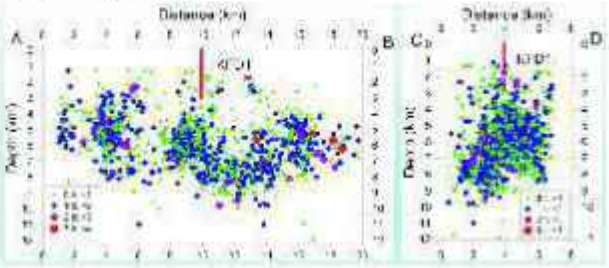


Fig.5.13: The depth distribution of events along the profiles AB and CD (shown in Fig. 5.12). Vertical red line represents the 3 km deep Koyna pilot borehole KFD1.

The recorded seismograms have been analysed to obtain an optimum one-dimensional (1D) velocity model of the Koyna region (Fig. 5.14). Only well-located events with root mean square (RMS) error < 0.1 s and horizontal and depth error ≤ 5 km, were used in the analysis. The estimation of the velocity model was based on trial-and-error basis and requires a priori information about the subsurface structure. Due to the ambiguity of the procedure, 19 a priori 1D models were used and several parameters that controlled the inversion were varied to get the minimum 1D model for the region. A total of 3350 phases consisting of 1688 P-phases and 1662 S-phases were inverted to get the 1D velocity model of the study region. Next, a grid search was adopted to obtain the best model, by varying the velocity as well as depth based on the standard deviations in the model as predicted by the a priori models. The obtained minimum 1D velocity model of the Koyna region consists of 4 layers up to a depth of 10 km with P-wave velocities ranging from 4.1 to 6.43 km/s and Vp/Vs ratio of 1.65. As most of the earthquakes in the Koyna region are located within a depth range of 0 to 12 km, therefore velocity model beyond 12 km depth could not be constrained from the present analysis. The events were relocated using the proposed velocity model (Fig. 5.15 a, b) and improvement in the location error of ~2.0 km in depth and horizontal coordinates (Figure 5.15 c,d) has been obtained from the analysis.

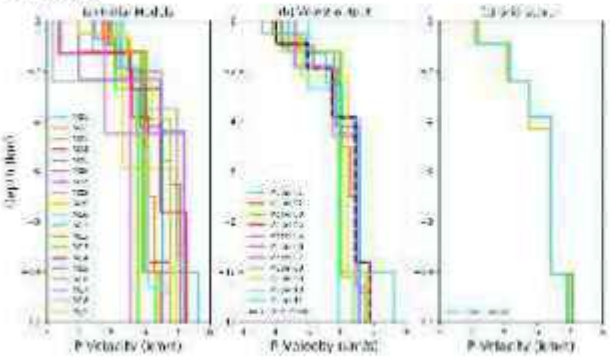


Fig.5.14: (a) Plot showing the a priori velocity model used in the inversion to obtain a minimum 1D velocity model of the Koyna region. (b) output of the inversion process, and (c) final model after adopting the grid search technique.

(ii) AI/ML technique to pick P and S phases

The BGRL seismic network has been established to capture the microseismic activity of the Koyna region. A large number of events are recorded by the network every day, which makes the preliminary earthquake location process a laborious task. Some ultra micro-earthquakes are missed due to poor signal-to-noise ratio (SNR) and human error in the identification of the events. Therefore, AI/ML techniques have been developed to segregate seismic events from the earthquake records and identify seismic phases (P- and S-waves). A Convolutional Neural Network (CNN) has been designed to identify the seismic phase arrivals and the CNN is trained with 3716 (80%) data sets and tested with 929 (20%) data sets of the recorded data (Fig. 5.16). It was found that during the testing, more than 80% of data detected primary P-phases and more than 75% of data detected S-phases accurately with a standard deviation of ± 0.3 s. Once the network was trained, it took ~0.95 s to predict the phases of 929 recorded data sets in the testing phase. An example displaying the phases identified by the CNN and phases picked manually is shown in Fig.5.17. The difference in the manually picked phases and CNN output is found to be ~0.07 s.

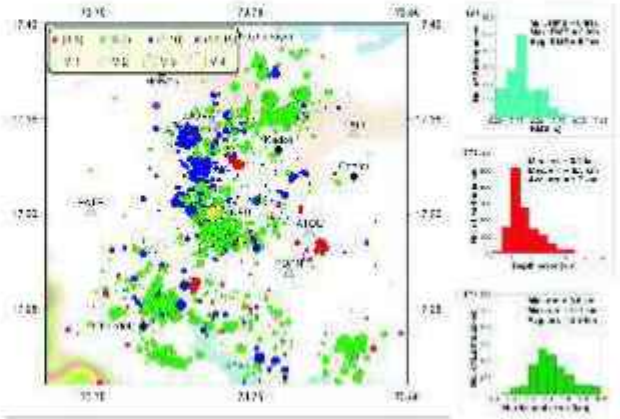


Figure 5.15: (a) plot showing relocated events of the Koyna region using the estimated 1D velocity model, (b) histogram plot showing the distribution of RMS of relocated events, (c) & (d): errors associated with earthquake location in depth and horizontal coordinates respectively.

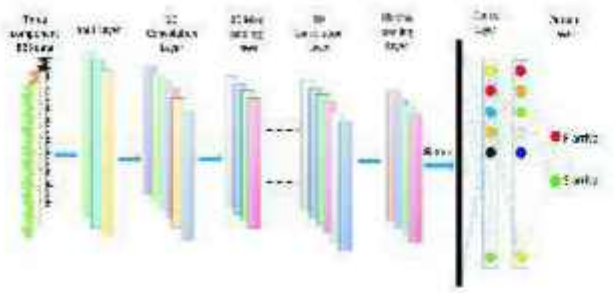


Fig. 5.16: A representation of the 1D CNN-based network architecture to identify the P- and S-phases of an earthquake record.

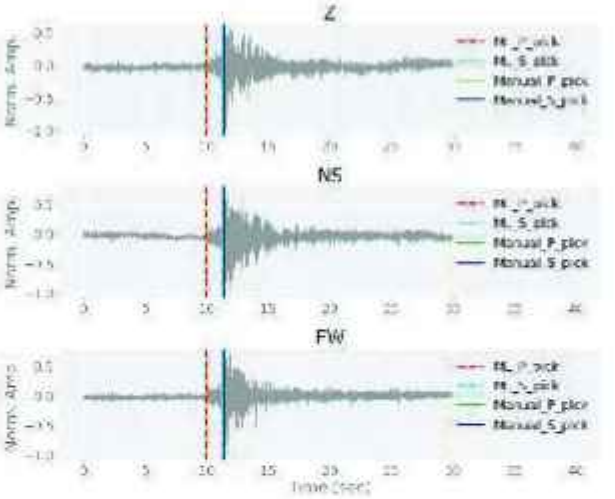


Fig. 5.17: A seismogram with manually picked phases superposed over the seismic phases identified from the CNN output.

5.2.1 Mechanical properties of granite-gneiss basement rocks

Rock mechanical study was carried out on granitic rocks covering intact as well as fault damage zone specimens to understand: (i) how mechanical properties, e.g., strength, deformation rate, elastic properties, etc. of an intact rock differ from fault/fractured zone rocks; (ii) what is the microstructural control on rock strength, and (iii) does rock strength vary with the angle between the direction of load and pre-existing cracks. Analysis of data showed that unconfined compressive strength (UCS) show a range from 26 MPa to 193 MPa, Young's modulus varies between 7 GPa and 25 GPa, and Poisson's ratio show a range from 0.11 to 0.4. Deformation behaviour (stress-strain response) of individual test specimens is plotted in Fig.5.18.

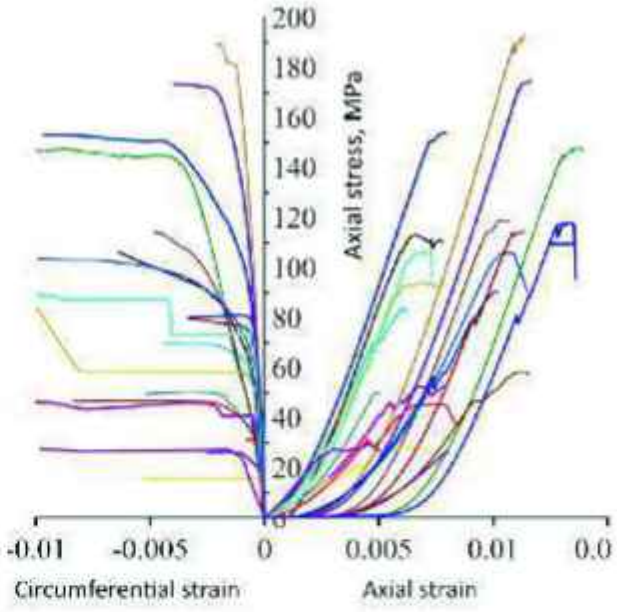


Fig.5.18: Stress-strain responses of individual test specimens.

Such large variation in rock strength and deformation behaviour is controlled by varying densities of fractures, mineralogical variations, varying concentrations of secondary minerals / precipitations, alterations, grain size and, to some extent, the angle between the loading direction and pre-existing cracks/fractures. However, a detailed micro-structural study is underway to figure out the primary parameters controlling rock strength. Integration of the laboratory rock mechanical data along with micro-structural and geochemical information obtained from the geological study, in-situ rock properties from borehole measurements and borehole stress data will provide critical insights towards understanding mechanics of earthquake in the Koyna region.

5.3 Geological and Geophysical studies

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

IODP is an international marine research endeavor that explores Earth's structure and history recorded in oceanic sediments and rocks beneath and monitors sub-seafloor environments. Being an associate member of the IODP consortium through a MoU between the MoES and the National Science

Foundation, USA; NCPOR, Goa acts as the nodal agency to act as IODP-India and the Program Management Office (PMO). Through this consortium, scientific drilling at complex geological realms across the globe has been accomplished successfully using unique drilling platforms. IODP-India is responsible for coordinating all Indian scientific activities pertaining to the program. Ever since our association with the IODP in 2009, more than 56 young Indian scientists have taken part in various IODP expeditions.

During this year, Indian scientists participated in expeditions IODP-398 (Hellenic Arc Volcanic Field), IODP-399 (Building Blocks of Life, Atlantis Massif), IODP-395 (Reykjanes Mantle Convection), IODP-389 (Hawaiian Drowned Reefs) and IODP-400 (NW Greenland Glaciated Margin).

5.3.1.1 Paleoclimatic insights from fossil records across the Danian Warm World in the Northern Indian Ocean (IODP Expedition 355)

The scientific drilling endeavors in the Laxmi Basin (IODP Expedition 355) are tailored to gain insights into the parallel development of mountain formation, weathering, sediment dynamics, climatic shifts and paleoenvironmental conditions across various time scales. The sediment cores ranged between Recent to late Miocene period, a condensed Paleocene segment overlying the igneous basement of the late Cretaceous age was recovered. A study was carried out to understand the early Paleocene climatic condition (c. 66 – 61.6 Ma) through benthic foraminiferal diversity patterns, morphotypes, and oxygen conditions with carbonates and magnetic susceptibility records in the Northern Indian Ocean sediments.

Three major geological events: The cretaceous-Paleogene (K/Pg) transition, Dan-C2, and the Latest Danian Event (LDE) during the Early Palaeocene geologic period caused potential impact over mass extinctions of several marine life and also rapid change in climate from icehouse to warehouse condition. Micropaleontological studies revealed the global faunal diversity pattern as an indicative proxy of the post-impact K/Pg event, evidenced by impulsive incursions in $\delta^{13}C$ and $\delta^{18}O$ at c. 66 Ma. Foraminiferal responses in the Early Paleocene or Danian from Laxmi Basin provided valuable insights into rapid global warming, carbon cycle perturbations, and recovery and evolution of marine ecosystems after a major extinction event.

5.3.1.2 Insights on the organic matter provenance and the depositional environment of the Nicobar Fan sediments, Indian Ocean

Deep sea sediment core samples retrieved from the Nicobar Fan (IODP-362 - Sumatra Seismogenic Zone) were analyzed to determine organic matter provenance, paleodeposition, and paleoclimatic conditions on the hinterland. The carbon and nitrogen isotope values suggested that organic matter was mostly derived from mixed terrestrial C_3-plants and freshwater phytoplanktons, with some marine organic matter. Palynofacies analysis indicated that during the late Miocene, the majority of organic matter was identified of terrestrial origin with little of marine origin. The dinoflagellate cysts were found most abundant between ~8.32 and 6.25 Ma in the Nicobar Fan sediments, reflecting productivity changes primarily associated with the high primary productivity and nutrient-rich conditions. These results indicated that the terrestrial organic matter productivity was relatively higher than marine production during the Late Miocene and declined in the Early Pliocene period, indicating a shift in monsoon conditions.

5.3.1.3 Seismic imaging of the intra-plate oceanic deformation in the Indian Ocean Geoid Low

The ongoing intra-plate deformation in the Indian Ocean and its concurrence with the Indian Ocean geoid low region makes this process one of the most intriguing phenomenon worldwide. The present study utilizes the geometric analyses and vertical displacement data from the high-resolution Multi channel seismic (MCS) data to assess the temporal and spatial evolution of intra-plate deformation throughout the Central Indian Ocean Basin (CIB). The findings provide novel insight into the degree of deformation as well as the probable timing of their onset. The results suggest the widespread compressional deformation in the CIB that was initiated around the early Miocene (17–18 Ma),

with an average of 40% of faults activated around or before the early Miocene. Two distinct fault activation modes were identified as Class 1, involving the activation of pre-existing fault structures in the basement, and Class 2, showing evidence of reactivation coinciding with

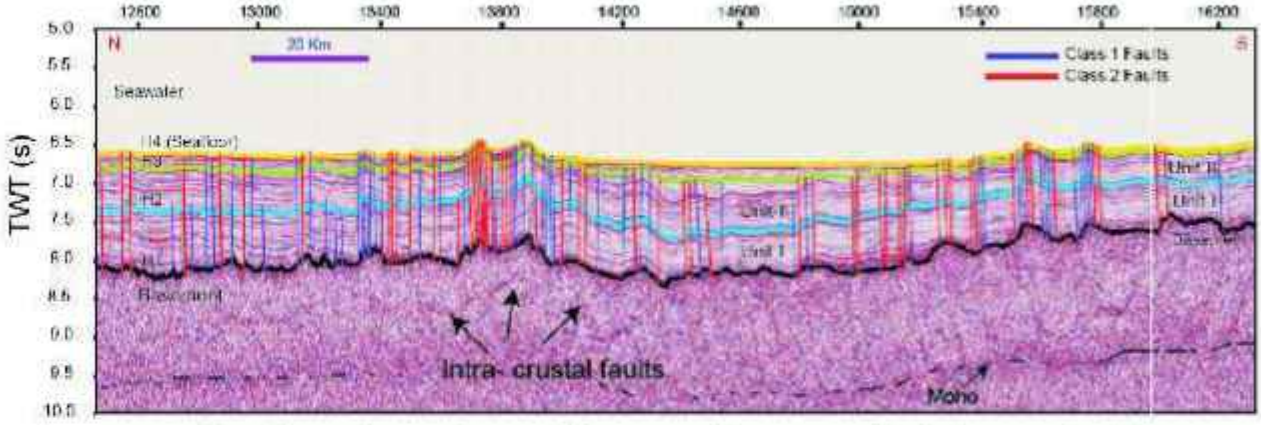


Fig.5.19: Intensive deformation as observed along one of the MCS profile in the central Indian Ocean.

compressional deformation. This classification provides valuable insights into the complex processes that govern fault behavior and the mechanisms that control the deformation in the study area (Fig. 5.19).

5.4.1 An extended Neoarchaean to Neoproterozoic history of the Sandmata Complex (Aravalli Craton, northwestern India): Insights from metamorphic evolution and zircon-monazite geochronology of high-grade quartzofeldspathic gneisses.

The Sandmata Complex in the Aravalli Craton of northwestern India experienced syn- to post-collisional high-grade metamorphism and migmatization related to the 1.9–1.7 Ga Aravalli orogeny. Garnet-bearing quartzofeldspathic gneisses are an important rock type in the Sandmata Complex. Their prograde assemblage is represented by garnet cores and inclusion minerals Bt + Pl + Qz, whereas the assemblage Pl + Kfs + Qz + Bt_{matrix} + Sil + Ilm, along with chemically homogeneous garnet porphyroblasts, represents peak metamorphism. Post-peak retrograde metamorphism is reflected in the growth of muscovite, chlorite and biotite, and diffusion adjustments in garnet rims. Mineral paragenesis, mineral chemistry, conventional thermobarometry, and phase equilibrium modelling indicate P–T conditions of 6.7–10.2 kbar at 725–830 °C for peak metamorphism, and 4.8–6.9 kbar at 450–610 °C for post-peak retrogression. The P–T conditions determined from the quartzofeldspathic gneisses define a near-isobaric cooling P–T path. In contrast, previously studied high-grade pelitic gneisses and metagranitoids from the Sandmata Complex define an isothermal decompression P–T path. U–Pb dating of magmatic zircon cores in the quartzofeldspathic gneisses provides the crystallization age of their felsic protoliths as ~ 2.52 Ga. Zircon and monazite geochronology show that peak metamorphism occurred at ~ 1.90–1.78 Ga and thus shortly preceded the emplacement of the Gyangarh-Asind igneous suite and Anjana granite, previously dated at ~ 1.72–1.64 Ga. A model of oceanic crust subduction followed by continent–continent collision during the Aravalli orogeny can explain granulite facies metamorphism in the Sandmata Complex (Fig. 5.20). The combined results of present and previous studies support modern-style plate tectonic processes involving subduction and continental collision during Palaeoproterozoic time. A younger (~ 0.90–0.78 Ga) metamorphic episode, preserved mostly in recrystallized monazite grains elongated parallel to the final deformation fabric, likely related to the South Delhi orogeny also identified.

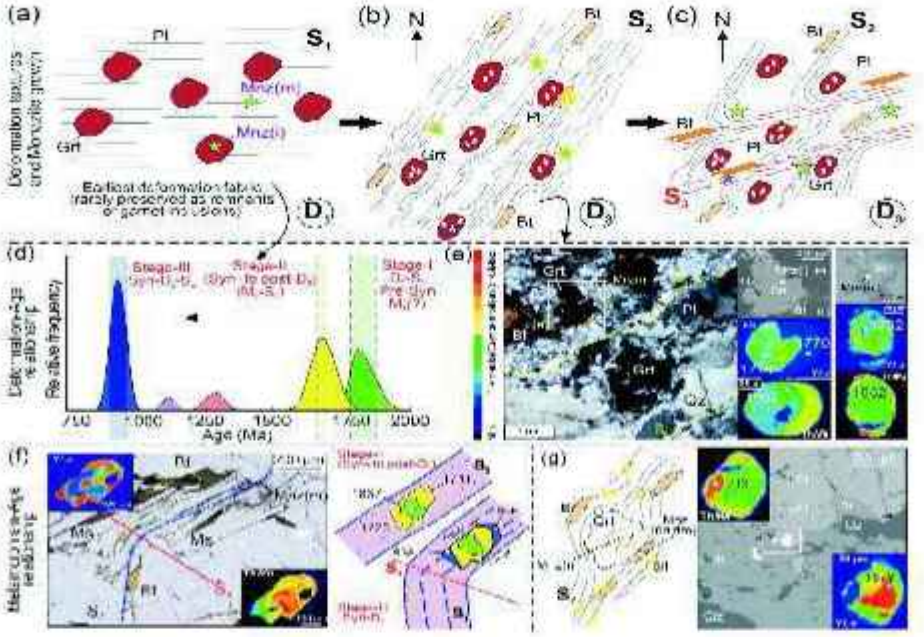


Fig. 5.20: Schematic sketches showing summary of deformation (a-c), garnet growth and chronological evolution (d) for quartzofeldspathic gneisses of the Sandmata Complex. (e–g) Photomicrographs, backscattered electron images and schematic sketches showing three stages (stage-I to III) of evolution for the texturally constrained monazite grains.

5.4.2 Metamorphic evolution of granulites from Grovnes peninsula of Larsemann Hills, East Antarctica: Constraints from phase equilibrium modelling and geochronology

Petrology, geothermobarometry, and phase equilibrium modelling of garnetiferous felsic gneiss from Grovnes peninsula in the Larsemann Hills of Prydz Bay, East Antarctica provide pristine evidence for the preservation of high-grade metamorphic imprint in the area. The metamorphic evolution of the sample is demonstrated by the development of the assemblage Grt+Bt+Melt+Pl+Sill+Kfs+Qtz+Ilm at peak metamorphic conditions of ~ 790 °C and ~ 7.5 kbar, which subsequently underwent retrogression and cooling to lower P-T conditions along a clockwise path. Texturally constrained chemical dating of monazites constrain the timing of peak metamorphism and garnet formation at ~ 575 Ma, whereas the apatite U–Pb ages constrain cooling ages at ~ 518 Ma. The clockwise P-T-t trajectory of the studied samples, together with the Ediacaran-Cambrian metamorphic/cooling ages demonstrate the long-lived nature of metamorphism in Prydz Bay, which is ascribed to collisional tectonism prevalent during the final stages of the assembly of East Gondwana supercontinent (Fig. 5.21). Similar results from adjacent continental fragments including Sri Lanka, Eastern Ghats Belt, Madagascar, and South India suggest their coeval metamorphic evolution during the East African orogeny.

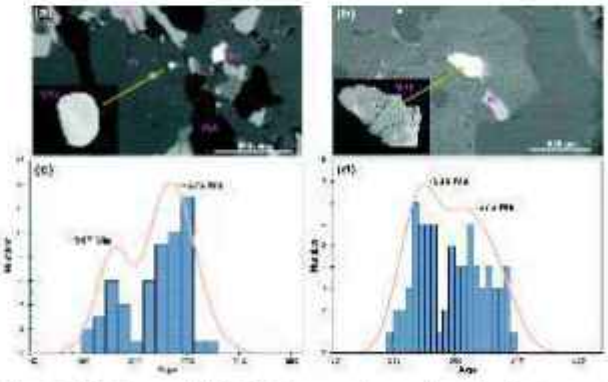


Fig. 5.21: (a and b) BSE image showing the internal structure and textural location of monazites from the melanosome and leucosome of garnetiferous felsic gneiss. Probability density plot of U–Pb-total Th ages of monazites from (c) leucosome and (d) melanosome.

5.4.3 Imaging of crustal structure beneath the Larsemann Hills, Antarctica using scattered wave technique – First Results

The crustal structure in terms of crustal thickness, shear wave velocities and Poisson's ratio plays a crucial role in understanding and/or deciphering the tectonic setting and its evolution. The receiver function analysis, H–K stacking and inversion techniques are the widely used tools to determine these parameters. In the present study, the data obtained from the first-ever established broadband seismological observatory at Larsemann Hills, East Antarctica has been utilized for the P receiver function (PRF) analysis and H–K stacking to decipher the crustal thickness, Poisson's ratio and the intra-crustal layer. Further, the obtained PRFs were inverted using Bayesian inversion to get the crustal structure. The results obtained from H–K analysis reveal a crustal thickness of ~ 37.9 km and the corresponding Poisson's ratio is 0.19. The inversion technique also yielded consistent results, indicating a Moho depth of ~ 37 km with a velocity jump from 4.1 km/s to 4.6 km/s and an intra-crustal layer at around 16 km with a velocity jump from 3.95 km/s to 4.06 km/s (Fig.5.22). It indicates a Poisson's ratio of 0.20. These findings suggest that the crust beneath the Larsemann Hills is felsic in nature and has high crustal shear wave velocity. Further, the variation in the crustal thickness along the coast of the Princess Elizabeth Land (PEL) region, ranging from 37.9 km to 36 km with the intra-crustal layer variation from 16 km to 13 km distinguishes the Neoproterozoic Larsemann Hills from the Archean-Mesoproterozoic Vestfold Hills.

5.4.4 A broadband seismological observatory at Larsemann Hills, Antarctica: Noise characteristics and data quality

Antarctica, the southernmost ice-covered continent, plays a pivotal role in unraveling Earth's intricate evolutionary processes. Several studies have been conducted to comprehend the crustal structure of West Antarctica. However, understanding of the sub-surface structure in the East Antarctica region, particularly along Princess Elizabeth Land (PEL), remains limited due to the scarcity of geophysical data. To bridge this knowledge gap, NCESS established a permanent broadband seismological observatory in the

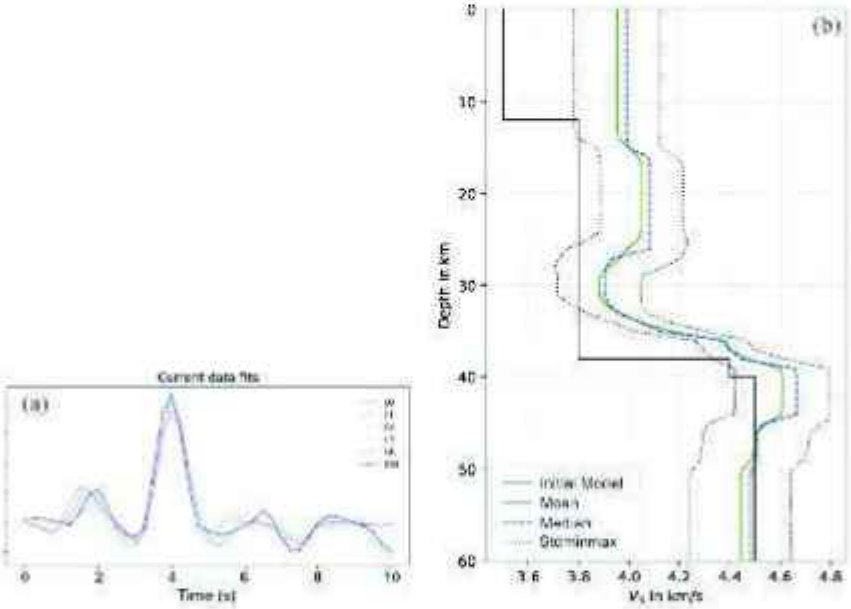


Fig. 5.22: (a) The best fitting PRFs of the top 5 chains along with the input or observed PRF (blue trace). (b) The mean (solid green line) and median (dotted blue line) velocity models of the best-fitting results. The minimum and maximum standard deviations of the best-fitting models are indicated as dotted black lines. The solid black line indicates the initial velocity model.

captivating region of Larsemann Hills, East Antarctica. In addition, noise characteristics at the station was investigated, employing power spectral density (PSD) measurements. Results have been promising, indicating that the noise levels are within the range of New High Noise Model and New Low Noise Model. Monthly variations in PSD reveal different noise levels throughout the year, with winter months exhibiting lower levels of microseismic noise attributed to lower temperatures and frozen sea surfaces (Fig. 5.23) . The long-period noise is higher in April and May, possibly due to high-speed winds and lower in

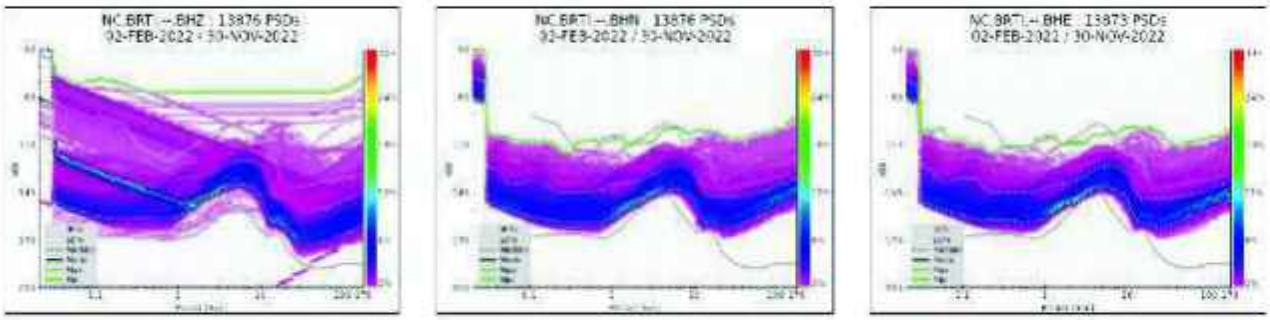


Fig. 5.23: Plots of PSD estimated at BRTI stations, using 10 months of data. The period range of data and components utilized to estimate the PSD is mentioned at the top of each plot. Solid gray lines indicate the NHNM, NLNM models, solid black line indicates mode, dashed lines indicate 90th and 10th percentile.

September and October. The outcomes serve as a testament to the success of our installation and ensure a valuable data set. The data will contribute to a comprehensive investigation of sub-surface structures in the PEL region of East Antarctica, enhancing the understanding of geological processes and tectonic evolution. Furthermore, the findings will serve as a valuable resource for future research and contribute to knowledge of Earth's dynamic processes.

5.4.5 Tectonic and structural elements of Southern Granulite Terrane, South India: Inferences from gravity and magnetic studies

The Southern Granulite Terrane (SGT), at the southern tip of the Indian shield, is an integral component in the Proterozoic orogens of India. It is a collage of many crustal blocks amalgamated through several tectonic processes. These blocks are demarcated by several shear zones that can be traced across different Gondwana fragments. Characterizing the tectonics and anatomy of shear zones is essential to understand the controlling factors for mineral deposition, igneous activity, migmatisation, and crustal deformation. In the present study, terrestrial and satellite-derived gravity data, EMAG2v3 global Earth Aeromagnetic data were utilized and gravity gradient computed to understand structural heterogeneities within geological formations. The Bouguer anomaly and gravity gradients in the region highlight spatial variability of the terrane at different depth scales, and unambiguously decipher the Mayur-Bhavani-Cauvery Shear System (MBCS) and its continuity to a lower crustal depth of 30–40 km, similar to other shear zones. In contrast, signatures of the Achan-Kovil shear zone (AKSZ) and other minor shear zones disappear at shallow depths whereas the Palghat gap, Nilgiris hills, and Coorg block extend up to deeper levels. The derived reduced-to-pole map, however, reveals an extended wide negative magnetic anomaly, which clearly marks the band of low-amplitude anomalies separating SGT from the northern Dharwar craton. The 2-D joint modelling across the NNW-SSE traverses across the SGT covering the major Shear zones (AKSZ, PCSZ, and MBSZ) and EDC, revealing a four-layer crustal configuration constrained by seismic results. The Moho ranges from 36 km to 45 km along the profile, and beneath the Palghat gap (Fig. 5.24). The Moho is upwarping (~ 5 km) showing positive gravity anomaly caused by high density material (2.80 gm/cc) at intermediate crustal levels. The combined

analysis of qualitative interpretation of gravity and magnetic anomalies and joint modelling results clearly distinguishes between different crustal block and their bounding shear zones in accordance with the available tectonic framework.

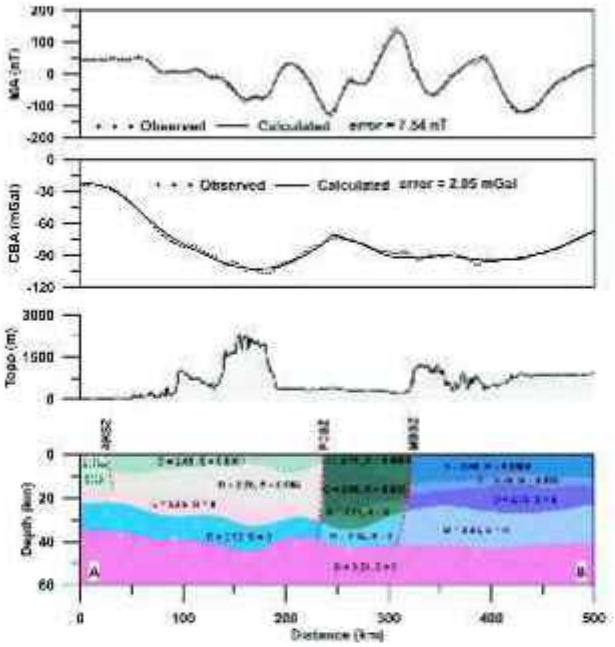


Fig. 5.24: The 2-D joint forward modelling across the SGT. The red dashed lines denote major shear zones. The white stars represent constrained seismic moho. AKSZ: Achankovil Shear zone, PCSZ: Palghat Cauvery Shear zone, MBSZ: Moyar Bhavani Shear zone.

5.4.6 Timing of Garnet Growth in Granulites from Southern India: Insights from Zircon-monazite-garnet REE Partition Modelling

The Nagercoil block, which is situated at the southernmost part of the Southern Granulite Terrane of south India, is dominantly comprised of garnet-bearing I-type massive charnockites. These charnockites preserve imprints of two major thermal events timed at Palaeoproterozoic (~ 2.0–1.9 Ga) and Neoproterozoic (~ 550 Ma). However, there is a lack of understanding on correlating the growth and stabilization of garnets within these charnockites, corresponding to these events. In the present study, rare earth element-based partition modelling between garnet and age-constrained accessory phases such as zircon and monazite is carried out to identify the exact timing of garnet formation in a representative sample from the area. U-Pb dating of zircon cores constrains the timing of protolith emplacement at ~ 2.0 Ga and metamorphism at ~ 550 Ma from zircon rims and monazites. REE modelling of zircon and monazite from these age domains suggests an equilibrium relation between the Neoproterozoic zircon rims and monazites, while the Palaeoproterozoic zircon cores are not in equilibrium with garnet (Fig. 5.25). These results suggest that the formation of garnets in the Nagercoil charnockites is in response to the Neoproterozoic metamorphism recorded in the terrane associated with the final stage of the Gondwana supercontinent assembly.

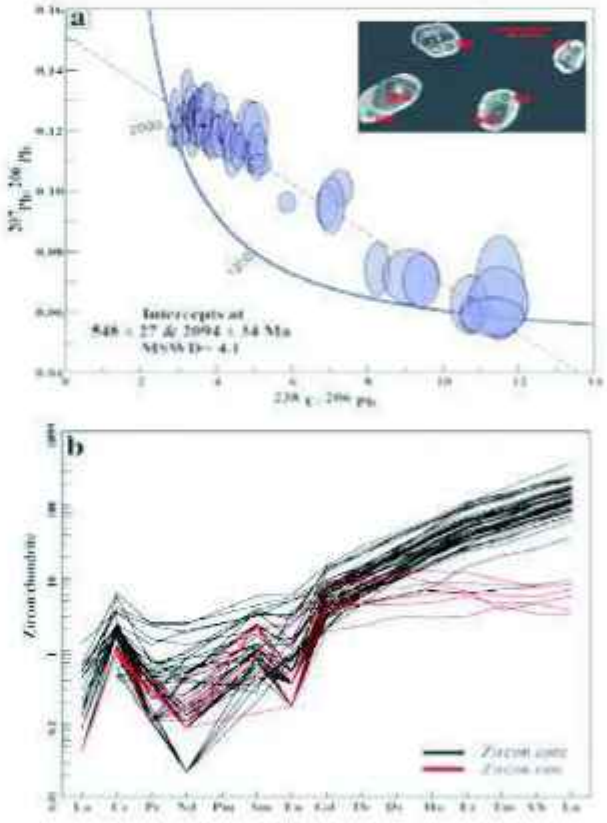


Fig. 5.25: (a) Weighted mean $^{206}Pb/^{238}U$ average age of monazites from charnockite. (b) Chondrite normalised REE pattern of monazites. Inset shows the BSE images of selected monazite grains. Green circles mark the position of the laser spot for U-Pb dating. Laser spot sizes are scaled to size.

5.4.7 Tracing the crustal evolution of the Precambrian Southern Granulite terrane in

East Gondwana: New insights from zircon U-Pb/Hf geochronology

The Precambrian Southern Granulite terrane of south India has a crustal evolution history broadly bracketed between the late Archean and Cambrian with records of polyphase deformation, metamorphism, and magmatism. The Southern Granulite terrane comprises distinct crustal blocks bounded by shear/suture zones that have been variably correlated with supercontinent fragments including Madagascar, Sri Lanka, Africa, Eastern Ghats, and Antarctica. However, the timing and mechanism of assembly of different crustal blocks within the Southern Granulite terrane and its linkages with counterparts in East Gondwana are highly debated. This study aimed to unravel the complex crustal evolutionary pattern of the terrane by generating robust zircon U-Pb/Hf isotopic data from basement charnockites, gneisses, granitoids, and alkaline intrusive units from the central part of Southern Granulite terrane and comparing these results with similar data from different East Gondwanan terranes. The study identified four distinct crustal growth episodes in the Madurai block: (1) Neoarchean–early Paleoproterozoic, (2) Rhyacian–Orosirian, (3) late Tonian, and (4) Ediacaran–Cambrian. Analysis of zircon Hf isotope data revealed that the first two events are marked by juvenile magmatic signatures, whereas the latter two are distinctly associated with intense reworking and remelting of older crust with no significant juvenile input. New results combined with existing data from other Gondwanan terranes suggest a common Paleoproterozoic ancestry for the Southern Granulite terrane and its corresponding Gondwanan fragments, proposing a revision to the existing geodynamic models.

5.4.8 Utility of fluid inclusion paleo-temperature in petroleum system modelling: A case study from western offshore, India

The paleo-temperature (T_h) data from fluid inclusions are utilized for thermal history modelling using PetroMod software. Generally, bottom hole temperature (BHT) and vitrinite reflectance (VR_o) measurements are widely used in petroleum system modelling (PSM) in the oil industry for calibration purposes. T_h representing the minimum temperature of fluid entrapment estimated from fluid-inclusion study provides extra support to build the thermal models for PSM. Fluid inclusion parameters along with Rock-Eval pyrolysis analysis have been used to predict the maturity of oil in terms of API gravity as well as the maturity of source rocks respectively. Two exploratory wells RV-1 (Mumbai Offshore Basin) and KK4C-A-1 (Kerala-Konkan Offshore Basin), India were examined and the T_h from most of the fluid inclusions of wells RV-1 and KK4C-A-1 fell in the oil window range of 60–140 °C suggesting thermal conditions favourable for oil generation in both of the wells. T_h of coeval aqueous inclusions along with the Hydrocarbon Fluid inclusions (HCFIs) was used to calibrate PSM. Vital parameters show that source rocks of well RV-1 are mature and that of well KK4C-A-1 are immature. Two sets of PSM are created in terms of generation and expulsion for the dry wells RV-1 and KK4C-A-1 and calibrated each well using fluid inclusion T_h and BHT (Fig.5.26). From the fluid inclusion analysis method, it is evident that hydrocarbon generation happened in both wells and the paleo-temperature indicates that the formations of both wells were subjected to temperatures in the oil window range, even though it was designated as dry wells in the present scenario. The present study highlights the application of fluid inclusion paleo-temperature (T_h) during calibration instead of commonly used methods.

5.4.9 Engineering geological investigation and runout modelling of the disastrous Taliye landslide, Maharashtra, India of 22 July 2021

The Taliye landslide, a hill slope debris flow, is one of the recent large-scale landslides in India in terms of mortality and socio-economic predicaments. In general, the Taliye area exhibits a moderately dissected plateau relief, and the landslide was initiated from a north-westerly slope of a west trending major ridge and flowed through a paddy field to bury houses located just below it. The landslide had a total runout of 563 m and maximum

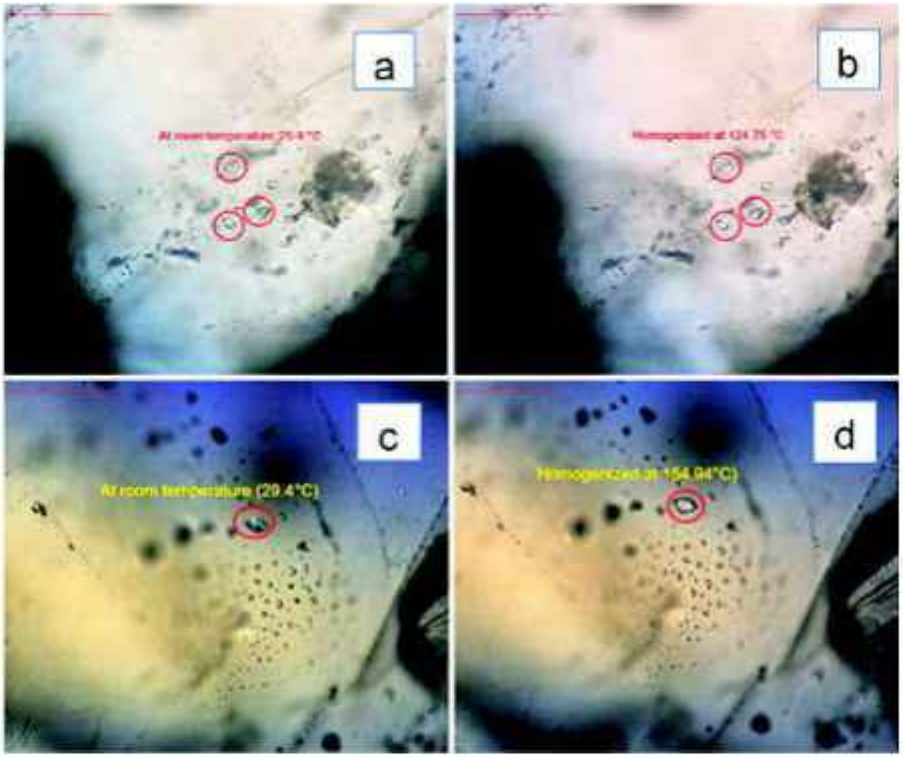


Fig. 5.26: Temperature of homogenization (T_h) of fluid inclusion from well RV-1 (a, b) at burial depth of 2715m and from well KK4C-A-1 (c, d) at burial depth of 4650 m.

width of 230 m at the toe. The heavy rainfall and presence of a narrow stream may be the prime triggering factors, but the affected area had also been exposed to human interference for farming as well as for habitation. Given its socio-economic relevance and landslide proneness of this area, a post-event engineering geological investigation and numerical modelling of this landslide have been carried out to have a closer look at its type, causes of failure, back calculation of run-out characteristics, as well as to calibrate frictional parameters for this area. The numerical modelling package, rapid mass movements (RAMMS) was used to undertake back analysis of this debris flow by referring the original flow shape. For the precise preference of Voellmy frictional parameters, dry-Coulomb friction (μ) and viscous-turbulent friction (ξ) coefficients, this study applies the popular receiver operative characteristics (ROC) technique as the model validation tool. The landslide may have initiated as a talus or translational failure of shallow soil on the hillock, but later might have transformed into a debris flow by entraining materials from the paddy field. Amongst the different combinations of frictional parameters, the model with μ of 0.06 m/s^2 and ξ of 1450 m/s^2 has emerged as the best with an area under the curve (AUC) value of 0.883 for the ROC assessment. With these calibrated frictional parameters, the maximum flow velocity of this debris flow was simulated to be in the order of 5.26 m/s taking place at the middle reaches, and the maximum flow velocity and pressure were derived as 21 m/s and 0.92 kPa, respectively, concentrated in the hillock zone (Fig. 5.27). Although it was a rain-induced failure, the investigation suggests that improper slope management practices might have amplified its magnitude and got manifested as devastating landslide. Therefore, human activities in these hilly regions shall be supported with systematic landslide hazard evaluation, and here in this case, the calibrated frictional parameters may be useful for debris flow modelling and landslide risk reduction in the area.

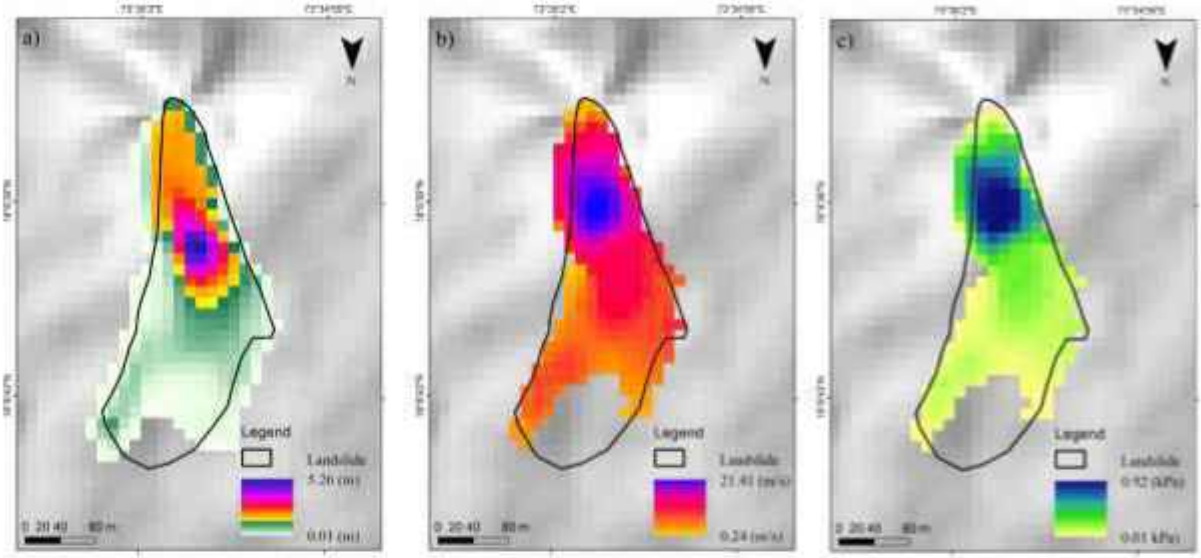


Fig. 5.27: Flow parameters of debris flow (a) flow height, (b) flow velocity and (c) flow pressure.

5.4.10 Influence of COVID-19 lockdown on river water quality and assessment of environmental health in an industrialized belt of southern Western Ghats, India

The COVID-19 pandemic and sudden lockdown have severely hampered the country's economic growth and socio-cultural activities while imparting a positive effect on the overall fitness of the environment especially air and water resources. Increased urbanization and rapid industrialization have led to rising pollution and deterioration of rivers and associated sectors such as agriculture, domestic and commercial needs. However, various available studies in different parts of the country indicate that the COVID-19 pandemic has changed the entire ecosystem. But it is noted that studies are lacking in the southern Western Ghats region of India. Therefore, the present study attempts to investigate how the continuous lockdowns affect the River Water Quality (RWQ) during lockdown (October 2020) and post-lockdown (January 2021) periods in the lower catchments (Eloor-Edayar industrialized belt) of Periyar river, Kerala state, South India. A total of thirty samples (15 samples each) were analysed based on drinking water quality, irrigational suitability, and multivariate statistical methods to evaluate the physical and chemical status of RWQ. The results of the Water Quality Index (WQI) for assessing the drinking water suitability showed a total of 93% of samples in the excellent and good category during the lockdown, while only 47% of samples were found fit for drinking during the post-lockdown period. Irrigational suitability indices like Mg hazard, KR, PI, SAR, and Wilcox diagram revealed lockdown period samples as more suitable for irrigational activities compared to post-lockdown samples with site-specific changes. Spearman rank correlation analysis indicated EC and TDS with a strong positive correlation to Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, TH, SO_4^{2-}, and Cl^{-} during both periods as well as strong positive correlations within the alkaline earth elements (Ca^{2+} and Mg^{2+}) and alkalis (Na^{+} and K^{+}). Three significant components were extracted from principal component analysis (PCA), explaining 88.89% and 96.03% of the total variance for lockdown and post-lockdown periods, respectively. Variables like DO, BOD, Ca^{2+}, NO_3^{-}, and Cl^{-} remained in the same component loading during both periods elucidating their natural origin in the basin (Fig. 5.28). The results of health risk assessment based on US EPA represented hazard quotient and hazard index values below the acceptable limit signifying no potential noncarcinogenic risk via oral exposure except As, suggesting children as more vulnerable to the negative effects than adults. Furthermore, this study also shows rejuvenation of river health during

lockdown offers ample scope to policymakers, administrators and environmentalists for deriving appropriate plans for the restoration of river health from the anthropogenic pressures.

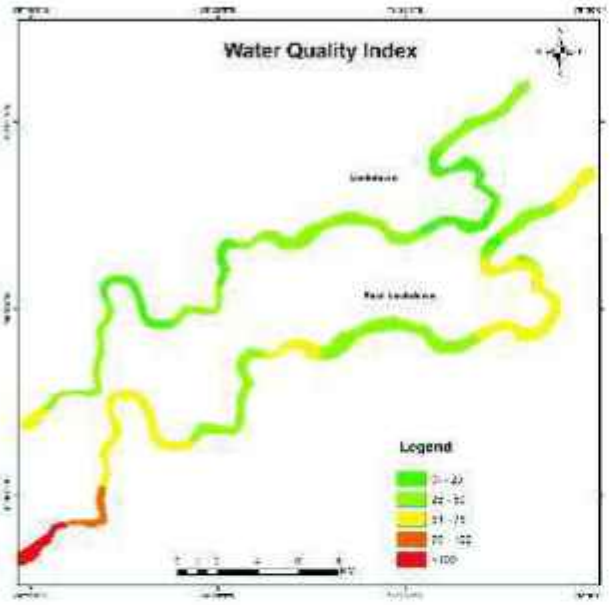


Fig. 5.28: Spatial variation of river water quality index during the two sampling periods (the lower catchment area of 46 km^2 of Periyar river was digitized in ArcGIS 10.3 software).

5.4.11 Streamflow prediction using machine learning models in selected rivers of Southern India

The need for adequate data on the spatial and temporal variability of freshwater resources is a significant challenge to the water managers of the world in water resource planning and management. The problems will be acute in the coming years because of the increase in frequency and intensity of hydrologic extremes due to climate change. Therefore, streamflow prediction has become an important area of research because of its importance in flood mitigation, reservoir operation, and water resource management. In this paper, we have tested four Machine Learning models (ML models): Support Vector Machines (SVM), Random Forest (RF), Long Short-Term Memory (LSTM), and Multivariate Adaptive Regression Splines (MARS) for streamflow prediction at daily and monthly time scales in three rivers draining in the different climatic and geological settings. The SVM, RF, LSTM, and MARS models have been trained and tested in the Suvarna, Aghanashini, and Kunderu River Basins in peninsular India. Model intercomparison was made to identify the best suitable model for streamflow prediction. The RF outperforms other models for daily streamflow, and MARS outperforms other models for monthly streamflow prediction in the Suvarna river with Nash-Sutcliffe efficiency (NSE) values of 0.676 and 0.924, respectively. SVM (NSE = 0.741) and RF (NSE = 0.826) are found to be the best models for daily and monthly streamflow prediction in the Aghanashini River. MARS outperformed other models in the case of high, severe, and extreme flow simulation with NSE values of 0.481, 0.374, and 0.455, respectively, in the Aghanashini River. Other hydrological variables (groundwater level data, antecedent soil moisture, potential evapotranspiration data) and a better spatial resolution of rainfall data can be used to develop more accurate machine-learning models for streamflow predictions.

5.4.12 Rock–water interaction, chemical weathering and solute transport of two rivers draining contrasting climate gradients in Western Ghats, India

Rock–water interaction and chemical weathering are critical factors that determine the quality and quantity of solute transport in river catchments. However, most studies in this field have been limited to temperate regions and data from the tropics and subtropics are scarce, particularly for small rivers that are more responsive to environmental and climate changes. In this study, NCESS investigated chemical weathering, its causal mechanisms and controlling factors that determine changes in the quality and quantity of solutes in two small, tropical mountainous rivers - the west-flowing Thuthapuzha river and the east-flowing Bhavani river - that drain through contrasting climate and geologic gradients across the southern part of the Western Ghats, in India. This region is an elevated passive continental margin and an ecologically sensitive area.

Hydrochemical analysis of river water revealed that the cationic and anionic concentrations in the samples are in descending order of importance $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-}$. Principal component analysis (PCA) indicated that geogenic factors (geology, chemical weathering and leaching/erosion) have a significant role in determining the hydrochemical characteristics of the rivers. To discriminate the relative contributions of silicate weathering in the river basins, a detailed analysis of the major ion ratios along with forward and inverse modelling was performed. The weathering index computed from the molecular ratio of cations and silica concentrations suggested that silicate weathering leads to kaolinite formation in the soil profile. The carbon dioxide consumption rate (CCR) estimated for the Thuthapuzha river, which is draining the humid western flank of the Western Ghats, was 2.18×10^5 mol·km^{-2} year^{-1}, whereas the Upper Bhavani River, which is draining the semi-arid area of the Western Ghats was 1.39×10^5 mol·km^{-2} year^{-1} (Fig. 5.29). This study highlights the interplay of climatic factors and the geologic characteristics of the terrain that significantly influence the nature and characteristics of solute transport through the rivers in the study area.

5.4.1 GIS based NRCS-CN modelling of rainfall-runoff in river Thamirabarani sub-basin, Southern India

River Thamirabarani sub-basin lies in the southern part of the Western Ghats in the Kanyakumari district of Tamil Nadu, India. The basin's landforms

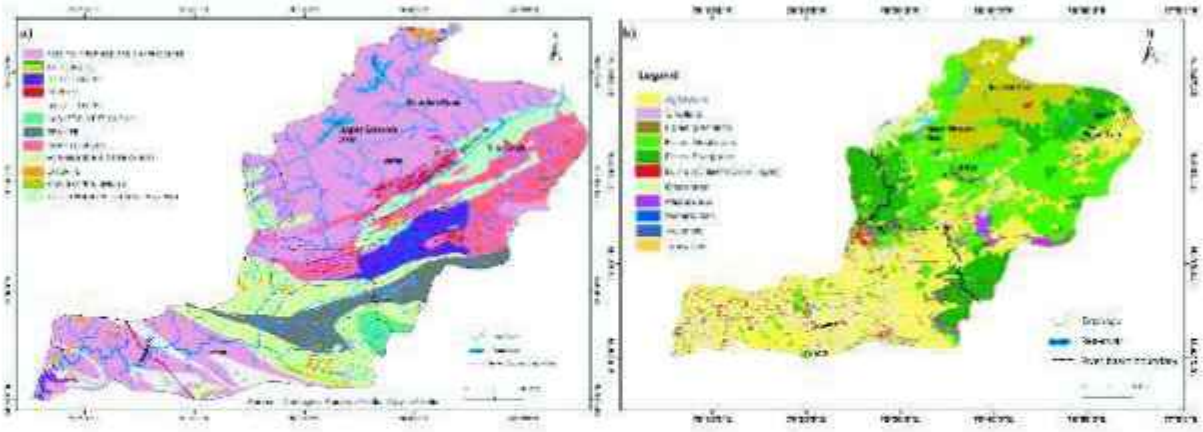


Fig. 5.29: (a) Geology map, (b) Land use / Land cover map of the study area showing drainage network of the Thuthapuzha (TPRB) and the Upper Bhavani River basins (UBRB).

are formed by swift surficial characteristics with undulated terrains composed of steep-sloped valleys, valley fills, and short-length streams with intensive flows that makes-up site-specific hydro-morphological characteristics. In this study, the GIS-based Natural Resource Conservation Service-Curve Number (NRCS-CN) model is used to assess rainfall-induced runoff by analysing various hydrological parameters. The curve number (CN) is assigned to each hydrologic soil group (HSGs) based on the measurement of initial abstraction (Ia) and potential maximum retention (S) derived from soils, land use/ land cover, antecedent soil moisture, etc. The resulting map shows the estimated runoff at the rate of 2.27 – 5.94 mm/m^2/yr for the whole study area, whereas the higher runoff rate (4.83 – 5.94 mm/m^2/yr) is noted in the upland range of the swift surficial terrains in the north and north-eastern parts that encompasses undulated structural hills, steep-sloped valleys, inselberg, and denudational hills, etc., whereas the work of swift surficial terrains and associated slope gradient of the landforms are considered to be higher runoff rate than the other parts. The moderate runoff rate (2.92 – 3.98 mm/m^2/yr) is estimated in the middle parts of pediplains that consist of croplands, plantations, riverbanks, fallows, and built-up areas. Significantly, the lower runoff rate (<2.92 mm/m^2/yr) sparsely

occurred in the different landforms of the middle and southern parts that include pediplains, riverbanks, natural vegetative covers, valley-filled sediment deposits, etc. Overall results indicate that the higher runoff found over the swift surficial landforms in the north and north-eastern parts due to intensive flow through short-length stream orders. This study is mainly used for understanding hydro-morphological processes and their impacts on basin environments.

5.4.14 Impact of stone quarries on groundwater quality at Achenkovil River Basin, Southern Western Ghats, India: Investigation using WQI and GIS

The quality concern of groundwater owing to human activities is mounting at a shocking rate in many of the river basins in Southern India. A study was carried out in this work to determine the quality of groundwater in the Achenkovil River Basin (ARB) in the Southern Western Ghats region of Kerala, India. A total of 25 dug well water samples were collected from the vicinity of aggregate quarries during the pre and post monsoon seasons of 2020–2021. The water quality index has been applied to categorize the water quality, namely, excellent, good, poor, etc. to infer the quality of water. The WQI results showed that 12% of the water samples in good and 28% samples in very poor categories. The Hill-Piper Trilinear diagram reveals that the groundwater of the study area falls under Ca^{2+}/Mg^{2+}, and HCO_3^- and SO_4^{2-}, Cl^-, Mg^{2+} types. The hydro-chemistry of the rock-dominant water type of the quarrying area is inhibited by geogenic-processes along with the percolation of prevailing quarry leachate and infiltration into the nearby wells. The correlation matrix has been created and analysed to observe their significant impetus on the assessment of groundwater quality. The overall quality of groundwater systems in the quarrying area, according to the various indices, is not fit for domestic consumption without mandatory quality treatment, but the water can be used for irrigation purposes.

5.4.15 Seasonal Assessment of Sedimentological Parameters in the Estuarine and Coastal Compartments of Southwest India

A comprehensive seasonal sedimentological study comprising pre-monsoon, monsoon, and post-monsoon was conducted along estuarine and marine transects near Kadinamkulam Estuary, Kerala, Southwest India. Physico-chemical parameters of bottom waters; sediment texture; organic carbon; heavy metals such as Cu, Cr, Ni, Zn, Pb, and Hg; and macrobenthic composition were analysed. Heavy metal contamination was not a serious issue in any of the sampling transects (CF < 1). Retting of coconut husk in the estuary resulted in hypoxic conditions of bottom waters (D.O > 3 Mg/L) during pre- and post-monsoon seasons. NCESS identified salinity (> 20 psu) and alkaline pH favoured metabolic activity of bivalves and clay/heavy clay texture pattern with comparatively high organic matter preferred growth of bivalves in estuarine-marine mixing zone and coastal transects. PCA studies revealed that uncontrolled anthropogenic activities in the estuary could enhance the heavy metal concentration (especially of Cu, Cr, and Ni) of the surface sediments in the estuary leading to probable bioaccumulation in bivalves.

5.4.16 Coupled coastal monitoring framework for the analysis of beach stability and nearshore hydrodynamics of a structure influenced medium energy coast in India

This study presents a Coupled Coastal Monitoring Framework (CCMF) that integrates remote sensing (CoastSat), video beach monitoring system (VBMS), and numerical modelling to analyse the morphology and hydrodynamics of a structure-influenced beach. A 10.2 km stretch of straight beach with an artificial breakwater along the Kozhikode coast of Kerala, India, is selected for the study. The shoreline change analysis revealed that 38% of the total coast is under erosion, with the northern sector of the breakwater being highly erosive and the southern sector being stable. Continuous monitoring from the VBMS confirmed the stability of the southern sector with varying erosion accretion trends during 2018–21. Coastal morphological features such as double bars, cusps, and rip-like formations were

identified through the VBMS, validated and analysed in detail with distinct wave-current interactions and sediment transport through numerical modelling (Fig. 5.30). The study concludes that the breakwater is effectively protecting the beach adjacent to the south but has disturbed longshore transport, potentially leading to increased erosion to the north. The proposed CCMF provides real-time and post-performance monitoring of structure-influenced beaches, enabling timely decision-making at critical locations and appropriate remedial measures for efficient coastal management.

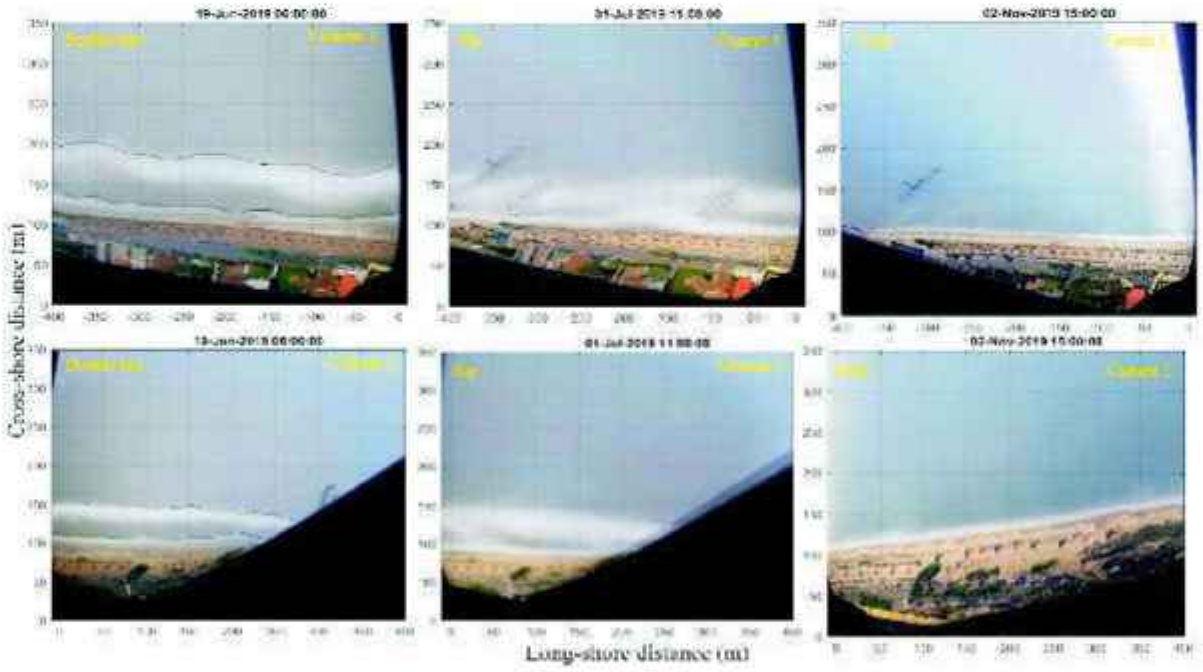


Fig. 5.30: Double bar, rip channel and cusp formations identified in Timex images from the two cameras of the VBMS.

5.4.17 Remotely induced storm effects on the coastal flooding along the southwest coast of India

The southwest coast of India is exposed to long-period swells propagated from the South Indian Ocean during pre- and post-monsoon seasons. Although swells from the Southern Ocean and Atlantic Ocean were identified in the North Indian Ocean, their existence and impact along the southwest coast of India were not well investigated. On 19 March 2019, the Valiyathura-Shangumukham coastal stretch along the southwest coast of India experienced an unexpected coastal inundation without having a prompt forecast/warning, and not induced by a storm/cyclone in its vicinity. The present study investigates the causative forces of this inundation and estimates the wave runup and inundation. The study reveals that an unusual swell system was developed in the Indian-Atlantic-Southern Oceans (IASO) interface during 10–12 March and propagated towards the southwest coast of India (Fig. 5.31). The measured wave spectra off Varkala clearly depicts the presence of long-period swells (T_p>18 s), which dominantly occurred as single-peaked. Wave modelling has been carried out to characterize the wave transformation associated with the "IASO interface swells" along the southern Kerala coast. A wave runup of up to 0.93 m height and a coastal inundation of up to 83 m onshore have been estimated during this event.

Fig.5.31: Field photographs of Valiyathura – Shangumukham stretch during the event on 18 March 2019.

5.4.18 Coastal flooding by wave, wind, tide interactions and related processes along the southern part of SW coast of India

Occurrences of coastal flash flooding events are not always associated with extreme events, which are often responsible for the high wave activity and ensuing flooding along coastal areas during the rough season. In the present study, the causative factors that led to a flash flood event at Valiyathura, Thiruvananthapuram, located along the southern part of the SW coast of India, during September 2018 have been investigated based on both field observations and numerical model studies. Numerical simulations reveal the presence of high period swells from the Southern Indian Ocean, leading to a rise in wave runup, coinciding with the Perigean Spring Tide (PST), along with the increased wind speed that sustained for more than 6 h, resulting in the piling up of nearshore waters and sudden flooding along the coast. This inference is well reflected in the beach morphology, particularly the sediment characteristics depicting the impact of coastal flooding. Further, field observations confirm that the nearshore wind–wave interaction prior to the event also contributed to the flooding. Thus, the study emphasizes the need for continuous monitoring of nearshore and other contributing factors such as waves, wind, tide, and beach morphological conditions for reliably predicting coastal flooding events and their probable impacts.

5.4.2 Analysis of localized features during wet and dry rainfall episodes over southern tip of India

The large spatial and temporal variability of wet and dry spells of the Indian Summer Monsoon (ISM) poses a great challenge in understanding and predicting monsoonal rainfall. This challenge is further exacerbated over smaller regions, such as the southern tip of India, which receives the first spell of ISM rainfall. In this study, the characteristic features and possible precursors for wet and dry spells of rainfall over the southern tip of India are investigated. NCESS also explore the variability in monsoon low-level jet (LLJ) in relation to wet and dry spells over a coastal station Thiruvananthapuram (8.48°N, 76.95°E) in southwest India using in situ observations and other ancillary datasets. The results show that a wet spell spanning 3–4 days contributes about 30% of seasonal rainfall. Wet spells are characterized by westerly wind anomaly in the southern tip of India and easterly wind anomaly in northern India, leading to anomalous cyclonic vorticity over the Indian subcontinent. The opposite situation happens during dry spells. These characteristics are prominent from 2 days before the initiation of the spells, suggesting that they may be used as precursors for forecasting wet and dry spells over Thiruvananthapuram (Fig. 5.32). Analysis of low- to mid-tropospheric (2 and 4 km) humidity reveals significant moistening during wet spells. Yet, both wet and dry spells experience humid (>80%) boundary layer. The differences in mid-level humidity and thermodynamical structures between wet and dry spells seem to contribute to distinct rainfall characteristics over the southern tip of India. These results indicate that the use of in situ

observations along with large-scale reanalysis datasets may provide valuable information on the precursors for wet and dry spells over the southern tip of India, which can help both in regional- and city-level planning and management of water resources.

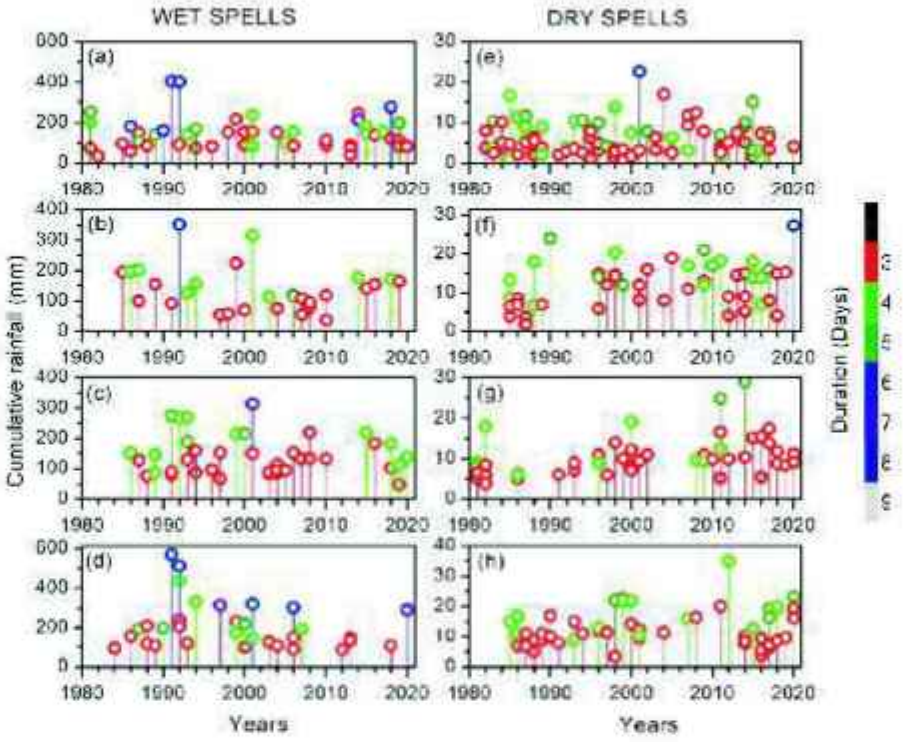


Fig. 5.32: Year-to-year variability of rainfall (mm) during summer monsoon season for (a-e) wet and (f-j) dry spells of 3-8 days duration for the 4 IMD stations for Thiruvananthapuram city, Nedumangadu, Neyyatinkara, and Varkala observing stations from 1981-2020. Different colours depict spells with different durations (days).

Chapter–6

Research Education Training and Outreach (REACHOUT)

To fulfil the primary mandate of the Ministry of providing the nation with best possible services skillful 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. 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 and Development in Earth and Atmospheric 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 programs, 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 22 proposals have been sanctioned as shown in the table below:

Number of New Proposals	Atmospheric Science	Ocean Science	Geo Sciences	Seismology	Hydrology & Cryosphere
Sanctioned during FY 2023-24	03	7	4	3	05

6.1.1 Atmospheric Science

Three new projects are sanctioned and the achievements under the completed projects are given below

Development of QCL-based robust and portable infrared spectrometer for measurements of HONO at atmospheric levels and probing HONO production in trace quantities in some laboratory reactions, by Indian Association for the Cultivation of Science, Jadavpur Calcutta

Hydroxyl radical (OH) is known as the detergent of the earth's atmosphere, and in the daytime more than 60% of the troposphere's OH is produced by photodissociation of atmospheric nitrous acid (HONO). It is believed that the main atmospheric source of HONO is the heterogeneous nighttime reactions of NO_2, produced primarily via different anthropogenic activities, on wet surfaces. However, recent atmospheric modeling studies predict that there are missing sources of atmospheric HONO. Under the scope of this project, two new atmospheric production channels for HONO have been identified through laboratory investigations. Those are the reactions of gaseous NO_2 with hydroxyacetone and glycolaldehyde, where both the latter two belong to the category of atmospherically significant volatile organic compound. The accumulated experimental data indicate that these reactions occur in the gas phase only, and not via heterogeneous surface reactions. In addition, under the project's scope. a new gas phase reaction channel for the production of atmospheric nitric acid has been found where NO_2

reacts with phenol, and the implication of the reaction has been analyzed thoroughly.

A mobile quantum cascade laser-based spectrometer has been developed for the direct estimation of the atmospheric abundances of HONO. It is aimed that the spectrometer will be deployed at a suitable location in the near future. An alternative long path optical wave guide type apparatus has been developed, and which has been used to measure the atmospheric abundances of HONO in the premises of the Indian Association for the Cultivation of Science in the rainy season of 2019. The measured data is consistent with the reports of investigations carried out in the other parts of the world. Three research papers are published and one JRF is trained in the project.

Kinetic Investigations of Reactions of Criegee Intermediates With C1-C3 Carbonyl Compounds and Carboxylic Acids in the Earth's Atmosphere, by IIT, Madars

A collinear Cavity Rig Down Spectrometer was established where tens of kilometers of optical pathlength can be established. The built-in spectrometer was used to study the reactions of Criegee Intermediates with important VOCs (carbonyl compounds, in particular) relevant to the Earth's atmosphere. The Criegee Intermediates play a very significant role in the Earth's troposphere, where emission of olefinic compounds is large, particularly in the urban/industrially developed areas. As the lifetimes of these olefines are significant, they live long and can be transported from these regions to others. Therefore, the Criegee Intermediates compete with OH radicals to react with the available VOCs in their vicinity. As expected, it was observed with the experimental data that, they do compete with the OH radicals and the atmospheric lifetimes of VOCs should be computed taking the Criegee Intermediates int consideration, particularly in the industrial areas. Two research papers are published and one Ph.D student is trained in the project.

6.1.2 Hydrology & Cryosphere

During the year five new projects are sanctioned and six research publications are done and 19 people are trained in different projects. The achievements under the completed projects are given below :

Advanced Research in Hydrology and Knowledge Dissemination by IISc Bangalore.

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 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.

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

The quantification of the discharge contributions from glacier, snow, rain and groundwater 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 streamflow data set 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 was 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).

Estimating Mass balance of glaciers in the Bhaga Basin, Western Himalaya using GPR and Remote Sensing methods by IIT Bombay

This study introduces a new model named "VOICE" model, an improved version of the ice thickness model originally proposed by Gantayat et al. (2017). Compared to its predecessor, the VOICE model features improvements in its model formulation as follows: Firstly, the shape factor value was initially assumed to be a constant value for all the glaciers, whereas in this version, an optimization approach giving shape factor value unique to the glacier was implemented. Secondly, basal sliding factor contribution was assumed to be a constant but here in the VOICE model, we used the ratio of mean values of winter and annual surface velocity values that are unique to glacier The predecessor model holding such parameter assumptions are prone to errors which is now being reduced in the VOICE model. Also, the VOICE model's robustness was thoroughly tested by comparing its ice thickness estimates to field-collected data from the Patsio glacier. These field-collected data can also be used to validate other ice thickness models. Apart from these contributions, the study provides an ensemble estimate of the current glacier stored ice volume for Patsio and Panchi II glaciers, which can be used in other glaciological studies.

6.1.3 PAMC-Geoscience & Seismology Seismology

Lithospheric transect study across the eastern part of Narmada-Son Lineament based on Constrained potential field modeling implications on seismogenesis by IIT, Bombay

A high-resolution 3D density model of the western part of the study region was carried out using the available gravity data imposing constraints based on the seismic sections available in the study region. Gravity-derived Moho depth map reveals that the values vary between 30 and 59 km in the Narmada-Son Lineament (NSL) region with deeper Moho below the Vindhyan basin. Further, the crustal models obtained from the constrained potential field modelling for two long transects across the NSL in the study area revealed (i) the absence of crustal underplating in the eastern part of NSL below Hirapur-Mandla region, (ii) the presence of mid-crustal horst like structure below NSL, (iii) undulating Moho with higher density crustal rocks within the NSL compared to the surrounding areas. The modelled crustal structure and the analysis of Curie depth as well as heat flow maps of the study area, reveal that the NSL region was affected by repeated tectonic activities since the Proterozoic times, and the present-day tectonics of this belt is greatly influenced by the reactivation of pre-existing faults along the NSL.

3 papers were published in SCI journals and 2 students have completed their PhD and under the project.

Investigation on Batter Piles in Laterally Spreading Soil by IIT (ISM), Dhanbad

The pile displacement is more in case of a sloping ground under bidirectional ground motions compared to unidirectional motion. The probability of failure of various soil-pile systems and probability risk factors were evaluated and the results indicate that the positive batter piles are more effective in restricting the forces and displacements induced in the piles compared to the vertical piles, and negatively inclined batter piles.

The prediction models, developed in the present study, for the forces and the displacements induced in the piles with different batter angles, may act as indicators of the performance of the piles in a laterally spreading ground for a varying range of parameters. It is expected that the study may boost up the application of batter pile groups for certain structural/geotechnical configurations considering liquefying and laterally spreading ground conditions. 6- papers were published in SCI journals under the project.

Feasibility study on low cost passive control devices to retrofit soft story RC buildings with experimental verification by IIT, Roorkee

The reinforced concrete (RC) soft-story frame structures that exist predominantly in the community are subjected to large lateral deformations and rotations in the event of a potential earthquake. To protect these buildings during an earthquake, seismic retrofitting or strengthening is the bare solution, which is cost-effective with a reduction in economic and human loss. The experimental test results for Passive Control Device (PCD) installation in the form of hysteresis behaviour indicates that they are very useful for the linear and non-linear characterization of the behaviour of a retrofitted building under earthquake simulation conditions. An appropriate selection of retrofitting solution for a seismic deficient building is a very challenging task, and its practical implementation with validation for its reliability as well as effectiveness is a more tedious job for the engineering community. Moreover, it is also very useful for the calibrations/ verification and updating of the numerical modelling of new/innovative techniques of seismic retrofitting of buildings. One paper has been published and the work of coupler-box is patented with the Intellectual Property Rights, GoI titled "A System and Method for Seismic Retrofitting of Severely Damaged Reinforced Concrete Frame Buildings using Coupler-Box Section" with an application number 202011007735 dated 24th of February, 2020.

Geosciences:

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 Nagpur.

This study relates to mass extinction at the K- T Boundary where two contrasting hypotheses exist. One is related to Bolide impact and the iridium anomaly associated with it. The other relates mass extinction to major flood basalt volcanism at the K- T Boundary as exemplified by Deccan Flood Basalt volcanism. The project has brought out many interesting aspects. In the Malwa region, Deccan Flood basalts belonging to the lower sequence of Deccan Traps were poured out in less than a million years and evidence of forest fires associated with volcanism are seen. There is evidence for increased greenhouse gases during volcanism and for increased intensity of rainfall.

Characterization, quantification and genesis of gas hydrate in Krishna- Godavari Basin, Bay of Bengal using benthic foraminiferal, geochemical and geophysical studies by IIT(ISM), Dhanbad.

The project has examined sediment cores close to submarine channels of the Krishna Godavari (KG) basin using foraminiferal assemblage, sediment carbon isotopic ratios and the seismic profile on the continental shelf and slopes, and deeper plain in the basin. The study infers that paleochannel sediments can accumulate methane and nucleate gas hydrates and therefore constitute target areas for gas hydrate Exploration in the KG basin. It has been inferred that 3D geophysical mapping combined with biological investigations can help locate new gas hydrate deposits in the Krishna Godavari basin. 3- papers were published in SCI journals and one student has completed his Ph.D. degree under the project.

Multi-Scale of the deep geology of India - Eurasian region and the adjoining sea by IISER, Pune.

An enhanced velocity model of crust and upper mantle of Indian lithosphere was derived from seismological data using noise tomography and other techniques. These models have allowed the investigators to constrain some of the geodynamic models, like extension of the indenting India plate, Karakoram faults and melt anomalies under the Deccan Traps. The work has improved the understanding of the Indian lithosphere and has provided new insights. Delineation of the nature of terrane boundaries in the Peninsular India would be another area where enhanced resolution of geophysical methodologies would help. The project adds to the existing understanding of the Indian lithosphere and also provides a better framework for future more detailed work. The project trained 3 PhDs and 2 RAs. Nine publications in reputed journals have come out from the project.

6.1.4 Ocean Sciences

Exploring India's Medieval Coastline using Geospatial Analysis and Historical Records by National Institute of Advanced Studies (NIAS)

Since the 16th century, European colonizers like the Portuguese, Dutch, British, and French extensively charted the Indian coastline for navigation, safety, and strategic reasons. These historical sea charts and maritime maps not only depicted geographical features but also held information about historical landmarks. However, the potential significance of these cartographic records' geomorphic and archaeological details has been largely unexplored. The present project, employs historical maps to study coastal changes and their impact on various sites. Crafted over four centuries by European colonial powers, these maps provide insights into coastal cultural heritage and geomorphology. By aligning historical maps with remote sensing imagery and using analytical methods, this research showcases the practical utility of these archival resources. Key case studies include: - Thangacherry fort site near Kollam, Kerala, highlighting the complexities of interpreting historical maps for coastal change understanding. - Analysis of shoreline changes along the Kollam coast was conducted utilizing a combination of remote sensing data and mathematical techniques. Different time frames are taken into consideration to investigate long-period, short-period, and annual changes within the designated study area.

Employing a novel mathematical model developed as part of the study, known as WAM, the research comprehensively examines various shoreline features.

- Evolution of the Tamirabarani delta, revealing the transformation of Korkai from a port located inland to its current position 7 km away, as well as the subsequent coastal geomorphic changes that connected Thoothukudi.

- Evolution of spits along the Kerala coast, from Kodungallur to Fort Kochi and around the Chettuva estuary.

- The study located and explored ports and coastal forts like Barcelore fort in Kundapura, and Virabhadra Nayaka's fort in Gangolli. It also revealed the location of the 'Onor' fort along the Sharavathi river and insights into the fortifications of old Goa.

In conclusion, this research enriches our understanding of long-term coastal dynamics, with practical implications for coastal management and cultural heritage preservation.

6.1.5 Earth System Science and Technology Cells (ESTC):

Focussed network R&D is continuing under following four ESTCs

I. ESTC on Marine Biotechnological Studies (MBS), at Sathyabama Inst. of Science & Technology (SIST) Chennai comprises 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

II. 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.

III. 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'.

Progress of all the aforesaid ESTC network projects was periodically monitored and reviewed by the respective Scientific Steering Committee/s (SSC) of

experts constituted by Ministry. Despite, the work in particular filed work/experiments got delayed due to Covid pandemic the outcome were found reasonably satisfactory.

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 (CMRE) Kochi and National Institute of Ocean Technology (NIOT) Chennai for ESTC-MBS projects for research outcome towards applications and mandate of Institutes.

A total of twelve number of Ph.D. are ongoing under the ESTC network projects.

Secretary MoES Dr Ravichandran inaugurated **Sathyabama Ocean Research Field Facility** as part of ESTC for Marine Biotechnological studies. This field facility established has Aquatic Animal Husbandry and Algal Culture Facility which spans around 10,000 Sq. ft.. It is utilized for large scale research / technology demonstration which leads to interdisciplinary work to augment the research needs of the students and faculties and to develop the human resources with future thinking. Senior officials from Ministry, University officials, scholars and students participated in the programme. Memorandum of Understanding (MoU) were signed with Bentoli Agrinutrition Indian Private Limited, Chennai and Vetbiotics Animal Health Care Private Limited, Thane as a part of collaboration.

6.1.6 Human resource Development and Capacity Building

- The memorandum of Understanding (MoU) between MoES and IIT Madaras was extended for five more years for the continuation of support to the MoES sponsored M.Tech Ocean Technology program in the Department of Ocean Engineering at IIT Madras.

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 INESO/IESO).

Ministry organized specific activities with students and public participation as a part of Azadi Ka Amrit Mahotsav (AKAM). The total number of major awareness events conducted by MoES and its

Hon'ble Cabinet Minister for Earth Sciences Sh. Kiren Rijiju ji addressing a Farmer Awareness Program in Arunachal Pradesh

Hon'ble Cabinet Minister for Earth Sciences Sh. Kiren Rijiju ji addressing a Fishermen Awareness Program in Andhra Pradesh

departments/institutes, as well as the number of places where these events were held, exceed 2575 which included 1137 Farmer Awareness Programs (FAPs,) fishermen awareness programs in 267 villages along the coast in collaboration with NGO partners, Yoga was performed by scientist teams from India and abroad at research stations including Bharati in Antarctica, Himadri in the Arctic, and Himansh, the high-altitude research station in the Himalayas, on International Yoga Day, 21st June 2023. More than 294958 participated in these events across the country from 15th August 2022 to 15th August 2023.

In a concluding function of Azadi Ka Amrit Mahotsav at Delhi on 29 Dec.2023, Ministry of Culture extended appreciation to MoES for outstanding contributions in AKAM, in the gracious presence of Honourable Union Ministers, Shri Arjun Ram Meghwal Ji, Shri G. Kishan Reddy Ji and Smt Meenakshi Lekhi Ji.

Foundation Day

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27th July 2023 in hybrid mode at Prithvi Bhavan, MoES Hq. New Delhi. Sh. Kiren Rijiju, Honourable Union Minister of Earth Sciences was the Chief Guest. The Honorable Union Minister, MoES, launched the following initiatives to mark the 17th foundation day celebrations of MoES.

- The Infographics book entitled "75 years of Earth Sciences in India"
- Four new meteorological centres were inaugurated in Imphal (Manipur), Kohima (Nagaland), Aizawl (Mizoram), and Port Blair (Andaman and Nicobar). With these new four additions, the country's total number of meteorological centres has risen to 26.
- A documentary on 'Cyclone Warning and Management in India: An End to End System' was released. The film showcases the scientific capability of IMD in providing timely alerts for natural disasters such as cyclones, close collaboration with disaster-management authorities, to save lives and minimise loss of infrastructure.
- A new mobile application named SAMUDRA (Smart Access to Marine Users for Data Resources and ocean Advisories) to provide comprehensive information on all ocean-related services of the Indian National Centre for Ocean Information Services (INCOIS), an autonomous institute of the MoES. The mobile app provides information on ocean-related services of INCOIS, including potential fishing zone advisories, ocean state forecasts, and alerts on tsunamis, cyclones, storm surges, high waves, swell surges, etc.
- A new web portal featuring the biodiversity of our Indian Ocean EEZ (Exclusive Economic Zone) was made open to the public. The web portal is called IndOBIS and can be assessed at https://indobis.in/. The portal has been developed by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi.
- A detailed scientific catalogue entitled 'Systematic account of Indian deep-water Brachyuran crabs collected during the expeditions of FORV Sagar Sampada' was released.
- A detailed report of the CAIPEEX IV (Cloud Aerosol Interaction and Precipitation

Enhancement Experiment) by the Indian Institute of Tropical Meteorology (IITM), Pune, an autonomous institute of the MoES, was released. The report elaborates results and recommendations of a scientific experiment strategy called cloud seeding used for enhancing rainfall and managing drought.

- As part of seamless modeling activities, the National Center for Medium Range Weather Forecasting (NCMRWF), DM-Chem, a high-resolution (330 m) city scale model for predicting fog in terms of visibility and PM 2.5 over Delhi & NCR region.
- **Compendium of Monthly seismological bulletins for the year 2021 – 2022**, prepared by NCS which contains a voluminous Phase arrival data from a total of 3500 well located and recorded local and regional earthquakes by National Seismological Network

(Ministry's Foundation, Day Celebration)

Earth Day 2023

Earth Day on theme "Invest in Our Planet" has been celebrated across the country on 22nd April 2023 and the event was supported at 75 places across the country including students centric activities and popular talks on subject in the schools, college, universities, institutes with participation of about 7500 students. Three time grammy awardee Mr Ricky Kej performed a musical program at IMD campus to mark the day

(HMoES, Secretary MoES and Mr Ricky Kej, 22April 2023)

International Earth Science Olympiad (IESO) 2023

Ministry supports the Indian National & International Earth Science Olympiad (INESO/IESO). The 16th IESO 2023 was conducted in virtual mode, owing to restrictions due to Covid. Team India was represented by eight students to compete in the IESO (20-26 August 2023). Amongst 27 countries that participated in this 16th Olympiad, team India won 3 Gold medals, 5 silver medals, and 6 Bronze medals in the 'National team field investigations (NTFI)', 'Earth Science Project (ESP)', 'Data Mining test (DMT)' and Certificate/s of Excellence, Very Good in 'art in Earth Science' events specifically designed for the 16th IESO.

Medal winners team students with HMoES Shri Kiren Rijiju, Secretary Dr. M. Ravichandran, IESO Mentors and observer.

Chesezu village, Phek, Nagaland

Honourable Minister congratulated the medal winners, mentors, parents and discussed various issues and challenges to improve the understanding of Earth Sciences as has been emphasized on 'One Earth, One Family, One Future' and LiFE by Honourable Prime Minister. HMoES appreciated the efforts by Ministry for supporting the IESO.

Ozone Day Celebration

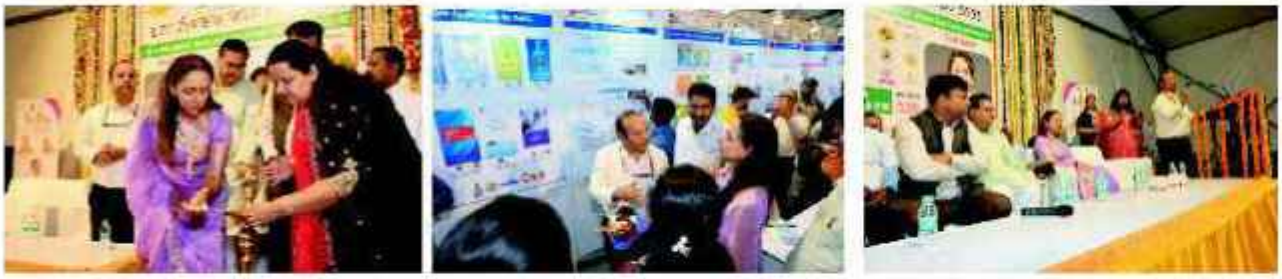
"Ozone Day" has been celebrated at 14 centers across the country on Sept 16th 2023. More than 1000 students participated in this event.

Exhibitions/Science Festivals/Fairs

During the year, the Ministry participated in 24 Exhibitions across the country to showcase MoES services for public and achievements. Some of their pictures are as given below.

I. India International Science Festival (IISF) on theme "Amrit Kaal with Science and Technology and Innovation" was held from 21–24 January 2023 at Maulana Azad National Institute of Technology (MANIT), Bhopal.

(IISF, 21-24 January 2023, Bhopal, M.P.)



ii. Honorable M.P. Smt Hema Malini at Mathura, Uttar Pradesh Expo, 28-30 October 2023

iii. Honourable Chief Minister Goa Shri Pramod Sawant Ji and Honourable Union Minister Shri Shripad Yesso Naik Ji, Panjim, 3-5 October 2023

iv. Secretary MoES, Dr Ravichandran, addressed about 1000 students in awareness symposium on 'Climate Change, Weather & seismology' at Govt Higher Secondary School, Saptur, T.N., 23Dec2023

v. MoES @Kulthali, WB, 22-29Dec.; @Tamulpur Assam 4-5 Dec.; @New Delhi 21-23July2023

6.3 BIMSTEC- Centre for Weather and Climate (BCWC)

Signing of Host Country Agreement : The Host Country Agreement between the Government of the Republic of India and the BIMSTEC Secretariat for Establishing BIMSTEC Centre for Weather and Climate (BCWC) in India was signed in a befitting manner at the High Commission of India in Dhaka, Bangladesh on 24 August 2023. On behalf of the Secretariat, the BIMSTEC Secretary General His Excellency Mr. Tenzin Lekphell signed the Agreement while His Excellency Mr. Pranay Verma, High Commissioner of India to Bangladesh signed on behalf of the Government of the Republic of India. Hosting of BCWC is a clear manifestation of the Government of India to its commitment towards enhancing regional cooperation within the framework of BIMSTEC.

The BCWC will promote the use of new scientific and technical tools to strengthen preparedness in handling disaster and improve early warning systems, encourage and assist the publication of important results of research on weather and climate induced disaster. It will also facilitate arranging collaborative research and development activities in weather and climate modeling resulting in improved weather prediction technique to reduce loss of lives and damage to property caused by natural disaster in the BIMSTEC region.

BIMSTEC Day Celebration at NCMRWF:

NCMRWF & BCWC observed BIMSTEC Day on 6th June 2023. All the staff and members of NCMRWF & BCWC attended the program. A brief introduction to BIMSTEC and recent activities of BCWC were highlighted in the program

3rd GB & SAC Meeting: The 3rd Meeting of the Governing Board & Scientific Advisory Committee of the BIMSTEC Centre for Weather and Climate was held at the National Centre for Medium Range Weather Forecasting in Noida, India, on 13 & 14 December 2023, with the participation of Governing Board Members from all the BIMSTEC Member States. The Governing Board, among other matters, considered and finalized the Rules of Procedure for the Centre. The members of SAC discussed training workshop and other activities to be conducted in the year 2024.

6.4 INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANOGRAPHY (ITCOocean)

The International Training Centre for Operational Oceanography (ITCOocean) conducted 15 training programs and 1 seminar. A total of 850 persons were trained of which 680 (Male: 436, Female: 244) are from India and 170 (Male: 116, Female: 54) are from other Indian Ocean RIM countries. ITCOocean started a short-term course on 10th October 2023 to 2nd batch officers from School of Naval Oceanology and Meteorology (SNOM), Cochin and this course spans for 4 months.

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

DESK has successfully implemented the MoES Research Fellowship Programme (MRFP) programme and fourth batch of 12 JRFs was recruited in the year 2023. Their ab-initio online training of 4 months with the following subjects is currently being conducted by DESK: a) Introduction to Earth System Sciences, b) Research Methodology and c) Computer programming and Data Analysis/Visualization.

The Annual progress of all the 32 MRFP Research Fellows of the Batch-I, II and III was reviewed during September and October and Ph.D registration certificates of MRFP Batch-II have been collected.
Eight JRFs have been recruited for their course work at IITM Pune in the month of October 2022. DESK has conducted exams and annual progress review for MRFP previous batches. 13 peer reviewed research papers have been published / accepted by MRFP research fellows in 2023.

Ph.D. admissions through AcSIR at IITM: IITM has signed an agreement (MoU) with the Academy of Scientific and Innovative Research (AcSIR) for Ph.D. program on 25 January 2023. Under this MoU, IITM has become an Associate Academic Centre of AcSIR and can admit Ph.D. students through AcSIR channel who would work for Ph.D. degree of AcSIR. IITM has advertised for 10 "Regular" Ph.D. positions for the admission to the August 2023 academic session. Out of 6 selected candidates, three JRFs joined IITM.

DESK has conducted following Training Programs in 2023-24 with help of Library, Information and Publication Division and Computer Division:

- Virtual lecture series on Cloud and Precipitation Physics and Dynamics are being conducted. Details are available at https://www.tropmet.res.in/static_pages.php?page_id=3056
- National Atmospheric Chemistry Seminar Series NACSS (introduced in February 2023; Monthly Seminar series Feb 2023 onward)
- 2nd Training workshop of Indian Air Force (IAF) Officers during 3-7 October 2023.
- Prof. R. Ananthakrishnan Seminars/Colloquium,
- Lectures and Talks by invited speakers were organised.

All the videos are made available for public online through IITM YouTube channel.

6.6 MoES KNOWLEDGE RESOURCE CENTRE NETWORK (KRCNET)

MoES has signed a MoU with the Council of Scientific & Industrial Research- National Institute of Science Communication and Policy Research-National Knowledge Resource Consortia (CSIR-NIScPR NKRC) for the subscription of all the E-Resources.

Chapter–7

Deep Ocean Mission

Background: Oceans cover nearly 70% of Earth's surface, its resources remain mostly unexplored, unmapped. India, with a coast line of approximately 7500 kilometres has a large Exclusive Economic Zone which is a treasure trove of living and non-living resources. To understand and utilize the deep oceans; for harvesting the energy, mineral resources, biodiversity, climate forecasting etc it is imperative to use due means of technology since the remoteness of the deep sea demands heavy reliance to technologies to move forward with forefront research. Thus, today researchers are increasingly using multi variant platforms of different categories to observe the deep seafloor. Considering the importance of Ocean for sustainable development of the country, Ministry of Earth Sciences (MoES), Government of India, has launched Deep Ocean Mission in September 2021 which aimed at developing technologies to explore deep ocean resources and their sustainable use, growing the country's marine and maritime economy and tackling the climate change and pollution. This multi-institutional mission is the follow up of Sustainable Development Goal 14 (SDG-14) as proposed by United Nations (UN) deals with "the life below the water" emphasizes the importance of ocean in modulating and sustaining the life and environment on the planet Earth. To cater the need, Deep Ocean Mission (DOM) is implemented by MoES with following objectives:

1) Development of Technologies for Deep Sea Mining and Manned Submersible, Underwater Vehicles and Underwater Robotics for exploring and harnessing ocean resources.
2) Development of Ocean Climate Change Advisory Services.
3) Technological innovation for exploration and conservation of deepsea biodiversity.
4) Deep Ocean Survey and Exploration.
5) Energy and Freshwater from the Ocean.
6) Advance Marine Station for Ocean Biology.

The Mission has overall cost of Rs. 4077.0 crore for a period of five years to be implemented in a phase-wise manner. The estimated cost for the first phase for the three years (2021-2024) is Rs. 2823.4 crore.

7.1. Development of Technologies for Deep Sea Mining, Manned Submersible and Underwater Robotics

7.1.1 Design and Development of 6000 m depth rated Manned Submersible

The underwater vehicles are developed under the Deep Ocean Mission for the exploration and harvnessing ocean resources, defense, surveillance etc. The deep-water human submersible MATSYA 6000 is designed and is being developed indigenously at National Institute of Ocean Technology (MoES), Chennai for carrying out scientific exploration up to 6000m water depths. The battery-powered submersible with a capability to carry three persons for a period of 12h as normal endurance and supports 96h during emergency period. Subsystems of MATSYA 6000 along with 2.1 m diameter Spherical Hull (Personnel Sphere) is shown in Fig 7.1a The design has been completed and most of the subcomponents like sphere, control electronics, battery, lift support system and communication system have been realized and shallow water demonstration trials shall begin during Mar-April 2024.

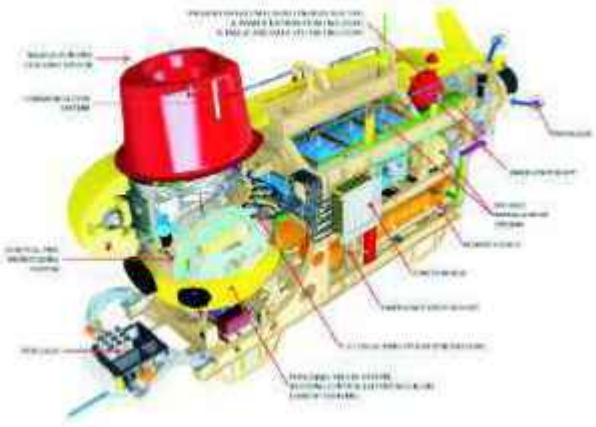


Fig 7.1a : Details components of Manned Submersible (MATSYA 6000)

For the 6000m depth-rated Manned Submersible, Titanium-alloy (Ti6Al4VELI) personnel sphere is being developed by VSSC-ISRO being certified by international certification agency. As a part of the fabrication process, Ti alloy Gr 23 material processing carried out for forming of rings from billets. LPSC facility augmentation for welding the rings with the thickness of 85 mm is completed (Fig 7.1b). Control hardware assembly is completed and a mock-up for the submersible is in place for understanding the subsystem placements, clearances and cable interfaces, for facilitating integration of the actual submersible (Fig 7.1c).

Fig 7.1b : Progress in the development of personnel sphere with VSSC-ISRO and Fig 1c Assembly of mansub internal electronics assembly and mock up frame with assembled components.

The design and development of the Manned Submersible are overseen by a Project Monitoring and Guidance Committee (PMGC) and expert subcommittees on Concept of Operations (ConOps) & General arrangement, Mechanical systems and Electrical, Electronics and Navigation (EEN) Systems Design and components realization including testing are being monitored and approved by DNV, Germany by following the Underwater Technology Rules of Manned Submersible.

7.1.2 Development of Deep Sea Mining Technology

The Integrated Mining System envisaged consists of a dynamically positioned surface platform from which the Mining Machine and a High-Pressure Pump Station are deployed-suspended by an umbilical cable-flexible riser system.

The mining technology development plan is to develop and test at sea the modules of the seabed Mining Machine (Stage-1) and the Pumping Station with the slurry transport riser system separately (Stage-2), and then demonstrate as an Integrated Mining System (IMS) at the nodule bearing areas of the CIOB. Progressive developments of the seabed mining machine were tested at increasing depths, culminating in a very successful locomotion trials for prolonged durations, at a depth of 5270 m in the Central Indian Ocean during 2021– this was one of the deepest dives and seabed trials of a nodule mining system and the integrated system with collector was tested during Mar – Apr 2023 at 3300 m water depth (Fig 1d).

Nodule collection and local slurry pumping trials by the Seabed Mining Machine – in demonstrating Stage-1 of the IMS is scheduled during Jan-Feb 2024. Towards this an Towards the planned trials for "Environmental Impact Statement" (EIS) as mandated by the International Seabed Authority (ISA), long subsea moorings with extensive instrumentation of ADCP, current meters, CTD-turbidity sensors and sediment traps have been deployed at the mining site and the reference area since Dec 2021. These are over depths of about 5300 m, for a period of 12-13 months, to record the baseline data of the water column, from the 500 m level to the seabed. This is one of the most densely instrumented deep water subsea mooring sets deployed in recent times, as part of the project.

Fig 7.1c : Deployment and testing of mining system in Bay of Bengal at 3300 m at the Central Indian Ocean during Mar-Apr 2023 and deployment of deep sea mooring at PMN site

7.1.3 Exploration at Central Indian Ocean using OMe 6000 - AUV

As per the International Seabed Authority requirement of high resolution mapping before seabed mining trials, AUV – OMe 6000 (Ocean Mineral Explorer 6000) was deployed from Sagar Nidhi during December 2022 for high resolution sea floor mapping at poly metallic manganese nodule exploratory test mining site. Close grid sea-bed bathymetry performed for 14 sq km area at a depth of 5271 m at an altitude of 30 m for more than 26 hours. High resolution seabed images were acquired in 1 km x 0.5 km block at 6 m altitude of 5170 m water depth. Observation from 113 line km of images shows deep sea bio diversity (Fig 1e).and nodule clustering with reference to the plains and slopes. Average nodule density observed at the deployed site is 7 kg/m2.

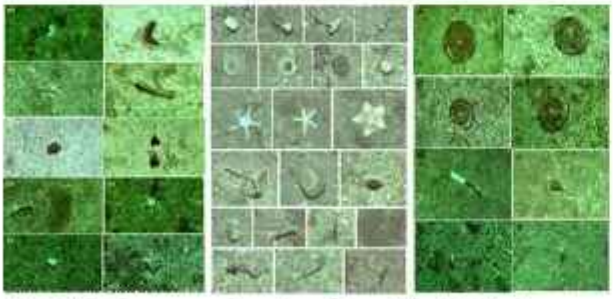


Fig 7.1d : Deep-sea benthos from the PMN site

7.2 Development of Ocean Climate Change Advisory Services

The major thrust areas of Ocean Climate Change Advisory Services (OCCAS) are assessing changes in sea level, the intensity of cyclone, storm surge, and waves and their impacts on associated coastal erosion and inundation in the projected climate. Another area of interest is to assess the impact of climate change on the coastal marine ecosystem and create advisories on the likelihood of intensity and spread of Harmful Algal Blooms that may impact the future potential migration of fishing zones and contribute to the marine-driven economy along the long coastline of India. The outcomes of all the modules in terms of climate assessments will be provided through interactive GIS-based mapping applications to utilize them for coastal zone management and policy decisions effectively.

7.2.1 Sea Level projections

This module provides downscaled assessment of the mean sea level projections under the possible climate change scenarios along the Indian coast. The downscaling of the sea level will be based on very high-resolution Indian Ocean regional model nested within a global model and forced by the selected CMIP6 atmospheric forcing fields.

The global model, designed with a 1/12° horizontal resolution encompassing 41 hybrid vertical layers, has reached a significant milestone with five years of integration completed. The initial stages of validation are currently underway, marking a crucial step in ensuring its accuracy and reliability. Concurrently, efforts are underway to configure a regional Indian Ocean model, a process that is actively in progress. To enhance the precision of the high-resolution IO-ROMS model, atmospheric

forcing derived from a curated selection of CMIP6 models is being bias-corrected and implemented for testing. This approach allows for a more thorough examination of the model's performance. Moreover, the assessment and computation of local thermostatic and barystatic sea level changes are ongoing, contributing to a comprehensive understanding of regional sea level dynamics (Fig 7.2a).

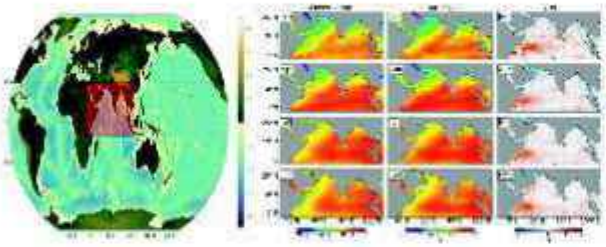
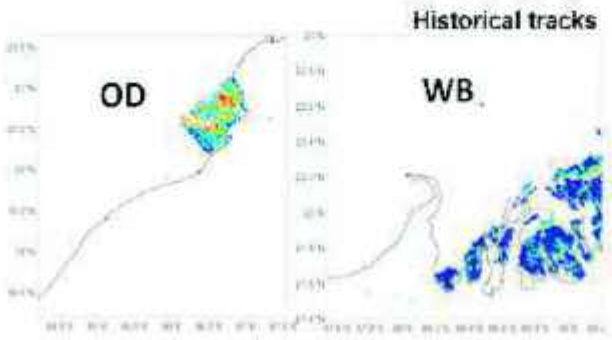


Fig 7.2a : Comparison of model simulated monthly mean SST from the IO regional model with GHRSST for the year 2010.

WWIII V6.07 were used and the model setup has four mosaic grids (Global (0°-360°, 80°S-70°N), Indian Ocean (30°E-120° E, 60°S-30°N), North Indian Ocean (32°E-100°E, 5°S-29°N) and Coastal (68.5°E-89°E,3.8°N-24°N)) in a nested pattern. Configuration of regional Indian Ocean model is in progress. ADCIRC model is used to assess the storm surge projections using synthetic cyclone tracks generated for 100 years for the east coast of India (Fig 7.2b). For assessing future cyclone activities, a new genesis potential index (GPI) is developed for the Bay of Bengal for the post monsoon season using multi reanalysis for the last thirty years, which displayed higher skill compared to currently available GPIs.



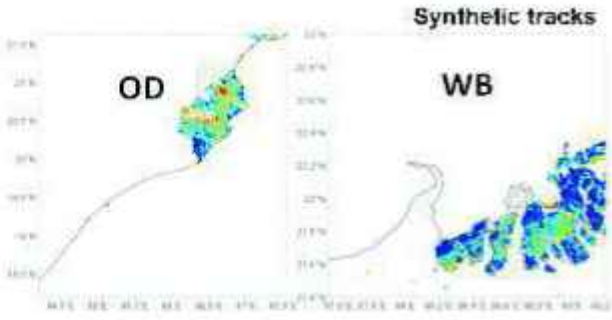


Fig 7.2b : Composite picture (state-wise) of the inundation depth and inundation extent due to all the historical and synthetic tracks.

7.2.2 Deep Ocean Observations

Deploying State-of the-Art observing systems such as Deep Sea Gliders, Deep Profiling Argo float, and Directional Wave Spectra Barometric Drifters (DWSBD) to understand the meridional overturning circulation, cross-equatorial flow and the impact of Southern Ocean swell on the coastal north Indian Ocean.

10 Nos of Deep Sea Gliders (Make: Slocum and Model: G3) and 30 Nos of DWSBD from the Lagrangian Drifting Laboratory have been procured. Two cruises (SAMA-14 from 25 February to 10 March 2023 and SAMA-17 from 18-24 April 2023) have been carried out in the BoB onboard RV Sagar Manjusha for glider deployment and recovery as part of DOM. During the transect, the glider SG890 collected unprecedented data of both physical and biogeochemical measurements along 88.47oE for nearly four months. Subsequently, two new gliders (SG1095 and SG1096) were deployed on 23 September 2023 during SN181 cruise onboard ORV Sagar Nidhi after successful ballasting and sea trial at off-Chennai. In addition, DWSBD drifters were deployed in the equatorial Indian Ocean and Southern Ocean (20 Nos) onboard R/V Roger Revelle and in the Arabian Sea (05 Nos) onboard ORV Sagar Nidhi. Seven days Intensive glider training was conducted under ITCOO from 06-13 September 2023 at INCOIS, Hyderabad and NIOT, Chennai. The training covered on glider deployment, recovery, and piloting aspects. There are more than 35 participants from various institutes such as INCOIS, NIOT, NCPOR, NPOL, NTRO, and ICGS (Fig 7.2c).

Fig 7.2c : Track of INCOIS Glider mission along with deployment of Slocum Gliders in the Bay of Bengal & Participants at Intensive glider training event conducted at INCOIS, Hyderabad and NIOT Chennai.

7.3 Technological Innovations for Exploration and Conservation of Deep-Sea Biodiversity

Inventorization of deep-sea fauna and flora of deep-sea at seamounts using Remotely Operated Vehicles, creation of DNA bank, isolation of deep-sea piezotolerant and piezophilic microbes and exploration for life-friendly molecules via systematic sampling.

7.3.1 Development of High-Pressure retainable sampling and culture system:

The comprehensive exploration of deep-sea microbial life necessitated the development of cutting-edge systems. A high-pressure retainable water sampler system (HPWS) was devised, integrating four 500 mL (600 bar pressure rated) bottles within a CTD carousel, enabling concurrent collection of pressurized and non-pressurized samples. This system, alongside eight Niskin water bottles, facilitates the retrieval of varied volumes for microbial and metagenomic analyses. Additionally, an in-situ microbial concentration system was realized, employing multi-filter arrays to concentrate deep-sea water samples while preserving them free from contamination and pressure alterations, crucial for culture-independent metagenomic studies. Furthermore, a high-pressure microbial culture system was designed, boasting a 600 bar pressure rating and temperature control spanning 25 to 120°C. This hydrostatically controlled setup enables the cultivation of deep-sea microbes under conditions closely resembling their natural habitat, fostering invaluable insights into their behaviour and characteristics (Fig 7.3a).

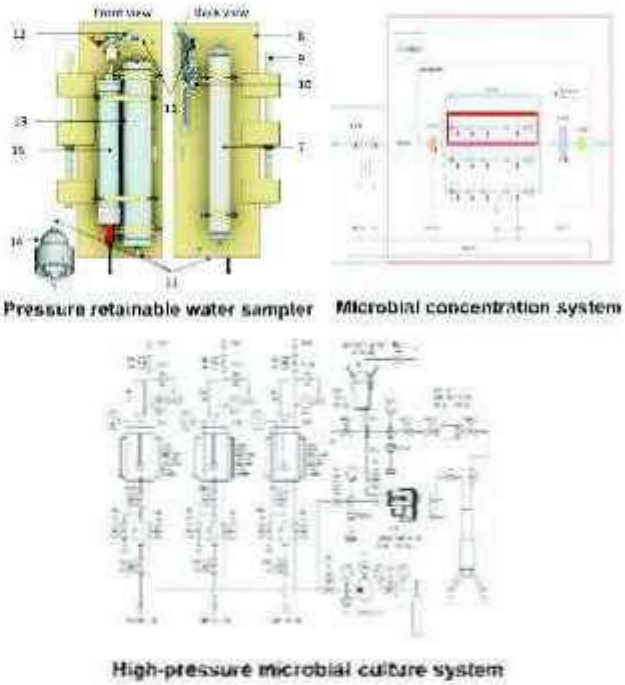


Fig 7.3a : Deep sea microbial exploration suite: High-Pressure Sampling, Concentration, and Cultivation systems.

7.3.2 Deep sea sample collection and Culture Based Bacterial Diversity Profiling

The deep-sea water and sediment samples were collected from Arabian Sea mounts on board ORV-Sagar Manjusha, Indian ocean, CIOB on board ORV-Sagar Nidhi and deep-sea sediment samples collected on board ORV Sagar Nidhi from Bay of Bengal. The samples were processed for isolation of bacteria and Actinobacteria. Although marine eukaryotes and prokaryotes continue to be studied extensively, the rate of discovery of novel

metabolites with significant bioactivity is decreasing. Deep-sea bio resources are source of diverse range of bacteria, archaea, fungi and viruses but till date only five % of deep-sea has been reported of being explored. Water and sediment samples were collected from the Arabian Sea and processed for bacterial profiling on different growth media. The CFU in water and sediment ranged from 1.72×10^{4}–5.01×10^{6} CFU/ml and 3.08×10^{3}–9.49×10^{5} CFU/g, respectively. A total of 79 morphologically distinct bacterial strains were isolated from the water samples, while 123 distinct bacterial strains were isolated from the sediment samples. Bacterial CFU ranged from 8.88×10^{3} – 4.18×10^{5} CFU/ml, while fungal CFU varied from 10 – 1.60×10^{5} CFU/ml. Morphologically distinct 23 bacterial isolates and 6 fungal isolates were isolated from the Indian Ocean deep-sea water samples. A total of 76 morphologically distinct bacterial strains were isolated from the Bay of Bengal sediment samples on different growth media. Based on standard colony morphological characteristics these strains were classified into 55 groups. The growth medium Streptomyces agar and Zobell Marine agar showed major population in terms of colony forming units (CFU) of heterotrophic bacteria, 1.49×10^{5} and 1.21×10^{5} CFU/g, respectively in comparison to other media such as ISP7, and Starch casein agar.

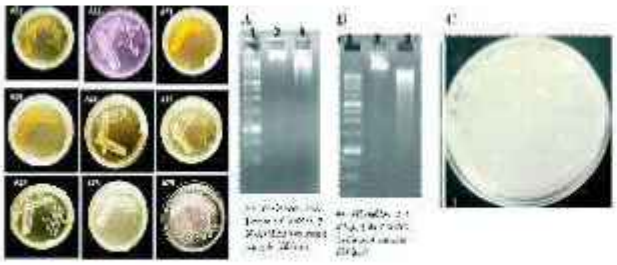


Fig 7.3b : Axenic bacteria isolated from the Arabian Sea and Indian Ocean & Metagenomic DNA Isolation from Sea mount sediment samples.

7.3.3 Marine Microbial Screening towards Novel Biomolecules

An extensive screening of, 210 bacteria for carbonic anhydrase activity, revealed the presence of this enzyme in 15 isolates. Simultaneously, 170 bacteria were assessed for exopolysaccharide (EPS) production, yielding 51 positive identifications. Within this diverse bacterial pool, five strains proficient in biosurfactant production were isloated. Among the screened strains, 120 exhibited the capability to degrade polyaromatic hydrocarbons, showcasing potential environmental remediation abilities. Additionally, a subset of 20 bacteria exhibited bioremediation capabilities with polyethylene, highlighting their promising role in addressing plastic pollution concerns. Under Screening of deep-sea metagenome sequence and clone library for functional enzymes, A metagenomic DNA clone library with 40 kb fragments was constructed. 1088 subclones were screened for phosphatase activity, revealing five promising clones with high specific activity (Fig7.3c).

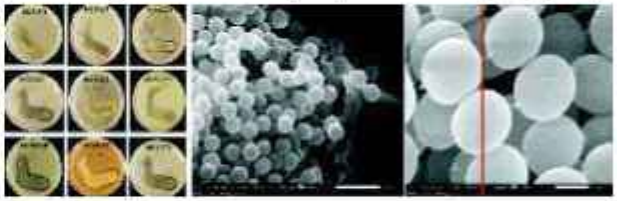


Fig 7.3c : Fungal strains isolated from deep sea water and sediment samples & Deep-sea Aspergillus terreus SEM.

7.3.4 Inventorization of deep-sea fauna and flora of deep-sea hotspots like sea mounts

A comprehensive database has been created in the Indian Ocean Biogeographic Information System. It currently holds more than 1,00,000 records of species occurrences, including information about 3352 species of deep-sea fauna that were archived at the CMLRE Referral Centre. Information about these species was collected from previous sample collections on board Sagar Sampada. Automatically identify organisms based on video footage from the ROV was developed, with a segmentation model called YOLO 8. It was trained with video footage collected during the Maldives expedition, which was held jointly with NEKTON, UK, and a few other Indian Ocean countries. Collaboration with NEKTON, UK, for a joint expedition in March 2024 has been initiated. A laboratory has been established for cell culture as part of the germplasm resource and tissue bank. 3D Models of all new species and records have been generated as part of the digital specimens and for training AI/ML (Fig 7.3d).

Fig 7.3d : Voucher Specimens and 3D Models of all new species and records.

Six Deep Sea Taxonomic Catalogues Compendium of Mantis Shrimps, Catalogue of Brittle stars, Pseudoceritud polychaetes of Lakshadweep, Deep sea angler fishes of the Indian EEZ, Systematic account of Indian Deep Water Brachyurans crabs, and The taxonomic guide for deep-sea mollusks are published with detailed morphological descriptions supplemented with photographs and biogeographic maps (Fig 7.3e)

Fig 7.3e : Deep Sea Taxonomic Catalogues Water Crabs and Mollusks.

OceanEyes is a mobile application designed for collecting marine species observations, functioning on both Android and iOS platforms. It seamlessly integrates with a backend ARCGIS server, allowing for the updating of spatial records in IndOBIS. The app operates in offline mode during data collection and provides a user-friendly interface for viewing species distribution (Fig 7.3f).

Fig 7.3f : User interface and functionality of OceanEyes: A mobile app

7.4. Deep Ocean Survey and Exploration

Exploration and Identification of potential sites of multi-metal hydrothermal sulphides along the Indian Ocean mid-oceanic ridges and acquisition of a new all-weather multidisciplinary research vessel.

The Government of India signed a 15-year contract with International Seabed Authority (ISA) in September-2016, for the exploration of polymetallic sulphides over a 100,000 km2 large area of the Central Indian Ridge (CIR) and Southwest Indian Ridge (SWIR) regions in the Indian Ocean (Fig 7.4a).

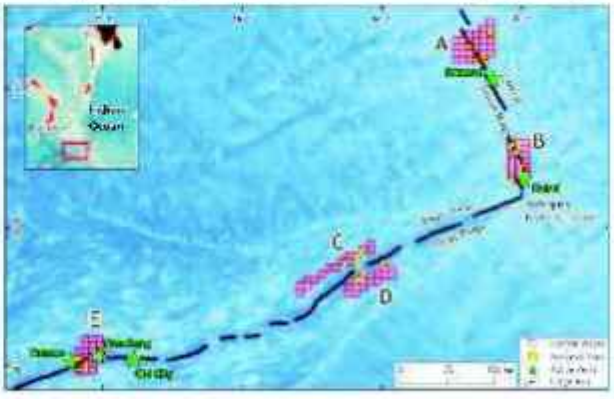


Fig 7.4a : Sites of potential mineralization along the Central Indian Ridge and South West Indian Ridge

7.4.1 High-resolution geophysical surveys using Autonomous Underwater Vehicles (AUVs) for the delineation of seafloor massive sulphides.

A wide variety of high-resolution near-seabed geophysical data will be collected using Autonomous Underwater Vehicles (AUVs) from potential sites in the CIR and SWIR. The AUV-based geophysical data acquisition will include multibeam bathymetry, side-scan sonar, sub-bottom profiler, electric self-potential, magnetic, and seafloor imagery. The geophysical data will aid in identifying hydrothermal vents and delineating zones of sulphide deposits. A high-resolution near-seabed geophysical survey will be conducted during January 2024 using Autonomous Underwater Vehicles (AUVs) from 10 potential sites in the Central Indian Ridge and South West Indian Ridge, through M/s. Argeo Survey AS, Norway with a cost of~ Rs 114 Cr.

7.4.2 Acquisition of a new Research Vessel

A new research vessel would be an ideal platform for the Indian oceanographic research fraternity for the protection of India's strategic interests in the global framework of nations operating in research fields. The proposed new research vessel shall render services to the nation for about 30 years to explore and identify potential sites of multi-metal hydrothermal sulphide mineralisation along the Indian Ocean mid-oceanic ridges. The vessel shall be registered in India and shall comply with all statutory and regulatory national and international requirements applicable at the time of construction and delivery. A new all-weather multidisciplinary Research vessel will be constructed at an Indian shipyard through M/s Garden Reach Shipbuilders & Engineers Ltd., Kolkata at an estimated cost of Rs. 839.55 Cr. The expected period of construction is estimated to be 36 months (Fig 7.4b).

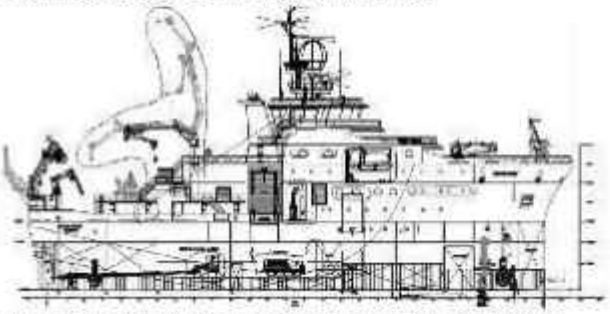


Fig 7.4b : Multidisciplinary research vessel for Indian Ocean operations.

7.5 Energy and Fresh water from the Ocean

Renewable ocean energies are the need of the hour. India is surrounded by tropical ocean waters and has surface temperatures in the range of 27°C–32°C throughout the year and about 7°C at 1000 m depth. Thus, appreciable thermal gradient in the seas is constantly available to generate energy. Ocean Thermal Energy Conversion (OTEC) is a base load source of power and can be the future sustainable power source. The activities under vertical-5 (Energy and Fresh water from the Ocean) in the Deep Ocean Mission include comprehensive studies towards detailed engineering design for the high capacity offshore OTEC powered desalination plant. Also, for implementing the larger plant, as an intermediate step before scaling up and towards studying the behaviour of complex offshore components, it is planned to demonstrate a scaled down offshore OTEC based platform with long cold water conduit and mooring system in deep sea.

7.5.1 Detailed engineering design for high capacity offshore platform mounted OTEC powered desalination plant.

- A local tender was floated and suitable contractor was identified with the approval from Technical and Financial Evaluation Committee (TFEC) and Independent External Monitors (IEMs) for the preparation of Detailed Project Report for 2 modules of gross 5MW each closed cycle OTEC and 2 modules of 2.5MLD each desalination plant powered by open cycle OTEC.
- A contract was signed between NIOT and the successful bidder, M/s Oceanergy on 22/09/2023 towards commencement of the work on preparation of DPR. Several meetings with the contractor were held towards the concept development and process design with handholding from NIOT.
- The detailed design will include equipment for Thermal system including power module, Platform to house plant components, Instrumentation & Control, Electrical, Transportation of fresh water and transmission of electricity from platform to Mainland,

Physical Model Testing for the selected Platform configuration, Stages of construction of platform and installation, feasibility study for hydrogen generation, Classification society approval and Calculation of project costing.

Fig 7.5a : Contract signing for the preparation of DPR for high capacity OTEC-Desalination plant.

7.5.2 Studies on scaled down deep sea cold water conduit and mooring system in open sea trials in deep waters

- The planned study includes demonstration of long conduits held by a suitable floating structure moored in deep waters. State of the art instrumentation would be deployed to assess performance behaviour of long cold water pipeline in real sea conditions.
- This study is being modified to aim for generation of energy and freshwater offshore using OTEC. Baseline design for sizing of equipments, platform and other offshore components have commenced.
- A surface buoy was successfully deployed with subsea sensors up to 1000m off Kavaratti Island in UT Lakshadweep and current and temperature data is continuously being acquired for the past ten months.

Fig 7.5b : Deployment of buoy system using Sagar Nidhi.

7.6 Advanced marine station for Ocean Biology

A site for the establishment of Advanced marine station has been acquired at Vadanemmeli by the National Centre for Coastal Research (NCCR), Ministry of Earth Sciences (MoES) from the Government of Tamil Nadu at a cost of 18.3 crores. This Hub will provide the necessary infrastructure and facilities to support a wide range of activities related to ocean biology. It is planned to include the following key components: state-of-the-art in-house research laboratories, classrooms, library and information centre, administrative offices (Purchase, Account, Central Store, Computer Networking), conference hall, meeting rooms, hostels, multimedia studio, specialised facilities equipped with cutting-edge research equipment, instrumentation, and technology to support advanced research and educational programs in various areas of marine science. The Centre also provides accommodation facilities for researchers and students who may visit the main centre for short or extended periods, ensuring a conducive environment for focused research along with Outreach programmes (Fig 7.6a).

Fig 7.6a : Vadanemmeli land 4.99 Acers (106.32 × 190 m = 20,200.8 sq meters).

Chapter–8

International Cooperation

8.1 INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES (INCOIS):

8.1.1 Intergovernmental Oceanographic Commission (IOC)

The Indian delegation led by Secretary Ministry of Earth Sciences (MoES), participated in the 56th session of the Intergovernmental Oceanographic Commission (IOC) Assembly in Paris, France from 19-30 June 2023 and India made several interventions on various topics. Exchange of Letter of Agreement between INCOIS and IOC on Decade Coordination Centre-Indian Ocean Region were accomplished in the presence of Secretary, MoES. INCOIS Director Dr. T Srinivasa Kumar was elected on 28 June, 2023 as the Vice President of Intergovernmental Oceanographic Commission (IOC) of UNESCO for the period of 2023-2025.

8.1.2 UN Decade of Ocean Science for Sustainable Development

- INCOIS participated in the bi-monthly meetings conducted by the IOC Decade Coordination Office with all National Decade Coordination Committees (NDCC) focal points to update and review the progress of national activities under UN Decade of Ocean Science for Sustainable Development, to discuss on the contributions of NDCs to the success of the decade, discussion on Global Stakeholder forum, etc.
- INCOIS partnered with UN Decade Collaborative Centre on Ocean Prediction and actively participated in its Kick-off meeting held through online platform during 11-12 January 2023. INCOIS is playing a major role in formulating and coordinating the formation of the Indian Seas Regional Team for Ocean Prediction.
- A project proposal by IIOE-2 Early Career 'Scientist' Network (ECSN) titled 'Devising Early-Career Capacity Development in the Indian Ocean region (DECCaD-IO)' has been endorsed as an Ocean Decade action under ECOPs programme in March 2023. The first of the trainings under DECCaD-IO was conducted in September, 2023 under the aegis of ITCOocean.
- Dr. Srinivasa Kumar, Director, INCOIS has been invited to be a Member of the Working Group on Ocean Cities for One year and he has also been the Co-Chair of the WG (Working Group) on Ocean Resilience.

8.1.3 Decade Collaborative Centre for the Indian Ocean Region (DCC-IOR)

- Formalization of the DCC-IOR was accomplished during IOC Assembly session in June 2023. Official launch was organized through a dedicated session of the Eighth Biennial Conference of Ocean Society of India (OSICON-23) on 25August, 2023.
- IOR-DCC team participated in the initiation networking meeting with the Ocean Observing Co-Design Tropical Cyclone (TC) Exemplar Steering team on 24 Apr 2023.

8.1.4 Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS)

- As a part of the ICG/IOTWS of the IOC of UNESCO, INCOIS is acting as Tsunami Service Provider (TSP) and continued to provide tsunami services to the Indian Ocean Region together with TSPs Australia & Indonesia. TSP-India is providing services to Australia, Bangladesh, Comoros, France (La Réunion), India, Indonesia, Iran, Kenya, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Myanmar, Oman, Pakistan, Seychelles, Singapore, South Africa, Sri Lanka, Tanzania, Thailand, Timor Leste, UAE and Yemen.
- INCOIS Scientists involved in various capacities (Vice-chairs and members) in the ICG/IOTWMS in Steering Group, Working Groups, Task Team and participated in related virtual meetings and contributed to related activities.
- ICG/IOTWMS has coordinated Indian Ocean wide Tsunami Exercise – IOWave23 in October 2023. As a TSP, INCOIS participated and issued test bulletins for Indian Ocean countries during IOWave23 exercise.

8.1.5 Indian Ocean Global Ocean Observing System (IOGOOS)

- IOGOOS Secretariat located at INCOIS successfully organised the 18th annual meeting of IOGOOS and its allied programmes such as Indian Ocean Regional Panel (IORP), Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER), IndOOS Resource Forum (IRF), International Indian Ocean Expedition (IIOE)-2 during 06-09 February 2023 at Perth, Western Australia.
- The Sixth meeting of the Steering Committee (SC) of the IIOE-2 was organised virtually during 06-07 February 2023 at Perth, Western Australia by the IIOE-2 Project Office (JPO) located at INCOIS.

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

- As a part of the MoU between MoES, and RIMES, INCOIS has continued to provide the ocean state forecasts for Comoros, Madagascar, Maldives, Mozambique, Seychelles, and Sri Lanka. INCOIS has continued to receive seismic/GNSS data from Myanmar, Bhutan and Nepal established by RIMES and INCOIS.
- INCOIS has provided weekly updates including past week briefing and upcoming week forecast of Ocean State (Wave, Wind, Current, Swell, Sea Surface Temperature) for Indian Ocean under South Asia Hydromet Forum (SAHF) administrated by RIMES.

8.1.7 Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER) International Program Office

- INCOIS hosts the International Program Office to coordinate the activities of SIBER.
- Prof. Raleigh Hood University of Maryland, Cambridge, USA and Dr Gregory Cowie, University of Edinburgh, UK continue to be co-chairs of the SIBER Scientific Steering Committee (SSC) and Dr Aneesh Lotliker, Scientist-F and Head of Ocean Observation Network Division of INCOIS as an Executive Director, SIBER-International Program Office.

8.1.8 Second International Indian Ocean Expedition (IIOE-2) Joint Project Office (JPO)

- The Second International Indian Ocean Expedition (IIOE-2) program was executed with the secretarial support from Joint Project Offices located at Australia (IOC Perth Program Office, PPO) and India (INCOIS, Hyderabad).
- Dr. Vladimir Ryabinin, Dr Marie-Alexandrine Sicre and Dr T. Srinivasa Kumar continued to be the co-chairs of the IIOE-2 Steering Committee (SC) and Dr Aneesh Lotliker as a coordinator of IIOE-2 PO India. Further, JPO-India continued to maintain the website (https://iioe-2.incois.gov.in) including timely updates on IIOE-2 expeditions and metadata portal.
- The IIOE-2 PO India convened the sixth meeting of the steering committee (IIOE-2 SC6) at Indian Ocean Marine Research Centre (IOMRC), University of Western Australia (UWA) during 06-07 February 2023 along with meetings of IRF (15th major meeting), SIBER (13th major meeting), IORP (18th major meeting), IOGOOS (18th major meeting) and KUDOS Workshop as part of International Indian Ocean Science Conference (IIOSC 2023).

8.1.9 Other International and Bilateral Collaborations

- Dr. T Srinivasa Kumar, Director INCOIS delivered a presentation on "High-Level Principles for a Sustainable and Climate Resilient Blue Economy" during the session at 1st Environment Climate Sustainable Working Group of G20 India at Bengaluru on 11 Feb, 2023.
- Dr. Nimit Kumar was awarded the PORSEC Distinguished Service Award including an award-winning MOOC (IUCEL-2021 silver award) during the 15th PORSEC for his contributions. He is the first Indian to have received a PORSEC (science/service) award.
- INCOIS scientists participated in QUAD Space Working Group's technical workshop on extreme precipitation events, held virtually, 05-09 February 2023 (USA)/06-10 February 2023 (Australia, India, Japan).

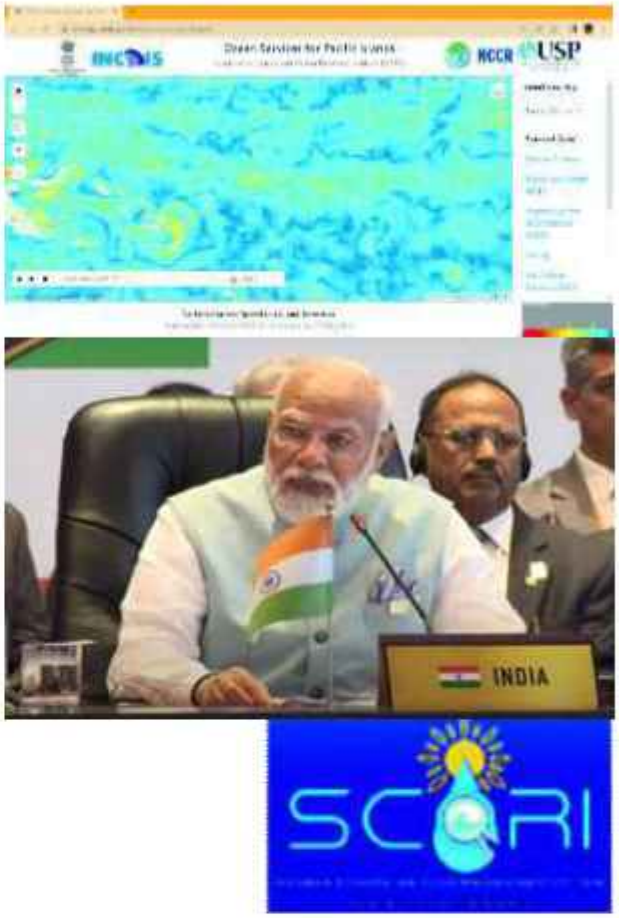
- INCOIS-ITCOocean has been selected to host the International Ocean Color Coordination Group (IOCCG)'s biennial training program 'Summer Lecture Series' (SLS) from 2024 onwards. The IOCCG-SLS have been organized since 2014 at the Laboratoired'Océanographie de Villefranche (LOV), which is part of the IMEV (Institut de la Mer, de Villefranche), France.
- INCOIS-ITCOocean has been endorsed to host an international training under the Indian Technical and Economic Cooperation (ITEC) program of Ministry of External Affairs (MEA). First of these trainings has been announced. These will be 2-3week residential trainings along with field visits, catered exclusively for about 20 foreign participants in a batch.

8.10 Contribution of INCOIS to the establishment of SCORI, Fiji

The Government of India established the Sustainable Coastal and Ocean Research Institute (SCORI) in Fiji, which was remotely launched by the Prime Minister of India on 22 May 2023. Dr. P. Vijay, scientist from INCOIS was deputed to Suva, Fiji, during 6-12 May 2023 to make preparatory arrangements for the establishment of SCORI. This center is an initiative of the Government of India, under its 'Act East Policy', to promote multilateral cooperation with the Pacific Island Countries (PIC) in the area of ocean sciences and climate change adaptation. INCOIS provides value-added ocean data products and services to the PICs through its custom-made dashboard accessible at https://incois.gov.in/oceanservices/pacific.jsp. The products/services falling under three broad categories of i) Ocean State Forecast ii) Marine Heatwave Advisory Service, and iii) Satellite Ocean Data Products, are issued for the area enclosed between 26° S to 18° N and 130° E to 154° W covering all the PICs.

8.11 Visit of officials from UK met office and University of Reading to INCOIS

- On February 22, officials from UK met office and University of Reading, collaborating with Indian scientists under The Weather and Climate Science for Service Partnership India program



visited INCOIS to discuss collaboration to improve understanding on Ocean response to tropical cyclones, Ocean and coupled model development, Wave model coupling with ocean atmosphere coupled model, Model inter comparisons and identify common interests in Indo-Pacific Priority Evaluation Group (PEG), Ocean observations and development of Verification techniques for model evaluation.

8.12 Joint scientific expedition

- A joint scientific expedition consisting of sixteen (16) scientists from India, Bangladesh, and Mauritius organized by the Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences under the regional framework of Colombo Security Conclave (CSC), onboard Sagar Nidhi was conducted over the Arabian Sea during June 26 to July 24, 2023. During the cruise, apart from unique data acquired with vertical microstructure lowered

ADCP, underway CTD, eddy covariance flux system, and radiosonde, thirteen (13) Directional wave Spectra Barometric Drifters were also deployed. The primary objective of the expedition was to build capacity in ocean observation and services apart from collection of ocean data to predict and manage changes in the regional environment of the Indian Ocean.

8.2 CENTRE FOR MARINE LIVING RESOURCES & ECOLOGY MINISTRY (CMLRE):

- The Centre serves as a national focal point for the dissemination of information on the marine living resources and deep-sea biodiversity of the Indian EEZ.CMLRE functions as the regional node to the Ocean Biodiversity Information System under the Intergovernmental Oceanographic Commission. The Centre deals with the new global implementing agreement namely "Biodiversity beyond national jurisdiction" (BBNJ) under the Unite Nations Convention on the Law of the Sea (UNCLOS).The centre represents the country in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which was established for the management of the Southern Ocean resources particularly the Antarctic krill—single species with the largest total biomass. CMLRE hosted the Working Group meetings on Statistics, Assessments and Modelling (WG-SAM) from 26 to 30 June 2023, and the Ecosystem Monitoring and Management (WG-EMM) from 3 to 14 July 2023, at the Holiday Inn Hotel in Kochi, India. This marks the second time India has hosted the WG-EMM meeting, with the first meeting held in 1996 at Kochi itself.

  The meeting was attended by 24 foreign representatives from 12 countries and 6 Indian delegates with Dr C. Péron (France) and Dr T. Okuda (Japan) chairing the WG-SAM and 43 foreign representatives from 15 countries, and 10 Indian delegates (3 from NCPOR and 7 from CMLRE), actively participated in the WG-EMM.

8.3 INDIA METEOROLOGICAL DEPARTMENT (IMD):

International Memorandum of Understanding (MoUs) signed with WMO

- IMD signed a Memorandum of Understanding with United Nations Development Programme (UNDP) to enhance India's climate resilience by using weather data to strengthen climate adaptation efforts on 22nd June, 23 With this collaboration, the community needs will be strengthened upto Gram Panchayat level.

MoU with UNDP signed on 22nd June-2023)

- Dr. M. Mohapatra, DG, IMD signed an MoU with Prof. Petteri Taalas, Secretary General World Meteorological Organization for the hosting of WMO Regional Training Centre with IMD as coordinator of training activities in South Asia region.

MOU with IMD –RTC & WMO signed by PR of India with WMO & SG of WMO

- IMD signed a Memorandum of Understanding with World Food Programme on 1st May-2023.

- India Meteorological Department (IMD) & Nigerian Meteorological Agency (NiMet), Nigeria signed a Memorandum of Understanding (MoU) on 2nd March 2023 in the WMO Headquarters at Geneva for collaboration between the two agencies for the mutual benefit of cooperation in the conduct of Scientific & Technical Research and the development of practical skills that benefit the International Community.
- The IMD & NiMet came forward to work together to provide WMO standard services in the field of Numerical Weather Prediction Capability, Meteorological Sensor Designing, Satellite Meteorology, Scientific research on meteorology and its applications in various sectors, Nowcasting, Early warning capabilities and Capacity building activities.

In picture (left to right): Senator Hadi Sirika, Hon'ble Minister of Aviation, Federal Republic of Nigeria; Dr Mrutyunjay Mohapatra, Permanant Representative (PR) of India with WMO: Professor Mansur Bako Matazu, PR of Nigeria with WMO & Ms Barkha Tamrakar, First Secretary, Permanent Mission of India, Geneva.

- Collaboration with Dominican Republic is in process. In this regard, Mr. David Puig, Ambassador of Dominican Republic made a courtesy visit to the office of Dr. M Mohapatra, DG IMD on 11th May-2023. Mr. Alan Ramírez, Technical Director of the National Council for Climate Change and Clean Development Mechanism of the Dominican Republic, met with Dr. Mrutyunjay Mohapatra, Director General of the Indian Meteorological Department. Together, they discussed areas of cooperation in this field.

77th Executive Council Session Meeting

- The Executive Council 77th session was held 05-06th June-2023 to implement Congress decisions, while six Regional Associations are

responsible for the coordination of meteorological, hydrological and related activities within their respective Regions. Technical Commissions study and make recommendations to Congress and the Executive Council on subjects within the purpose of the Organization.

- The seventy seventh session of the WMO Executive Council (EC-77) held in Geneva from 05 to 06 June 2023, at the WMO headquarters.
- The President emphasized the historical decisions made by the eighteenth Congress concerning the adoption of the constituent body reform and the resulting tasks assigned to the Executive Council to implement it. The Secretary-General also welcomed the participants to Geneva, underlining the lasting impact of the outcomes of Congress, in particular the reform of constituent bodies, which will entail significant changes in the modalities of work of the Organization as well as the Secretariat.

Institutes and have developed the Marine Spatial Plans for two pilot areas namely, Puducherry and Lakshadweep.

- ❖ NCCR and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) are collaborating on various aspects of coastal research such as Marine Litter and Micro Plastics
- ❖ NCCR and Centre for Environment, Fisheries and Aquaculture Science (CEFAS), United Kingdom are working together on coastal research activities related to marine litter and micro plastics.
- ❖ As part of the FIPIC summits, the Government of India initiated the establishment of a Sustainable Coastal and Ocean Research Institute, SCORI, in the Fiji Islands and the National Centre for Coastal Research is identified as the lead institute to collaborate with the University of South Pacific in Fiji for this path breaking initiative.

8.4 NATIONAL CENTRE FOR COASTAL RESEARCH (NCCR):

- ❖ India and Norway signed a Memorandum of Understanding (MoU) establishing the India - Norway Ocean Dialogue in January 2019 which emphasized "the need to move towards integrated and ecosystem-based approaches in the management of renewable and non-renewable natural resources and identified integrated ocean management as an area of mutual interest for future cooperation. In this connection, NCCR has worked with Norwegian
- ❖ As part of the Indo-Pacific Ocean Initiatives (IPOI), a bilateral collaboration has been established between the Governments of Vietnam and India to offer support in tackling coastal erosion and deploying protective measures along Vietnam's coastline. National Centre for Coastal Research (NCCR) coordinated with the Vietnam Administration of Seas and Islands (VASI) on issues related to coastal protection and shoreline management.

International workshops

- The International Workshop on Advances in Coastal Research with Special Reference to Indo Pacific- was conducted on 21-22 July, 2023. About 270 scientists, academicians, policy makers, and researchers from Indian, Japan, Norway, Fiji and Vietnam attended the workshop.
- Workshops on "Marine Spatial Planning" were held with Norwegian Scientists and administrators and officers of Puducherry and Lakshadweep during October 2023.
- Stakeholders' meeting on "Coastal Ecosystem Services and Accounting for Mangrove Ecosystems" was held on 25th November 2023 at Kakinada, Andhra Pradesh. This is an initiative under Indo-Norway collaboration of Ecosystem services and accounting program.

8.5 NATIONAL INSTITUTE OF OCEAN TECHNOLOGY (NIOT):

8.5.1 Agreement with United States Trade Development Agency (USTDA) for the design of Ocean thermal energy conversion (OTEC) plant:

- Subtasks on Ocean Energy Powered Desalination and OTEC Economics led by NIOT have been taken up currently at Ocean Energy Systems (OES), a Technology Collaboration Program under the International Energy Agency (IEA). India currently holds the position of Vice-Chair in the OES cabinet.
- NIOT-MoES and the United States Trade Development Agency (USTDA) have signed a Grant Agreement for the Engineering Design of a high capacity OTEC power plant for Andaman & Nicobar Islands through the US and Indian industry.

Grant Agreement with USTDA for the design of OTEC plant

8.5.2 Development of Ambient Noise System for Polar Region Measurements:

- Deployment of Acoustic Mooring System near glacier: An independent Acoustic mooring has been deployed at 78 º57'44.21" N and 12º 20" 52.78" E, at a water depth of 70 m at Kongsfjorden, Svalbard availing the Ship Ulla Rinmann during Sep 16-18, 2023. The location is 10 km northeast of Ny-Alesund harbor and 2.5 km from the Glacier. The system consisted of a pair of hydrophones, connected to data acquisition modules, CTD and Tilt sensors configured for duty-cycled time series acquisition for a year. The system is intended to capture the dynamics of glaciers and icebergs.

(a) System deployment at Kongsfjorden and (b) Field Team

Workshop Organised:

Regional Environmental Mining Plan workshop:

The five-day workshop during 1st to 5th May, 2023 hosted by the National Institute of Ocean Technology (NIOT) of India and chaired by the members of the Legal and Technical Commission of ISA was conducted at NIOT, the workshop was attended by around 34 foreign delegates — aimed to review and synthesize the scientific knowledge for the development of a Regional Environmental Management Plan (REMP) in the Indian Ocean.

(b) Regional Environmental Mining Plan workshop at NIOT

8.6 NATIONAL CENTRE FOR POLAR AND OCEAN RESEARCH (NCPOR):

- The 43rd Indian Scientific Expedition to Antarctica (ISEA), the National Coordination Committee for Polar Science Program (NCPP), under the Chairmanship of Secretary MoES, convened on 10 July 2023 at MoES, New Delhi.
- On 27 October 2023, the 43rd ISEA was launched with the first batch of 19 members and leader - Bharati, Shri Rivertis Pariong, IMD. The high-level delegation, including the Secretary, MoES, Additional Secretary & Financial Advisor, MoES, and the Director, NCPOR, joined for the maiden Cape Town to Bharati flight at Zenith Runway.
- NCPOR participated in International Ocean Discovery Program (IODP) Expedition 400 to North West Greenland during Aug-Oct 2023. IODP Expedition 400 focused on investigating the onset and development of glacial expansion in North West Greenland and the historical response of the Greenland Ice Sheet to past climatic changes.

NCPOR participated in IODP Expedition 400 to North west Greenland

- As part of Prydz Bay Air-Ice-Sea Exchange (PRAISE) Program India has established its first ice-tethered mooring system in Quilty bay, an embayment in Prydz Bay, East Antarctica in July 2022, which was later recovered in December 2022. In continuation of this program, the wintering team of 42nd Indian scientific Expedition to Antarctica (ISEA 42) has again successfully deployed the ice-tethered ocean mooring near Bharati Station, Prydz Bay in July 2023.

Deployment of ice-tethered mooring near Bharati Station, Prydz Bay in July 2023

Participation in GO-SHIP Cruise

- Ms Nirmala J., JRF, NCPOR has participated in the GO-SHIP IO5_2023 cruise aboard the Scripps Institution of Oceanography research vessel Roger Revelle from Fremantle, Australia to Cape Town South Africa for 55 days (22 July-14 September 2023) of hydrographic operations along 32°S in the Indian Ocean (Fig.14).

Ms. Nirmala, JRF, NCPOR onboard Research Vessel Roger Revelle

Awards:

- Ms. Aswathi Das, JRF NCPOR has received Antarctic Science International Bursary Fellowship-2023 to extend her research to understand basal melting of the Amery and West Ice shelves by the intrusion of water masses in the Prydz Bay region of East Antarctica using a numerical model.

8.7 INDIAN INSTITUTE OF TROPICAL METEOROLOGY (IITM):

I) Centre for Climate Change Research (CCCR):

World Climate Research Program: Contributing to the Coupled Model Intercomparison Project (CMIP) and Coordinated Regional Climate Experiment (CORDEX) over South Asia of the World Climate Research Program (WCRP).

Workshop conducted under this Collaboration:

ICRC-CORDEX 2023 Conference: The International Conference on Regional Climate – Coordinated Regional Climate Downscaling Experiment (ICRC-CORDEX-2023) was organized jointly by CCCR-IITM, MoES, the Abdus Salam International Centre for Theoretical Physics (ICTP, Italy), the Swedish Meteorological and Hydrological Institute (SMHI), and the World Climate Research Program (WCRP) with physical hubs in Pune, India and Trieste, Italy in hybrid mode during 25-29 September 2023. It was attended by 67 offline (in person) participants and 36 online participants. The conference sessions were devoted to address a wide range of topics ranging from the key scientific discussions to user impacts and applications thus eventually focusing on how the regional climate science community through the WCRP CORDEX can better respond to societal and policy needs and questions, and also how to connect climate science with solutions/action. Dr. M. Ravichandran, MoES-Secretary, Dr. Kamaljit Ray, Advisor at MoES and Dr. M.Mohapatra, DGM, India Meteorological Department were the Chief Guests of the program for the inaugural session. The Conference also hosted a side event session of WCRP My Climate Risk (MCR) Lighthouse Activity entitled, "Leveraging Climate Research and Modeling for Action in the Indo-Pacific region".

- JAMSTEC-Japan: Japan-India Joint Research on Coastal Sea Level Fluctuations. Project coordinated by IITM, INCOIS, NCCR and JAMSTEC, Japan.
- BRICS project between IITM, INPE Brazil and CAS, China "Artificial Intelligence and Earth System Modeling toward Detection of Extreme Climate Events in the BRICS".
- CMIP7 task force, WCRP: Contributing to CMIP7 task force as a climate modelling centre.
- Programmes focusing on climate research using different proxies are initiated with the National Taiwan University, Taiwan and The University of Queensland, Australia.
- Numerous other project-based collaborations have been undertaken with international institutions such as Forschungszentrum Jülich GmbH, IEK-7, Jülich, Germany; School of Earth and Environment, University of Leeds, Leeds, UK; Department of Meteorology, University of Reading, Reading, UK; University of Nebraska-Lincoln, Kagawa University, Japan; and MRI, Japan.

Physics and Dynamics of Tropical Clouds (PDTC):

- A collaborative research work is initiated with Karshruhe Institute of Technology to utilize their Ice Nucleation Spectrometer (INSKET) which is a freezing assay to quantify the content of ice nucleating particles in aerosol particle samples in the immersion freezing mode. Immersion freezing processes are relevant for the formation and evolution of mixed-phase clouds in the atmosphere.

ii) Air Quality Early Warning System:

- In collaboration with National Centre for Atmospheric Research (NCAR), USA, IITM has successfully implemented operational air quality early warning system for the Delhi National Capital Region (NCR).
- United Kingdom Met Office on collaborative work related to VERA offline model used for visibility prediction through the WCSSP-India program.
- GCRF (Global Challenge Research Fund)-National Environmental Research Council (NERC)-South Asian Nitrogen Hub (SANH)

- o Modelling of NH_3 using WRF-Chem for 2015 and its intercomparison using Edgar NH_3 emissions and new bottom-up emissions.
- o Intercomparison of NH_3 measurements over Delhi using Delta denuder system and other MARGA measurements.

- Qatar Meteorology Department on developing an experimental air quality forecasting system for Qatar during the FIFA World Cup 2022.

Monsoon Mission:

- The International Monsoons Project Office (IMPO): Establishment of IMPO at IITM in February 2022 through an agreement between IITM & WMO, with support from MoES, to support monsoon research activities of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP). The IMPO supported WMO's monsoon research coordination under WWRP and WCRP, aiding CLIVAR/GEWEX Monsoons Panel and engaging in various activities.

iii) IMPO Activities conducted during 2023-24:

- International Monsoons Project Office (IMPO) provided key support to the CLIVAR/ GEWEX Monsoons Panel (MP) in preparation of Annual Reports, new Membership recommendations, issuing appointment letters to new members, organising online meetings of MP and WG on Asian-Australian Monsoons, etc.
- IMPO successfully organized the 5th Session of the Monsoons Panel (MP) along with a meeting between MP and Working Group on African Monsoons (WG-AFM) in Hybrid mode on 27th October 2023 at Kigali, Rwanda.
- IMPO participated in the WCRP's Open Science Conference (OSC-2023), Kigali, Rwanda during 23-27 October 2023 with the following activities:
  - o Supported CLIVAR/GEWEX Monsoons Panel in the organization of the Session S03 on "Global and Regional Monsoons".
  - o Supported WCRP in the organization of OSC-2023 as Session Support in 3 sessions.
  - o Providing CLIVAR's travel funds to 2 MP members and GEWEX's travel funds to 2 WG-AFM members for participation in OSC
  - o Organized and participated in four online meetings of the Convenors of "Global and Regional Monsoons" session in OSC-2023. Issued the invitation letters to the identified Keynote Speakers of the session.
  - o Actively involved in drafting contributions from Concept Paper on Regional and Global Monsoons for the OSC Kigali Declaration, which is Co-lead by MP Co-chairs.
  - o A 5-minute video on MP & IMPO was created for display at the WCRP Booth during the OSC in Kigali
  - o Supported WCRP in the online poster (session S03) presentations on 11th October as Moderator.
- IMPO played a key role in the organisation of two webinars of the Joint WCRP/WWRP Monsoons Webinar Series on Global Monsoon and Asian-Australian Monsoons respectively (namely, in the identification of topics, speakers and date/time, advertising the webinars nationally/internationally, publishing the video recordings of the webinars in IITM YouTube Channel for wider outreach)
- IMPO played a key role in the securing WWRP/IMPO's funds (15000 CHF) towards travel support to invited speakers in the International Workshop on "Stratosphere-Troposphere Interactions and Prediction of Monsoon weather EXtremes (STIPMEX) to be held at IITM, Pune during 2-7 June 2024.
- **Unified model framework for Monsoon Variability and Predictability (UMVP)**

IITM collaborated in the international project "Impact of Initialized Land Temperature and Snowpack on Sub-seasonal-to-Seasonal Prediction (LS4P)" initiated by the Global Energy and Water Exchanges (GEWEX) program of WCRP. About 40 institutions worldwide are participating in this project, including the UVMP group from IITM.

UVMP participated in the LS4P-II meeting which was held during the 2nd International workshop on 10th Dec. 2023 Fall AGU Meeting.

iv) Meetings, Workshops, Campaigns Participated:

- **ASTRAL (Arabian Sea Transition Layer) cruise field campaign:**

CAIPEEX-IITM participated in the ASTRAL cruise field campaign over Arabian Sea which was held during 9th to 26th June 2023 from Mormugao, Goa. The ASTRAL project is part of the EKAMSAT initiative (Enhancing Knowledge of the Arabian Sea Marine environment through Science and Advanced Training) which is a joint research initiative between India (MOES) and the USA. The main goal of the EKAMSAT is to enhance our understanding of the air-sea interaction, boundary layers processes over the Arabian Sea, which is crucial for the better prediction of monsoon dynamics. IITM has collected valuable dataset over the Arabian Sea of the black carbon aerosols. This is first time that concurrent observations of BC are done over the Arabian Sea and over the inland location Solapur. That is the first of its kind measurements during the summer monsoon period over the important geographical region. The datasets can give valuable insights on the radiative forcing over the region during the onset of monsoon.

- CCCR participated in the Indian Scientific Expedition to the Southern Ocean and the Indian Antarctic Expedition.

V) IITM participation in important International meetings/Events :

- International Project Offices (IPOs) & WCRP Secretariat Group meeting held on 18th April, 6th July and 22nd September 2023.
- 25th South Asian Climate Outlook Forum (SASCOF-25), 27 April 2023 and Climate Services User Forum (CSUF), 28-29 April 2023.
- IMPO-WGTMR S2S Stakeholders Meeting held on 28th April 2023.
- GEWEX SSG-35 meeting, Santiago, Chile, during 1-4 May 2023.
- Second General Body Meeting (GBM) (online), South Asian Meteorological Association (SAMA) - India Chapter, 7 May 2023.
- WCRP JSC-44 sessions at Brussels, 8-11 May 2023.
- WWRP TMR meeting, University of Miami Rosenstiel School of Marine, Atmospheric, & Earth Science /Cooperative Institute for Marine & Atmospheric Studies (CIMAS), 10 May 2023.
- WRF-Chem South Asian Nitrogen Hub(SANH) modelling online meetings in 2023
- Regional Association-II (RAII) Working Group (WG-S) Meeting, 17 May 2023
- WMO UAS demonstration campaign Forum-V (online), 18 May 2023.
- Japan Geoscience Union Meeting 2023 (online), 23 May 2023.
- WRF-Chem South Asian Nitrogen Hub (SANH) modelling online meeting, 30 May 2023.
- WWRP/WCRP S2S Summit 2023, at University of Reading, United Kingdom, 3-7 July 2023.
- 28th General Assembly of the International Union of Geodesy and Geophysics (IUGG 2023), Berlin, Germany, 11-20 July 2023.
- 9th International Conference on Fog, Fog Collection and Dew (FOGDEW2023), Fort Collins, Colorado, USA, 23-28 July 2023.
- ICTP-CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts, International Centre for Theoretical Physics (ICTP), Trieste, Italy, 24-29 July 2023.
- WMO/WWRP Annual Scientific Steering Committee Meeting, 29 August - 01 September 2023.
- WCSSP-India meeting on discussion of collaboration on sea ice and polar processes, 13 September 2023.

- Global Ocean Summit 2023, Qingdao, China, 25-27 September 2023.
- WMO event on "Observations within the Global Greenhouse Gas Watch" WMO, Geneva, Switzerland, 3 – 5 October 2023.
- World Climate Research Programme - Open Science Conference 2023, Rwanda, 23-27 October 2023.
- 5th Session of the Monsoons Panel (MP) and the meeting between MP and Working Group on African Monsoons (WG-AFM) on 27th October 2023 at Kigali, Rwanda.

Pic1: Fifth Session of CLIVAR/GEWEX Monsoons Panel held in hybrid mode on 27th October 2023 at Kigali, Rwanda

8.8 Ministry of Earth Sciences (MoES) participation in G20 activities: -

- MoES participated in the Research and Innovation Initiative Gathering (RIIG) events which were co-ordinated by Department of Science and Technology (DST). Under the RIIG, a total of 6 meetings were undertaken based on various thematic areas. MoES led the 5th RIIG meeting in Diu from 18th-19th May 2023 under the theme **"Scientific Challenges and Opportunities for a Sustainable Blue Economy".**
- The RIIG does not come under the Engagement Group or the Sherpa Track. However, during India's Presidency 2023 this year, the G20 Research Ministers recommended the elevation of RIIG to the status of a formal Working Group, i.e., G20 Research and Innovation Working Group (RIWG) under the Sherpa Track.

5th RIIG meeting held in Diu

Team MoES at the 5th RIIG meeting in Diu

MoES co-chaired along with the Ministry of Environment, Forests and Climate Change (MoEF&CC), the Environment and Climate Sustainability Working Group (ECSWG) under the Sherpa track. A total of 4 meetings were undertaken successfully under the leading ministry, MoEF&CC. MoES organized the **'Ocean 20 Dialogue'** and also co-ordinated the **'Mega Beach Clean-up'** for G20 countries together with MoEF&CC during its third meeting at Mumbai in May, 2023.

- Out of the many outcomes of these deliberations 4 important outcome documents of the ECSWG meetings are
  - (I) The G20 ECSWG Communique,
  - (ii) The ECSWG Technical Study on "Accelerating the transition to a sustainable and resilient blue economy",
  - (iii) The Chennai High Level Principles for a Sustainable and Resilient Blue/Ocean-based Economy,
  - (iv) The Fifth G20 Report on Actions Against Marine Plastic Litter (MPL).

- The ECSWG Communique encompasses discussions on key priority areas of the ECSWG (arresting land degradation, encouraging resource efficiency and circular economy and promoting a sustainable and resilient Blue Economy) to ensure inclusive, ambitious, action-oriented, and decisive outcomes.
- The ECSWG technical study is an attempt to provide detailed report on the High-Level Principle (HLP) 'promoting sustainable and resilient blue economy'.
- The Chennai High-Level Principles for a Sustainable and Resilient Blue Economy sets the context for the transition to a sustainable and resilient Blue Economy, promoting conservation, protection, responsible use of ocean resources while building resilience to climate impacts, social equity, gender equality, and human development.
- The Fifth G20 Report on Actions Against Marine Plastic Litter (MPL) is a compilation of policies and measures undertaken to tackle marine plastic litter by countries and international organisations across the world.

3rd ECSWG meeting held in Mumbai

Mega Beach Clean-up event in Juhu beach, Mumbai

Chapter–9

Publications, Patents, Awards and Honours

MoES Publications for AR 2023-24

9.1 Publications in peer reviewed journals:

A total number of 502 research papers were published in 2023 by MoES Institutes under its various programs, and the details of which are given below.

Table1: MoES Publications

	ACROSS	OSMART	PACER	SAGE	TOTAL
Total no. of Publications	301	95	45	61	**502**
Cumulative Impact Factor	**1318.545**	**258.633**	**162.5**	**203.95**	**1943.628**

The number of research papers published and the total impact factor (1943.628) are comparatively much higher as compared to the previous years. The average impact factor of research papers was 3.872.

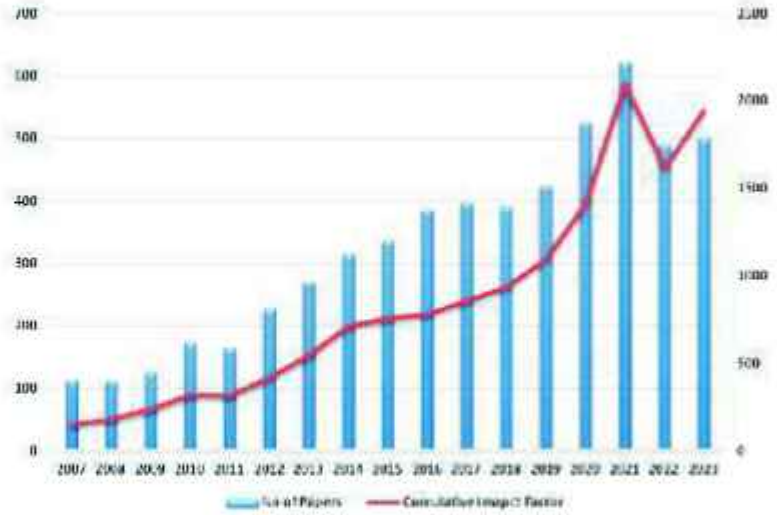


Fig. 8.1: Number of research papers and cumulative impact factor year wise

9.2 Patents Granted

Sl. No.	Inventors	Title of the patent	Awarded Reference	Country
1.	Dr.R.Venkatesan, Mr.M.AnilMuthiah, Dr.Jossia Joseph, Mr.P.Murugesh	A System and Method for Rapid Mode Transmission during Cyclone	438396 Dt.12/7/23	India
2.	Kirubagaran R, Thirupathi K, Ramesh N.R, AtmanandM.A	Apparatus for Deep-sea Microbial Culture and method thereof	423452 Dt.28.2.2023	India

3.	Dr.R.Venkatesan, Mr.M.ArulMuthiah, Dr.Jossia Joseph, Mr.P.Murugesh	A System and Method for Rapid Mode Transmission during Cyclone	438396 Dt.12/7/23	**India**
4.	G. A. Ramadass, S. Ramesh, D. Sathianarayanan, R. Ramesh, G. Harikrishnan, A.Vadivelan, N. Vedachalam, AN. Subramanian, E. Chandrasekaran, D. Muthukumaran, M. Murugesan & S. Elangovan	A polar Remotely operated vehicle	201841045387/ 31.11.2018 Patent No. and award 427580 / 29.03.2023	**India**
5.	Sreedev D.S, Shijo Zacharia, Dhilsha Rajapan, Shibu Jacob, Atmanand M.A.	A networkable hydrophone array for providing simultaneously digitized data'	418913 Dt.23.01.2023	India
6.	D.Muthukumaran, V.Doss Prakash, A.Vadivelan, S.Elangovan, E.Chandrasekaran, M.Murugesan, M.Radhakrishnan	A Water Proof LED Array Lighting System for Oceanographic Applications	406787 Dt.16.9.2022	India

9.2.1 Patents Filed

Sl. No.	Inventors	Title of the patent	Filed Application No.	Country
1.	R.Venkatesan, M.Arul Muthiah, B.Kesava kumar, K. Thirumurugan, G.Vengatesan, C.Muthukumar.	Artificial intelligence based autonomous data acquisition system and method for deep ocean and subsea environments.	No.202241005052, dt.31.01.2022	India

2.	R.Venkatesan, M.Arul Muthiah, B.Kesavakumar, G.Vengatesan, K.Ramesh.	Smart autonomous system for real-time monitoring and data acquisition for marine applications and method thereof.	No.202241005053, dt.31.01.2022	India
3.	R.Venkatesan, M.Arul Muthiah, B.Kesava kumar, K.Thirumurugan, G.Vengatesan, R.Sridhar.	System and method for fishing vessel based smart network for ocean observation.	No.202241022590, dt.17.04.2022	India
4.	Biswajit Haldar, Boby George, M.A. Atmanand, K. Thirumurugan, M. Arul Muthiah, Tata Sudhakar.	System and Method to Sense and Measure Ocean Current using integrated load cell in a data buoy.	No.202341063003, dt. 19.09.2023	India

9.2.2 Transfer of Technologies (ToT) to Industries

As a part of Indigenous technology developments, several ocean observation tools are developed and tested at fields. These technologies are transferred to industries for commercialization through National Research Development Corporation (NRDC).

2.	Met-Ocean Buoy System type – I (MOBS-1)	M/s. Norinco Pvt Ltd Mumbai 2022	2022
3.	Sea water Lantern (ROSHINI)	M/s Printlay Technologies	2022
4.	Sea water Lantern (ROSHINI)	M/s Poramina Water Technologies	2023
5.	Sea surface temperature Sensor (SST)	M/s.Tridel Technologies	2022
6.	Mechanical Components of Moored Buoy System Type - 1	M/s. GRP Industries	2023
7.	Mechanical Components of Moored Buoy System Type - 2	M/s. GRP Industries	2023
8.	Mechanical Components of Moored Buoy System Type – 1 &2	M/s Nexteng Enviro Pvt. LTD	2023
9.	Indigenous Acoustic Sub Bottom Profiler	M/s. BEL (Bharat Electronic Limited)	2023

9.3 Awards and Honours

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

Dr. Mrutyunjay Mohapatra, dgm, IMD was elected as **Third Vice-President of WMO** by the nineteenth World Meteorological Congress on 1st June, 2023 for a four-year term beginning immediately after the closure of the Congress-19.

Mr. Rahul Saxena, Scientist 'F' was elected as first Chair for PMC for the duration of four years.in the first Project Management Committee (PMC) for implementation of Global FFGS on 16 May, 2023 at Skopje, North Macedonia.

On 30th May, 2023 WMO organized a meeting to highlight the achievements of India Meteorological Department (IMD) as Regional Specialized Meteorological Centre (RSMC) for Tropical cyclones providing support to countries in Bay of Bengal and Arabian Sea region.

During the Cg-19, a video film on **"Cyclone Warning and Management in India : An End to End System"** developed by India Meteorological Department was screened by WMO during. The film showcased the multi-institutional mechanism in India to manage cyclones with case studies of cyclone Tauktae (2021) and Mocha (2023) discussed therein.

WMO recognised three IMD observatories, viz., Dwarka and Veraval in Gujarat and Cuttack in Odisha as long term observing stations for more than 100 years of hydrological observations. **Dr. M. Mohapatra,** Director General IMD received the certificates from the President during Cg-19.

Regional Specialized Meteorological Centre of WMO: INCOIS has been designated as a Regional Specialized Meteorological Centre (RSMC) for numerical ocean wave prediction and global numerical ocean prediction in WMO's 76th Executive Council session (EC-76) held in March 2023.

Indian Ocean Region Decade Collaborative Centre of IOC-UNESCO: INCOIS has been recognized as the Indian Ocean Region Decade Collaborative Centre (IOR-DCC) by IOC-UNESCO on 23rd August 2023.

Dr. T Srinivasa Kumar, Director, INCOIS was elected on 28 June, 2023 as the Vice President of Intergovernmental Oceanographic Commission (IOC) of UNESCO for the period of 2023-2025.

The Best Research Award: Dr. Chodavarapu Patanjali Kumar, Scientist-E, INCOIS was honored with 'The Best Research Award' for his exceptional research in the Disaster Management Policy Program by National Graduate Institute for Policy Studies - GRIPS and the Building Research Institute-BRI in Japan.

ICTP/IAEA Sandwich Training Educational Programme (STEP): Ms. Trishneeta Bhattacharya, Senior Research Fellow working under the guidance of Dr. Kunal Chakraborty at INCOIS has been selected to participate in the ICTP/IAEA Sandwich Training Educational Programme (STEP).

Jerome Paros Fellowship: Mr. Abhijith Raj, Senior Research Fellow working under the guidance of Dr. B Praveen Kumar, INCOIS has been selected for the prestigious Jerome Paros Fellowship for Geophysical Instrumentation in 2023, an award constituted by the American Geophysical Union.

Shri Abhijith Raj received the prestigious AGU Paros Fellowship in Instrumentation at American Geophysical Union Annual Meeting (AGU23) in San Francisco, California, USA from 11-15 December 2023

Dr. R. Krishnan, Director, IITM has become Member of the Joint Scientific Committee (JSC) for the World Climate Research programme has been extended for two years from 1 January 2023 to 31 December 2024.

Dr. Parthasarthy Mukhopadhyay, Sc-F, IITM has been elected as a Member of Working Group on Tropical Meteorology Research of the World Weather Research Programme (WWRP) w.e.f. 20 February 2023.

Dr. Parthasarthy Mukhopadhyay, Sc-F, IITM Elected as the Fellow of Indian Academy of Sciences, Bengaluru in 2022 (effective from 2023).

Dr. Swapna Panickal, Sc-F, IITM has been selected as member of the Scientific Steering Committee of Scenario Model Intercomparison Project (ScenarioMIP) of CMIP7, WCRP.

Dr. Sachin Ghude, Sc-F, IITM has been appointed as a LEAD Expert Team Urban Services (ET-US) Working Group on WMO - Regional Association II.

Dr. A. Surya Chandra Rao, Sc-G, IITM taken charge of a Co-Chair of CLIVAR/GEWEX Monsoons Panel (MP) of WCRP this year for 2022, in addition to his role in Working Group on Asian-Australian Monsoons (WG-AAM) of MP.

Dr. Suvarna Fadnavis, Sc-F, IITM has become the Editor of the Journal of Atmospheric Chemistry and Physics (ACP).

Dr. Susmitha Joseph, Sc-F, IITM was appointed by the WWRP/WCRP Sub-seasonal to Seasonal Prediction (S2S) Project to manage S2S Regional Activities Wikis for South Asia.

Dr. Phani Murali Krishna, Scientist –E & Shri S.M.D. Jeelani, Scientist –E from IITM were the recipients of the Dr. APJ Abdul Kalam HPC Awards 2023 in the category of Group Award (Efficient HPC Facility Design and Management) for efficient deployment, administration, and management of the largest HPC system in India.

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/Transaction	Success Indicators	Services
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 advsories at district level	To provide Agro-meteorological advsories at district level to the farmers	Twice a Week
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 (b) Tuna Fishing	24 Hrs.
		Ocean State Forecast (i) General Public	3 - 6 Hrs.
		(ii) Fishing Community	3 - 6 Hrs.
		(iii) Industries	3 - 6 Hrs.
		(iv) Defense/Security/ Researchers	3 - 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	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
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	45 Days
12	Release of funds to the responsibility Centers under the control of MoES	Timely processing of proposals received	30 Days
13	Disposal of applications/appeals under RTI Act 2005	Timely disposal of application/appeals	

10.2 Implementation of the 15 Point Programme on Minority Welfare

The proper implementation 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 (Rs. in Crore)

S.No.	Major Head of Accounts	2021-22 Actuals			2022-23 Budget estimates			2022-23 Actuals		
		Revenue	Capital	Total	Revenue	Capital	Total	Revenue	Capital	Total
Revenue Section										
1	3403-Oceangraphic Research	713.78	0.00	713.78	1133.11	0.00	1133.11	545.06	0.00	545.06
2	3425-Other Scientific Research	67.80	0.00	67.80	79.00	0.00	79.00	71.69	0.00	71.69
3	3451-Secretariat Economic Affairs	559.28	0.00	559.28	46.60	0.00	46.60	41.76	0.00	41.76
4	3455-Meteorology	754.00	0.00	754.00	949.23	0.00	949.23	839.28	0.00	839.28
Total (Revenue)		2094.86	0.00	2094.86	2207.94	0.00	2207.94	1497.79	0.00	1497.79
Capital Section										
1	5403-Capital outlay on Oceangraphic Research	0.00	7.15	7.15	0.00	225.00	225.00	0.00	15.81	15.81
2	5455-Capital Outlay on Mtoeorology	0.00	92.39	92.39	0.00	225.00	225.00	0.00	72.48	72.48
Total(Capital)		0.00	99.54	99.54	0.00	450.00	450.00	0.00	88.29	88.29
Grand Total		2094.86	99.54	2194.40	2207.94	450.00	2657.94	1497.79	88.29	1586.08

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
3	2015	Two (Para No. 6.1 of Report No. 30 of 2015- "Unfruitful Expenditure due to non-functional website" and Para No. 6.2 of Report No. 30 of 2015- "Installation and upkeep of meteorological observatories by Regional Meteorological...").	NIL	NIL	NIL	NIL
4	2016	One (Para No. 6.1 of Report No. 12 of 2016- "non-establishment of desalination plants and wasteful expenditure").	NIL	NIL	NIL	NIL
5	2017	Two (Para No. 7.1 of Report No. 17 of 2017 on "non-recovery of fuel charges due to improper contract management" and Para No. 7.2 of Report No. 17 of 2017-"Irregular implementation of promotion scheme").	NIL	NIL	NIL	NIL
6	2018	One (Para No.8.1 of Report No. 02 of 2018 on "Avoidable expenditure toward rent of bonded warehouse").	NIL	NIL	NIL	NIL
7	2020	One (Para No.6.1 of Report No. 08 of 2020 on "Grant of financial benefits without approval of competent authority").	NIL	NIL	NIL	NIL

10.5 STAFF STRENGTH

Strength 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	Group A	140	66	552	118	58	41	172	70	1217
2	Group B	69	17	3787	67	17	29	79	29	4094
3	Group C	74	14	2705	48	23	00	68	58	2990
4	Total	283	97	7044	233	98	70	319	157	8301

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

Administrative Support – MoES (Proper), CMLRE, NCCR

Detailed breakup of Sanctioned Strength of Ministry (Proper) including NCS + Koyana Project, CMLRE and NCCR.

Ministry/Attached Offices	Scientific/Technical Posts	Non-Technical Posts	Grand Total
Ministry (Proper) including NCS + Koyana Project	69 + 3 + 15	149 + 15**	251
CMLRE	27 + 7***	12	46
NCCR	18	8	26
Total	139	184	323

*69 (Scientists including Koyana Project) + 3 (DOM) + 15 (Technical staff at Koyana Project)

** 15 Nos. Of Sanctioned strength of personal establishment of HMoES.

*** 7 DOM

Representation of persons with disabilities in government services.

REPRESENTATION OF PERSONS WITH DISABILITIES IN GOVERNMENT SERVICES																	
Group	Office	Direct Recruitment								Promotion							
		No. of Vacancies Reserved				No. of Appointments made				No. of Vacancies Reserved				No. of Appointments made			
		VH	OH	HH	Total	Un-identified Posts	VH	OH	HH	VH	OH	HH	Total	Un-identified Posts	VH	OH	HH
A	MoES	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
	NCMRWF																
	CMLRE																
	NCCR																
	INCOIS																
	NCPOR																
	NCESS																
	IITM																
	NIOT																
B	MOES	NIL	NIL	1	1	NIL	NIL	NIL	1	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
	NCMRWF																
	CMLRE																
	NCCR																
	INCOIS																
	NCPOR																
	NCESS																
	IITM																
	NIOT																
C	MoES	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
	NCMRWF																
	CMLRE																
	NCCR																
	INCOIS																
	NCPOR																
	NCESS																
	IITM																
	NIOT																

Representation of SC/ST/OBC in government services in respect of Ministry (Proper).

Group	Representation of SCs/STs/OBCs				Number of appointment made during the calendar year 2023											
					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
Group A	104	4	3	8	2	0	0	1	1	0	0	0	0	0	0	0
Group B	57	3	0	3	4	0	0	1	0	0	0	0	0	0	0	0
Group C including MTS	57	13	3	10	6	0	0	1	0	0	0	0	0	0	0	0

10.6 Progressive Use of Hindi Official Language Act and Rules

The Official Language Section of the Ministry works under the able guidance of the Joint Secretary and supported by an Assistant Director (Official Language) along with two Senior Translation Officers and one Junior Translation Officer and and two Data Entry Operators. The Official Language Section is responsible for carrying out the overall translation work as well as implementing the Official Language Policy of the Government of India in the Ministry, its attached and subordinate offices and their field organizations. Some of the major activities undertaken during the year are as follows:

1. During the year, implementation of the provisions of the Official Languages Act and the rules made thereunder has been ensured.
2. To ensure implementation of the provisions of the Official Languages Act, 1963 and the rules made thereunder, check points have been set up in the Ministry. Effective measures have been taken to comply with these check points. 48 officers and employees of the Ministry, who possess proficiency in Hindi, were personally instructed to use Hindi in their official work and official language inspection of 5 sections was carried out during the year.
3. The orders issued by the Department of Official Language for the implementation of the Official Language Policy of the Union during the year 2022-2023 as well as other orders were circulated in the Ministry and all attached/subordinate offices for compliance thereof. The quarterly reports received from the subordinate offices were reviewed and progress made in this regard was reviewed in the Official Language Implementation Committee of the Ministry under the chairmanship of the Joint Secretary.

Important activities and achievements of the Official Language Section of the Ministry of Earth Sciences :

- During 15-17 February 2023, the 12th World Hindi Conference was organized by the Ministry of External Affairs at Denarau Island Convention Center in Nadi city of Fiji. On behalf of the Ministry, Shri D. Senthil Pandian, Joint Secretary, and Assistant Director (Official Language) and two other officials participated in the conference.
- The meeting of the joint Hindi Advisory Committee of the Ministry of Earth Sciences and the Ministry of Science and Technology held on the 7th July 2023 witnessed participation by Shri Keshav Kumar, Director and Mrs. Vimala Dahiya, Assistant Director (Official Language) from the Ministry .
- On 13 September, 2023, "Indian Culture and Environmental Science" workshop was organized by the Ministry's autonomous body, Indian Institute of Tropical Meteorology, Pune, wherein Dr. Nilay Khare, Scientist 'G', Mrs.

Vimala Dahiya, Assistant Director (Official Language) and Shri Brijesh Kumar Sharma, Senior Translation Officer participated from the Ministry.

- Hindi Day Celebration 2023 and the Third All India Official Language Conference was organized by the Department of Official Language on 14-15 September, 2023 at Shri Shiv Chhatrapati Sports Complex, Balewadi, Pune (Maharashtra). Dr. Nilay Khare, Scientist 'G', Mrs. Vimala Dahiya, Assistant Director (Official Language) and Shri Brijesh Kumar Sharma, Senior Hindi Translation Officer participated from the ministry in this conference.
- Under the Rajbhasha Gaurav Award Scheme of Department of Official Language for the year 2022, Dr. Nilay Khare, Scientist 'G' of the ministry was awarded the second prize for his book 'Mausam Vigyan (Meteorology)' in the category of original book writing on science in Hindi for the Indian readers. Dr. Nilay Khare received this award from the Honorable Minister of State for Home Affairs, Shri Ajay Mishra on the occasion of Hindi Day Celebration 2023 and the Third All India Official Language Conference held in Pune.

Dr. Nilay Khare , Scientist 'G'receiving the award for his book 'Mausam Vigyan (Meteorology)' from the Honorable Minister of State for Home Affairs, Shri Ajay Kumar Mishra.

- Hindi Pakhwada was organized in the Ministry from 14 September to 29 September 2023. During this period, 8 competitions viz Hindi essay, Hindi noting drafting, official language, Hindi poetry recitation, dictation, general Hindi knowledge were organized for the officials of the ministry.

Officials of the Ministry of Earth Sciences participating in the competitions organized during 14th to 29th September, 2023.

- 39 winners from various competitions organized during the Hindi Fortnight were given awards in the Ministry's 'Mahika Hall' on 13th October 2023, by Shri M Ravichandran. Secretary, MoES.

Award winners of various competitions organized in Hindi Pakhwada with the Secretary, MoES.

- During the year 2023, Second Sub-Committee of the Parliamentary Official Language Committee carried out official language inspection of the 11 Subordinate offices of the Ministry namely India Meteorological Department's Meteorological Center, Patna, Doppler Weather Radar, Patiala, Aviation Meteorological Office, Amritsar, Meteorological Center, Lucknow, Meteorological Observatory Office, Kozhikode, Meteorological Observatory, Mangaluru, Cyclone Warning Center, Visakhapatnam, Meteorological Center, Hyderabad,

Meteorological Center, Shimla, Aviation Meteorological Office, Ludhiana, and Meteorological Center, Varanasi A delegation of officials from the Ministry of Earth Sciences and India Meteorological Department under the able guidance of Shri D. Senthil Pandian, Joint Secretary, Ministry of Earth Sciences was present in these inspections .

Joint Secretary, Shri D. Senthil Pandian and other officers during the inspection by Committee of Parliament on Official Language at Cyclone Warning Centre , Visakhapatnam on 24.08.2023

- The Ministry's autonomous body, National Center for Polar and Ocean Research has been given the first prize in regional Official Language award for the year 2022-23 in the Western Region by the Department of Official Language, in the category of offices with more than 50 personnel in 'C Region'.
- "One-day National Hindi Scientific Seminar" was organized at National Center for Polar and Ocean Research, Goa on 27th September 2023. This seminar focused on various topics related to Science and Earth Sciences. Participants from various offices/universities/scientific institution presented scientific research summary/ fundamental research in Hindi.
- During this period, Smt. Vimala Dahiya, Assistant Director (Official Language) and Shri Brijesh Kumar Sharma, Senior Translation Officer, carried out inspection regarding use of official language in three subordinate offices of the MoES namely National Center for Medium Range Weather Forecasting, Noida, Centre for Marine Living Resources and Ecology, Kochi and Indian Institute of Tropical Meteorology.
- 9 Subordinate offices of the India Meteorological Department and the attached office of the MoES, Center for Marine Living Resources and Ecology , Kochi have been notified under the Rule 10(4) of the Official Language Rules, 1976, which prescribe for notifying the offices where more than 80% of the personnel have acquired working knowledge in Hindi.

10.07 Capacity Building and Human Resources Development -

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

10.08 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 forum within the stipulated period time.

10.9 Vigilance Activities and Achievements

Shri D Senthil Pandiyan, IAS is the Chief Vigilance Officer (CVO) of the Ministry w.e.f. 01.01.2023. 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. Sh. Ajay Kumar Lal, IRAS (retd.) & Sh. Pavan Kumar Jain, IDSE (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 30th October, 2023 to 5th November, 2023 with the theme.

"Say no to corruption; commit to the Nation (भ्रष्टाचार का विरोध करेय राष्ट्र के प्रति समर्पित रहें)". During the Vigilance Awareness Week, one workshop on PIDPI and Preventive Vigilance Measures for all Officers/Staff of the Ministry was organized. A quiz competition was also conducted for the officers/officials of this Ministry and prizes were awarded to the winners.

10.10 Parliament Matters

The Parliament Section, which caters to the correspondence with the Parliament Secretariats, replied Lok Sabha (72 questions) and Rajya Sabha (59 Questions) during the year 2023.

10.11 Significant Audit Points Printed in audit Reports of 2023

No significant audit point has appeared in the Audit Report of 2023.

Chapter – 11

Acknowledgements

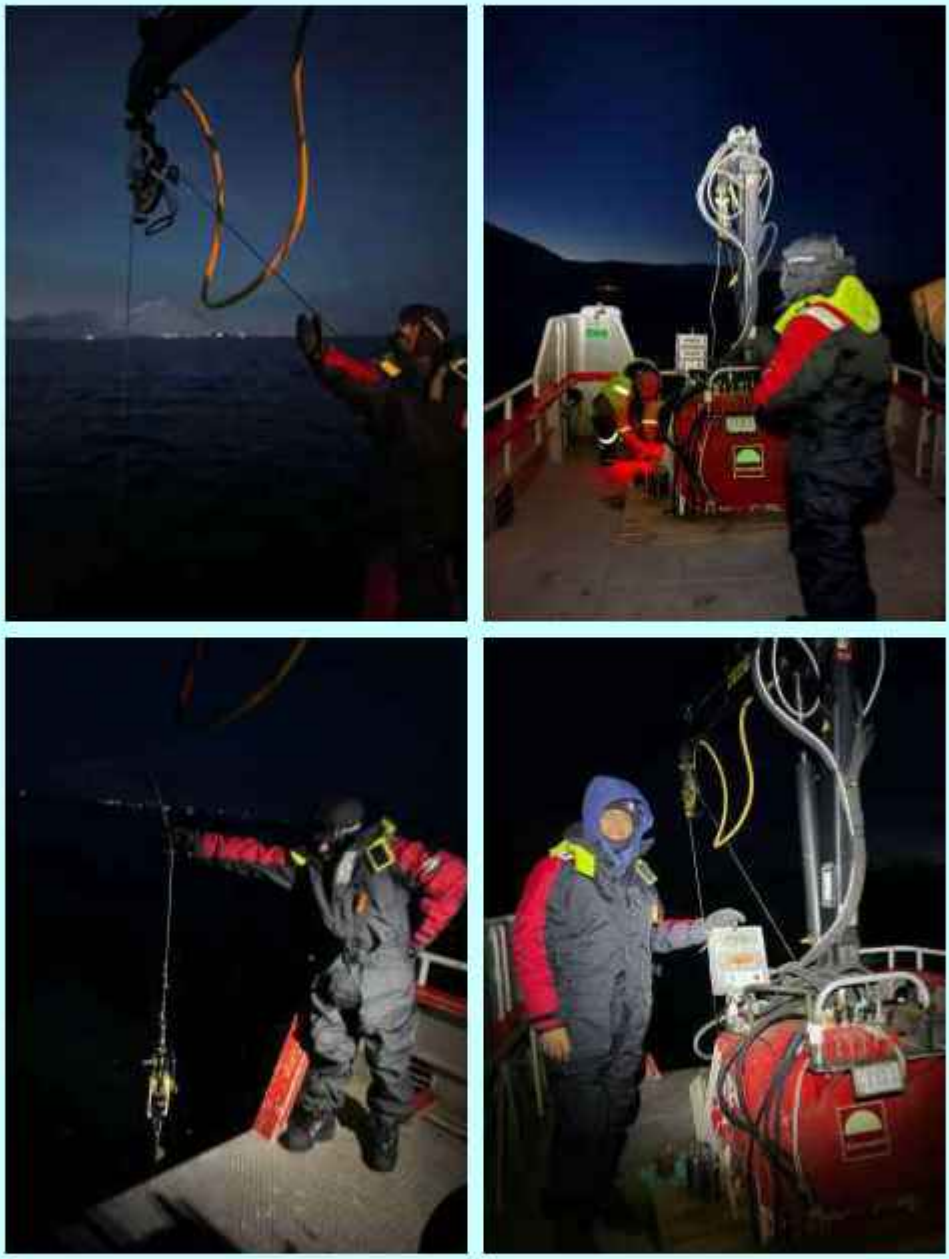
During the year, many scientists and academicians from India and abroad have contributed as external experts in the various committees in the ongoing activities and programmes of MoES. The Ministry extends its gratitude to all those who have provided their enormous support in both administrative and 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.

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 Mission National Steering Committee (NSC), Chaired by Hon'ble Cabinet Minister MoES, Sh. Kiren Rijiju.
2. Deep Ocean Council (DOC) Chaired by Prof. Ajay Kumar Sood, Principal Scientific Adviser to the Govt. of India.
3. Deep Ocean Mission Project Appraisal & Monitoring Committee (PAMC)-DOM- Chaired by Dr. Shailesh Nayak, Director NIAS, Bangalore.
4. Program Advisory and Monitoring Committee (PAMC) on Atmospheric Sciences chaired by Dr. M. Rajeevan, Vice Chancellor, Atria University, Bengaluru.
5. PAMC on Ocean Science and Resources chaired by Prof Y.V.N. Krishnamurthy, IIST, Thiruvananthapuram
6. PAMC on Hydrology and Cryosphere chaired by Prof Anil Kulkarni, IISc, Bengaluru
7. PAMC on Geosciences and Seismology, chaired by Prof. C.V.R. Murthy, IIT Madras.
8. Technology Research Board for Earth System Science Technology, chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
9. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Marine Ecology and Biology chaired by Prof Dileep Deobagkar, Former VC Goa University, Goa.
10. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Satellite Meteorology, chaired by AVM (Dr) Ajit Tyagi, Former DG, IMD.
11. Scientific Steering Committee for Earth Science & Technology Cell (ESTC) on Coastal Ocean Technology, chaired by Prof. V. Sundar, IIT Madras
12. Scientific Steering Committee for Inter-disciplinary Projects of Earth Sciences (IDES), chaired by Dr K. J. Ramesh, Former DG, IMD
13. Research Advisory Committee of IITM chaired by Dr. L.S. Rathore, Former DG, IMD
14. Research Advisory Committee of NCMRWF chaired by Prof. J. Srinivasan, IISc, Bengaluru

ivasan, IISc, Bengaluru

15. Research Advisory Committee of INCOIS chaired by Dr. Satish Shetye, Former Director, NIO, Goa
16. Scientific Advisory Council of NIOT chaired by Dr P.S. Goel, National Institute of Advanced Studies, Bengaluru.
17. Research Advisory Committee of NCCR chaired by Dr. Shailesh Nayak, Director, NIAS.
18. Research Advisory Committee of CMLRE chaired by Prof. T. Balasubramanian, Vice Chancellor, Chettinad Academy of Research and Science, Chennai.
19. Research Advisory Council of NCPOR, chaired by Dr. Shailesh Nayak, Director, NIAS.
20. Research Advisory Council of NCESS chaired by Prof Talat Ahmad, Vice Chancellor, University of Kashmir.
21. Scientific Review and Monitoring Committee, Monsoon Mission chaired by Prof Ravi Nanjundiah
22. Scientific Advisory Committee of BGRL chaired by Dr. Shailesh Nayak, Director, NIAS.



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