सत्यमेव जयते

Government of India
Ministry of Earth Sciences

ANNUAL REPORT

2022-2023

FRONT COVER

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X-Band Doppler Weather Radar Commissioned at Surkanda Devi Uttarakhand

BACK COVER

Doppler Weather Radar network of India Meteorological Department

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Chapter – 1

OVERVIEW

Earth System Science deals with all the five components of the Earth System, viz., Atmosphere, Hydrosphere, Cryosphere, Lithosphere and Biosphere and their complex interactions. The Ministry of Earth Sciences (MoES) holistically addresses all the aspects relating the Earth System Science for providing weather, climate, ocean, coastal state, hydrological and seismological services. The services include forecasts and warnings for various natural disasters like tropical cyclones, storm surge, floods, heat waves, thunderstorm and lightning; alerts for Tsunamis and monitoring of earthquakes etc. In addition, the ministry also has the mandate of making ocean survey and exploration for living and non-living resources and exploration of all the three poles (Arctic, Antarctic and Himalayas). The services provided by the ministry are being effectively used by different agencies and state governments for saving human lives and minimizing damages due to natural disasters. Several new application areas have been identified for providing weather forecasts like the Renewable Energy sector. Several major milestones have been accomplished under the six major programs of the MoES during the last year, which are illustrated below:

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

- Accurate and timely prediction of tropical cyclones Asani and Sitrang combined with fieldwork by disaster management agencies, that helped save thousands of precious lives of countrymen.
- Six Doppler Weather Radars (DWRs) have been commissioned at chennai, Leh, Aayanagar (Delhi), Mumbai, Surkanda Devi (Uttarakhand) & Banihal Top (J&K) taking the total number of DWRs to 35.
- Integration of Landslide Susceptibility Module into Flash Flood Guidance System for better predictability of landslide associated flash floods in the vulnerable hilly regions of Indian Subcontinent has been completed for Rudraprayag district of Uttarakhand and Wayanad district of Kerala jointly by GSI, NRSC, IMD and HRC.
- Conventional agromet observatory has been installed at Agromet Field Unit Port Blair, Andaman & Nicobar Islands to enhance weather observations and use in the Agromet Advisories under GKMS scheme.
- Agro-AWSs have been installed at 21 more stations in the premises of Krishi Vigyan Kendras (KVKs) to complete installation of a total of 200 Agro-AWSs in the first phase.
- Farmers' Awareness Programme (FAPs): FAPs organized at 713 locations so far by September 2022 by Agromet Field Units (AMFUs) and District Agromet Unit (DAMUs).
- INSAT-3D/3DR calibration campaigns have been conducted in Great Rann of Kutchh. It was a Joint Campaign with Space Applications Centre (ISRO), Ahmadabad.
- Latest version of Polar WRF model has been operationalized to provide day-to-day 72 hours weather forecast at 3 km resolution for the Maitri and Bharati region in the Antarctica. NWP products are routinely made available on.
- Installation of indigenous RS/RW System on 10 IMD stations has been completed.
- 05 Pilot Balloon stations out of 63 PB stations have been upgraded to automatic GPS PB stations and these PB systems are indigenous and manufactured/assembled in IMD Delhi.
- Installation of indigenous GPS PB system on 18 PB stations out of 20 PB stations has been completed
- IMD has augmented the surface observation network with AWS and established a network of 806 AWS all over India.
- Under 400 AWS Project, 99 AWS have been

installed (71 AWS are installed in Kerala state, 21 AWS installed in NE states and 7 AWS installed in Andhra Pradesh) in 2022.

- IMD has augmented the rainfall observation network with ARGs in Urban areas and established a network of 1382 ARGs all over India.
- IMD has augmented 52 ARG network in Mumbai, Kolkata, Chennai, Pune, Guwahati, Agartala and Shillong in 2021-2022.
- IITM high-resolution global forecast Model (HGFM) was inaugurated on the 60th foundation day of IITM on 17th November 2022.
- A Dual-polarimetric C-band Doppler Weather Radar was commissioned in the Atmospheric research tested facility in Bhopal recently for detailed precipitation process studies in the core monsoon zone.
- For the first time National Centre for Medium Range Weather Forecasting (NCMRWF) has started assimilating satellite observations from commercial satellite operators, viz SPIRE & Geo-Optics (GNSS-RO observations) from this year.
- For verifying the model forecasts, a new merged rainfall product - Multi-Ensemble Rainfall Analysis (MERA) has been developed in research phase. This product has a spatial resolution of 4 km, and temporal resolution is of 1 hour and involves satellite rainfall products from GPM-IMERG, GSMAP, INSAT, and that of from Indian radar network.
- New version of regional Unified Model (RA3) was implemented at 1.5km and 4km resolutions. The upgradation incorporated some new capabilities like improved microphysics with more interactive cloud-aerosol processes and the cloud generation scheme which accounts for improved entrainment at the top of the boundary layer. The lightning parameterization scheme was also re-tuned to improve the coverage and extreme weather signals for enhanced lightning forecast potential over India.
- The Tropical Cyclone (TC) tracker has been upgraded and implemented on the forecast of NCMRWF Regional Ensemble Prediction System (NEPS-R). The TC tracker provides strike probability forecast and animation of probabilistic TC movement.
- A new version of DAMINI- Mobile App for Lightning alerts has been released during IITM Diamond Jubilee Foundation day celebrations on 17th November 2022. This upgraded version allows user to receive warning in any one of the 15 languages (ENGLISH, HINDI, ASSAME, BENGALI, GUJARATI, KASHMIRI, ,KANNADA, KONKANI, MALAYALAM, MARATHI, ORIYA, PUNJABI, TAMIL, TELUGU AND URDU).
- Field campaign was conducted for 'Demonstration of Fixed wing UAV systems for atmospheric research purpose'. UAV flights beyond visual line of sight for profiling atmospheric boundary layer for the first time in India, were conducted at different airfields successfully in coordination with Airport Authority of India (AAI) and Air Traffic Control (ATC).
- Sodar and Compact weather sensor are installed at SGU campus under a MoU between IITM and Sanjay Ghodawat University (SGU), Kolhapur (Maharashtra).

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

- Indian National Centre for Ocean Information Services (INCOIS) continued to provide its flagship service of advisories on the Potential Fishing Zones (PFZ), which were disseminated in smart map and text form on daily basis, except during fishing-ban period and during adverse sea-state conditions.
- An Earth System Science Data Portal (ESSDP) of MoES (https://incois.gov.in/essdp) hosts about 1050 metadata records of data collected and maintained under different programs

implemented by MoES over the years and link them to the respective data centres.

- The underwater mining system was deployed from ORV Sagar Nidhi (Fig. 3. 17 a) and Seabed locomotion trials of the experimental undercarriage system of underwater mining system (Varaha-I and II) was successfully undertaken over a distance of 120m on water-saturated soft soil at 5270 m depth in the Central Indian Ocean (CIO).
- Two gliders were deployed in the Bay of Bengal to monitor the deep ocean physical and biogeochemical parameters with special emphasis to understand the temporal and spatial variability of the Oxygen Minimum Zone (OMZ). Both the gliders, after covering 5000 km distance, are recovered and collected data was retrieved.
- The Joint OMNI-RAMA Indian Ocean Data Portal developed by INCOIS jointly with NIOT and PMEL-NOAA was launched.
- An Indian patent has been granted for the invention titled 'REAL TIME TSUNAMI MONITORING SYSTEM', patent No. 369964. Six Indigenous Ocean observation technologies developed and has been successfully transferred to M/s L&T for commercialisation.
- A water quality buoy deployed by National Centre for Coastal Research (NCCR) in the coastal water off Puducherry at 10m depth (~1.5 km from the coast) was dedicated to the nation the Chief Minister of Puducherry. This is an automated water quality buoy fitted with sensors to monitor the variations in the water quality and productivity of the coastal waters. The real time water quality data will be disseminated through web-based forecasting system and a mobile app "clean coast" at every 20 minutes interval.
- Under the Resource Exploration and Inventorization System (REIS) programme taxonomic studies of samples collected on-board FORV Sagar Sampada within the Indian Exclusive Economic Zone (EEZ) yielded six new species of decapod crustaceans, one new species of polycheate and two species of deeps eels.

1.3 Polar and Cryosphere Research (PACER)

- The 42nd Indian Scientific Expedition to Antarctica was successfully launched from National Centre for Polar and Ocean Research (NCPOR), Goa.
- Glaciological field campaigns have been carried out for six glaciers during May to October 2022 covering total glacierized area of ~300 km^2.
- India is developing POLarAERosolNETwork (POLAERNET) for long-term and continuous observations of aerosols over the polar (Arctic,Antarctic and Himalayan) regions

1.4 Seismology and Geoscience Research (SAGE)

- The Existing National Seismological Network has now been strengthened to 152 stations to improve the operational capability to detect any earthquake of M:3.0 or above in most parts of the country
- During the period January-December 2022, a total of 1304 earthquakes were located and reported (Fig 5.2). Out of these earthquakes, 32 events are of magnitude M:6.0 and above, and 51 events are of magnitude M:5.0 and above.
- The seismic microzonation work of four cities, Bhubaneswar, Chennai, Coimbatore and Mangalore, is at advanced stage of completion and work related to eight more cities (Patna, Meerut, Amritsar, Agra, Varanasi, Lucknow, Kanpur and Dhanbad) has been started and various Geophysical & Geotechnical surveys are in progress.
- Under the Scientific Deep Drilling project in the Koyna Intraplate Seismic Zone, Maharashtra, the evidence of deep-water percolation in the Koyna Seismogenic Zone has been established with several damage zones being delineated between 2 and 3 km in the Koyna pilot borehole

based on the physical and mechanical properties of the rock formations.

- Under the national network project, Submarine Ground Water Discharge (SGD), National Centre for Earth Science Studies (NCESS) has estimated SGD flux from three coastal catchments of southwest coastal zone of India through aquifer modelling technique. There are nine critical zones with a total shore length of 106.5 km, out of 640km surveyed, in the SW coastal zone having SGD signatures
- NCESS developed a MATLAB-based inversion program, b-spline polynomial approximation using the differential evolution algorithm (SPODEA), to recover the concealed basement geometry under heterogeneous sedimentary basins

1.5 REACHOUT

- During the current financial year, a total number of 32 research proposals from various academic/research organizations and universities have been sanctioned
- The International Training Centre for Operational Oceanography (ITCOocean) established at INCOIS, Hyderabad a UNESCO Category 2 Centre, had trained 108 foreign nationals from Indian Ocean RIM countries till now. Till December 2022, 10 training courses, 1 webinar and 1 seminar were conducted. A total of 532 persons (Male: 315, Female: 207) were trained of which 424 are from India and 108 from other countries.
- Following up The Hon'ble Prime Minister's announcement of India's readiness to contribute 3 million dollars for restarting the work of BCWC at the 5th BIMSTEC Summit on 30 March 2022, BCWC at NCMRWF organized its 2nd GB and SAC meetings during 01-03 November 2022 in coordination with Ministry of External Affairs, Government of India and BIMSTEC Secretariat, Dhaka. The representatives from all the BIMSTEC member nations NHMs and BIMSTEC Secretariat participated in these meetings.
- An AI/ML virtual training workshop was organised on 9th and 10th May 2022, for scientists/students of MoES institutes, by the AI/ML virtual centre of MoES in collaboration with the DESK program of MoES.
- Under the Development of Skilled Manpower in Earth System Sciences (DESK) a National Training Workshop on Fundamentals of Data Assimilation (NTDA) was conducted from 9th to 21st September, 2022. About 50 participants attended the training workshop, and 9 resource persons gave training on both theory and hands-on practical.
- E-resources subscribed under DERCON (Digital Earth Sciences Consortium) in 2022 were made available to scientists and employees of MoES institutes through KRCNET
- Coastal clean-up programs are conducted at regular intervals as a part of the "Clean Seas Program (Swachha Sagar)" to create awareness on marine litter. In the context of "Azadi Ka Amrit Mahotsav", MoES launched the "Swachh Sagar, Surakshit Sagar" campaign to clean-up India beaches all across India and raise awareness about the importance of a Clean and Safe Sea.
- A total number of 75 beaches covering the entire Indian coast were identified for creating awareness among the beach visitors, fishing communities, other coastal stake holders and general public on the ill effects of beach litter on the marine environments (Fig.3.11). About 58,100 volunteers participated and collected a total of 64,714 kg marine litter from the coastal areas.

1.6 Deep Ocean Mission

- Polymetallic Nodule (PMN) collection and local pumping trials, by a self-propelled mining system - Deep Sea Miner, is planned during early-2023 at the International Seabed Authority's contracted Area in the Central Indian Ocean (CIO).

- Preliminary design for the development of a 6000m depth-rated manned Submersible capable of carrying 3 persons with an operating duration of 12h and emergency endurance of 96h is completed and detailed design is underway.
- A human acclimatization test in a shallow water sphere was conducted with three personnel for 2 hours at 7 m depth of ATF, NIOT with the measurement of human health parameters.
- For wave climate projections, a wave model based on WAVEWATCHIII (WWIII) - V6.0.7 for the Indian Ocean has been configured.

1.7 International Collaborations

- MoES regularly partners with international institutes for scientific collaboration in all fields related to earth sciences to broaden the scope of research through trans-national joint projects and joint developmental work.
- A Roadmap on the Blue Economy and Ocean Governance has been agreed upon between India and France to promote their bilateral exchanges. The Preparatory meeting of the Blue Economy and Ocean governance Dialogue between India and France was held in Paris at the Headquarters of the French Ministry of Foreign Affair on 13 June 2022 which was attended by Secretary, MoES and the French Ambassador for Poles and Maritime Affairs.
- A Memorandum of Understanding between Indian National Center for Ocean Information Services (INCOIS) and Ministry of Fisheries, Marine Resources and Agriculture of the Republic of Maldives was signed on 2nd August 2022. Under the MoU, it is proposed to collaborate through capacity building, data and technical expertise sharing to develop integrated potential fishing zone forecasting capabilities for the Maldives and to establish a formal mechanism for capacity building trainings at INCOIS for the official and scientist of Maldives.
- An Indian Delegation was led by Hon'ble Minister of Earth Sciences (I/C) Dr. Jitendra Singh, Secretary, MoES and members from Department of Fisheries, MEA participated in the 2nd UN Ocean Conference from 27th June to 1st July, 2022 at Lisbon, Portugal. The overarching theme of the Conference was "Scaling up ocean action based on science and innovation for the implementation of Goal 14: stocktaking, partnerships and solutions".
- India is participating in the Belmont Forum, Future Earth and JPI Oceans co-branded CRA on "Transdisciplinary Research for Ocean Sustainability" proposed by FORMAS, Sweden and MoES is supporting component of the project "Coastal Ocean Assessment for Sustainability and Transformation (COAST Card)" to be implemented by NIO, Goa under this CRA. First international meeting and workshop on COAST Card is scheduled to be held at Manila, Phillippines from 27 Feb to 3rd March 2023.
- The 14th RIMES Council Meeting, was held in Bangkok, Thailand from 11 to 12 November 2022. The meeting was presided by Dr. Ravichandran, Secretary, Ministry of Earth Sciences, Government of India, and RIMES Council Chair.
- Bimstec Centre for weather and climate (BCWC) at NCMRWF organized its 2nd GB and SAC meetings during 01-03 November 2022 in coordination with Ministry of External Affairs, Government of India and BIMSTEC Secretariat, Dhaka.
- Under the Cooperation with Natural Environment Research Council (NERC), UK, the progress of all Air Pollution and Human Health (APHH) projects were reviewed during the Internal Science Meeting held on 19th to 20th May 2022 conducted by the APHH Secretariat.
- MoES is spear heading the 'Oceanic Track' under the Environment, Climate & Sustainability Gorking Group of the G-20 Forum in partnership with MoEF&CC.

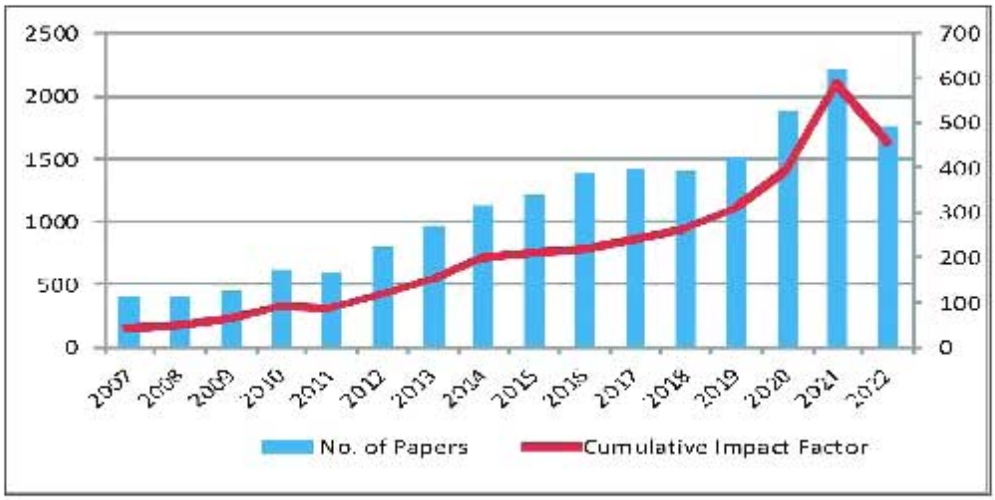
- **In addition, MoES is also organizing a side event as a part of the 'Research & Innovation initiatives gathering of G-20, under the theme "Scientific Challenges & Opportunities for a Sustainable Blue Economy".**

1.8 Scientific Publications

A total number of 491 research papers were published during 2022 by MoES scientists under various programs of the Ministry, and the total Impact factor is 1621.1 (Fig. 1.1). The average Impact factor of research papers was 3.30.

1.9 Budget Expenditure:

The total outlay for the Ministry for the year 2022-23 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	1597.69	1547.73
2018-19	1800.00	1800.00	1745.63
2019-20	1901.76	1809.74	1722.59
2020-21	2070.00	1300.00	1285.76
2021-22	1897.13	2369.54	2194.39
2022-23	**2653.51**	**2056.47**	**1336.96***

***As on 31/01/2023**

Chapter 2

ATMOSPHERE AND CLIMATE RESEARCH, OBSERVATIONS, SCIENCE AND SERVICES (ACROSS)

2.1 Introduction

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

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

2.1.1 Atmospheric Research Testbed (ART) facility in central India

The ART program is a highly focused observational and analytical research effort for understanding the physical processes. It will help compare observations with model forecasts and simulations in the interest of accelerating improvements in both observational methodology and monsoon prediction models. Various types of sophisticated scientific instrumentation are being augmented at the ART facility at Silkheda village inSehore District of Madhya Pradesh. Apart from the Dual-polarimetric C-band radar, other observing systems for clouds and precipitation such as Microwave radiometric profiler, Ceilometer, Impact disdrometer, micro rain radar have also been deployed and observational campaign was conducted during the monsoon season (**Figure 2.1**).

Fig. 2.1. Measurement facilities for observing clouds and precipitation deployed at ART facility.

2.2 Modelling work at NCMRWF

2.2.1 Global Observations and Data Assimilation

The NCMRWF Data Assimilation (DA) system makes continuous efforts to include new observations for improving the initial conditions and its forecast quality. In this direction, HRPT data from two Indian stations, Integrated Precipitable Water (IPW) over Japan, and for the first time satellite observations from commercial satellite operators, viz SPIRE & Geo-Optics (GNSS-RO observations) have been used in assimilation from this year.

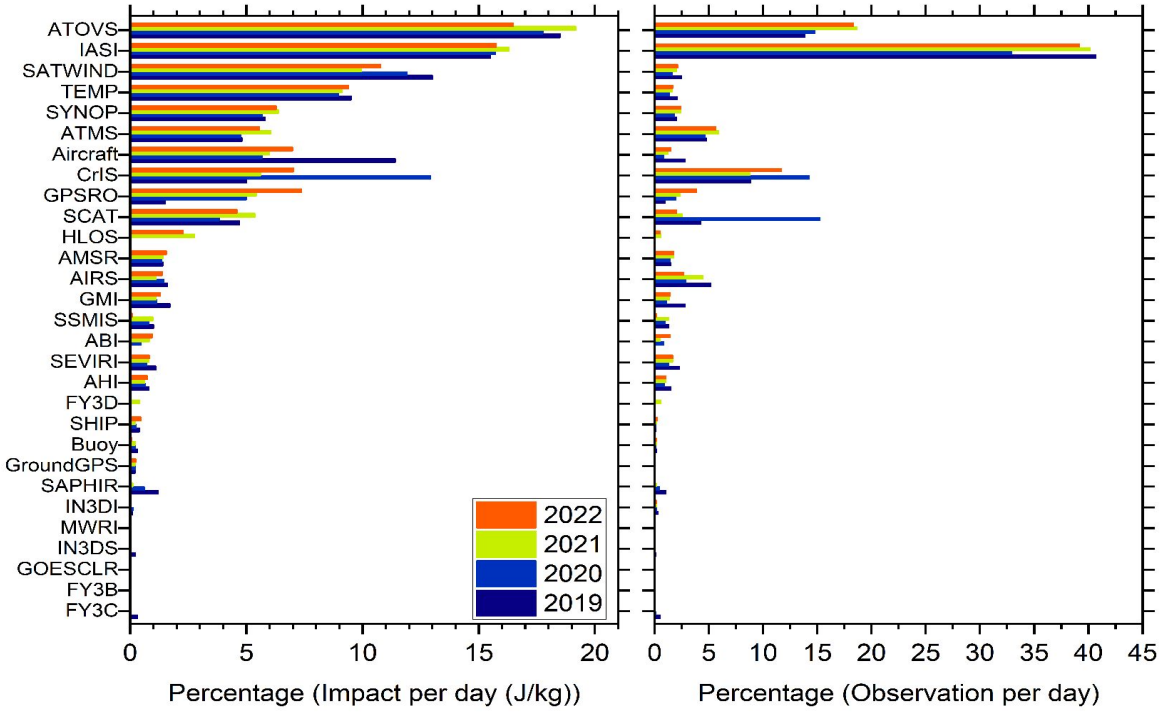


Fig. 2.2. (left) A comparison of the impact of relative contribution of various types of observation on 24 hr forecast during summer monsoon period of 2022, 2021, 2020 and 2019 corresponding (right) Number of observations assimilated

The impact of observations is continuously evaluated through Observations System Experiments (OSE) and through Forecast Sensitivity to Observation Impact (FSOI). Figure 2.2 depicts a comparison of the impact of relative contribution of various types of observations on 24 hours forecast during this year and compares it to that of the same period for last three years. It clearly shows increase of impact of satellite data sets than that of conventional observations

For verifying the model forecasts, a new merged rainfall product - Multi-Ensemble Rainfall Analysis (MERA) has been developed in research phase. This product has a spatial resolution of 4 km, and temporal resolution is of 1 hour and involves satellite rainfall products from GPM-IMERG, GSMAP, INSAT, and that from Indian radar network. The merged product was initially evaluated using the 25 km NCMRWF-IMD merged product. The final testing is being carried out by utilizing the quality-controlled daily rain fall from rain gauges. The MERA product is currently available in the domain as shown in figure 2.3(a). This product has been developed in collaboration with Australia's Bureau of Meteorology (BOM) and Australian National University (ANU). A sample plot showing the rainfall bands during monsoon on 13th June 2022 are shown in figure 2.3(b)-2.3(d). The figure 2.3b

shows the daily accumulated blended satellite and radar product and figure 2.3(c) shows the IMD-NCMRWF daily accumulated merged gauge-satellite product and figure 2.3(d) is the IMD gauge gridded product at 25 km. Figure 4b which is the daily ensemble product shows finer details of rainfall over the north-eastern states, Gujarat, East coast as well as west coast region.

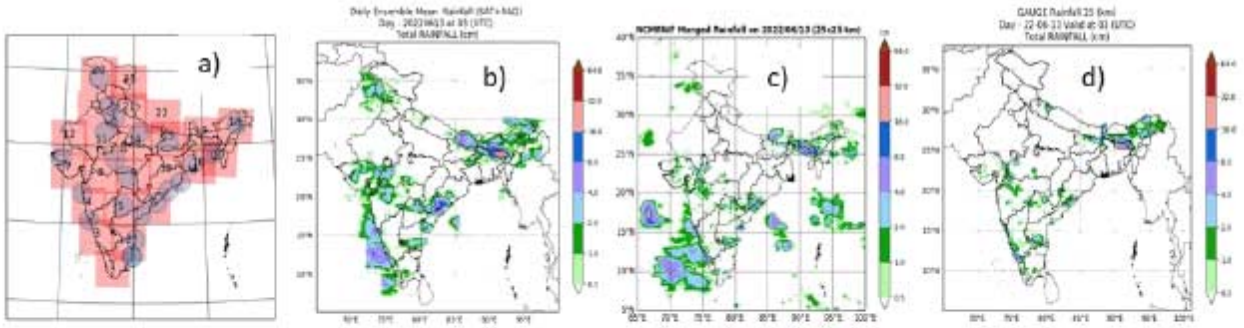


Fig 2.3. (a) Indian domain showing the division of tiles and the radar coverage area and a comparison plot showing (b) the merged satellite and radar rainfall using multi-ensemble method (c) IMD-NCMRWF merged rainfall at a resolution of 25 km (d) IMD gridded gauge data at a resolution of 25 km on 13 June, 2022.

2.2.2 NCUM Experimental Coupled global assimilation-forecast system for NWP

Coupled atmosphere-Land-Ocean-Sea Ice modelling systems have long been used for seasonal forecasting and climate prediction. However more recently evidence has been emerging that even on short timescales the interactions between ocean and atmosphere can be important and can improve the numerical weather prediction. A newly developed coupled global NWP system under the "UM Partnership" is being tested at NCMRWF. The new NWP system with coupled DA at NCMRWF is a major milestone in the progress of NWP in India. Salient features of the Coupled NWP system (Table 2.1) and the initial results (Figure 2.4) are presented here.

Model	Data Assimilation-Atmosphere	Data Assimilation – Land Surface	Data Assimilation-Ocean & Sea Ice
Model: Unified Model; Domain: Global Horizontal Resolution:10 km Vertical levels: 70 levels (model top at 80 km) Time step: 4 min.	Method: Incremental 4D-Var Observations assimilated: Observations received from GTS and various other sources (NOAA/NESDIS, EUMETSAT, ISRO etc.)	Soil Moisture analysis: Method: Simplified Extended Kalman Filter Observations assimilated: ASCAT soil wetness observations, Screen Temperature and Humidity increments.	Model: NEMO Resolution: ¼° quasi-isotropic resolution Vertical Levels: 75 levels in the vertical. Time step: 20-min (NEMO+CICE) Assimilation method: 3D-Var FGAT (NEMOVAR)
In coupled simulations the atmosphere and land components exchange information with the ocean and sea ice components via the OASIS3 coupler using an hourly coupling frequency			
Science configuration: Global Atmosphere (GA8.0), Global Land (GL9.0), Global Ocean 6.0 (GO6.0) and Global Sea Ice (GSI8.1).			

Table 2.1 Details of the experimental coupled NWP system at NCMRWF

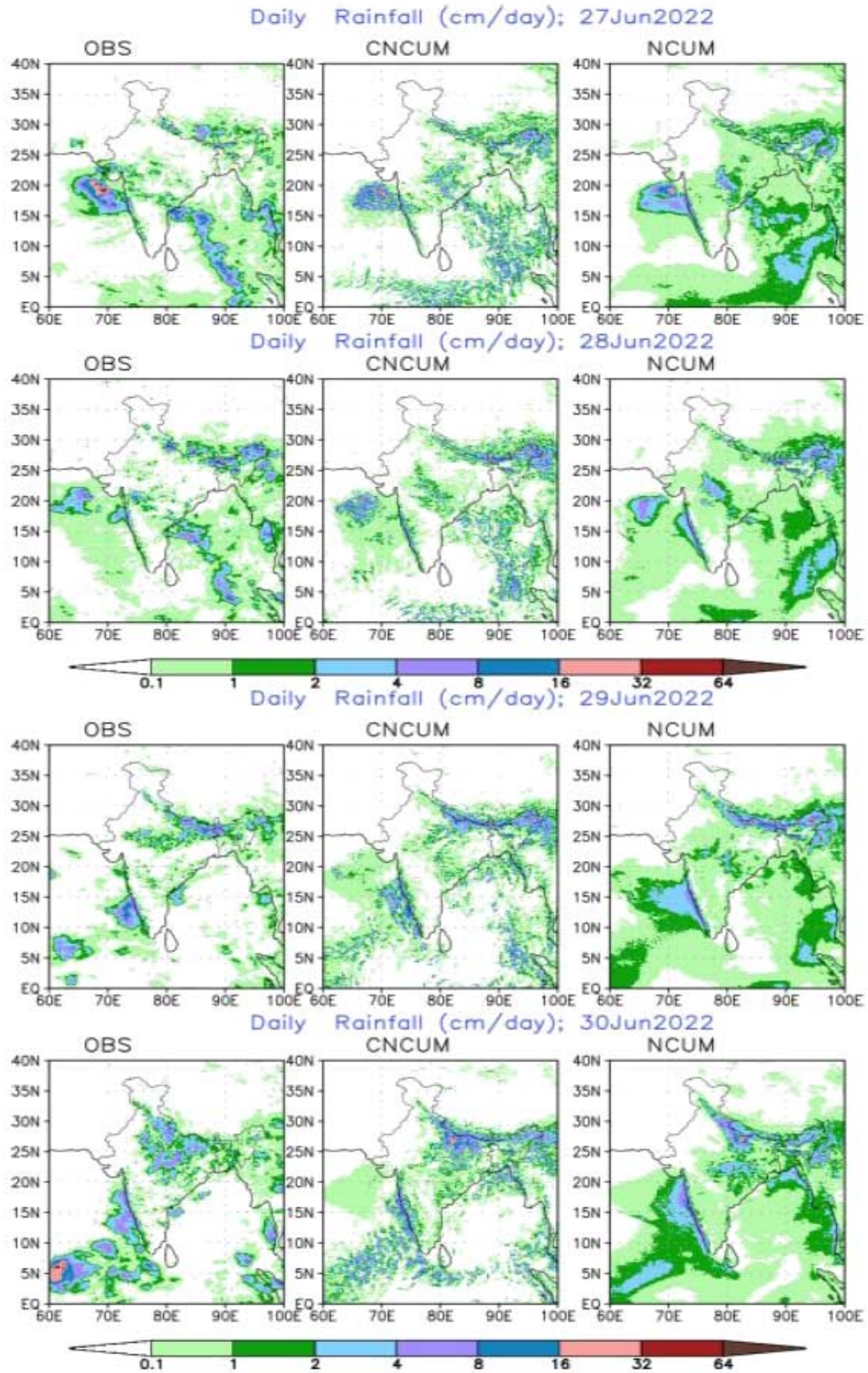


Fig. 2.4 Daily accumulated rainfall forecast based on 00 UTC 26 June 2022 initial condition (analysis). CNCUM is the experimental global coupled NWP system at 10 km horizontal resolution and NCUM is the operational NCUM NWP system of 12 km resolution at NCMRWF.OBS stands for NCMRWF-IMD merged rainfall product.

2.2.3 Global / Regional Modeling

New version of regional Unified Model (RA3) was implemented at 1.5km and 4km resolutions. The upgradation incorporated some new capabilities like improved microphysics with more interactive cloud-aerosol processes and the cloud generation scheme which accounts for improved entrainment at the top of the boundary layer. The lightning parameterization scheme was also re-tuned to improve the coverage and extreme weather signals for enhanced lightning forecast potential over India. Testing of the upgraded model was carried out at 4km resolution by running 45 test cases and found improved rainfall scores compared to the previous version (RA2). The case study of Vayu cyclone was carried out to evaluate the sensitivity of the modifications which resulted in more realistic track of the recurvature, whereas the previous version generated a false warning of landfall at Gujarat coast (Fig. 2.5 shows a comparison of the track of the new version RA3 with old version RA2, observed track OBS and IMDAA reanalysis). The study found that the turbulent generation of water and the secondary ice processes at the mid-troposphere due to the new cloud microphysics schemes changed the heating profile at the mid-troposphere which was instrumental in driving the cyclone motion.

2.2.4. Global /Regional Ensemble Prediction System

The Tropical Cyclone (TC) tracker has been upgraded and implemented on the forecast of NCMRWF Regional Ensemble Prediction System (NEPS-R). The TC tracker provides strike probability forecast and animation of probabilistic TC movement for named and unnamed storms. Figure 2.6 shows the ensemble member tracks (Figure 2.6(a)), strike probability (Figure 2.6(b)) and the storm following meteogram from NEPS-R forecast for the TC 'ASANI' based on initial condition of 00UTC 10 May 2022. The probability of passing the cyclone centre within 120 km from a grid point is depicted in the strike probability. The storm following meteogram provides probabilistic TC intensity forecast in terms of minimum mean sea level pressure and maximum sustained surface wind (at 10 m height) at TC centre.

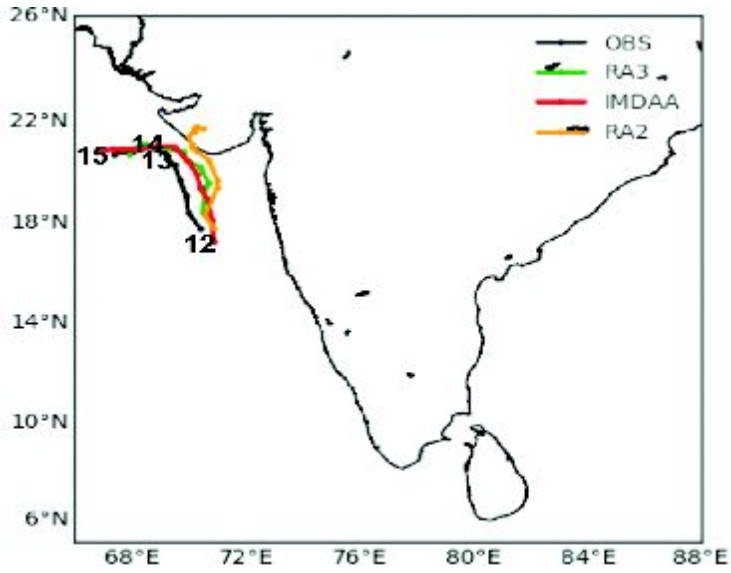


Fig. 2.5 Best track data from IMD (OBS), IMDAA, and forecasts from RA2 and RA3 for TC Vayu from the initial conditions of 00Z, 12 June, 2019.

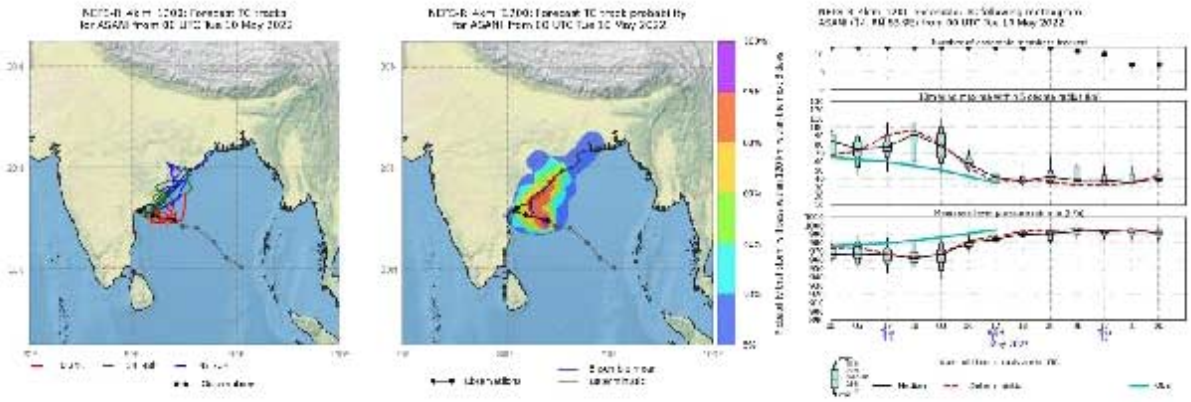


Fig. 2.6 The NEPS-R forecast of (a) ensemble member tracks, (b) strike probability for next 3 days and storm following meteogram for TC 'ASANI' based on initial condition of 00UTC 10 May

2.2.5. Atmospheric Model Verification & Applications

Implementation of NCMRWF Extended Range Drought Monitoring System

Drought is a complicated phenomenon, and the least understood of all "weather and climate extremes". The countries like India where the livelihood of 60% of the population depends on agriculture, drought is one of the most feared natural calamities as it impacts food production, the economy, and the morale of millions of farmers in the country. Hence, we have developed a new drought monitoring system using on a standardized precipitation index (SPI) computed from a multi-week extended range prediction system (NERP) based on the Unified global coupled modelling system that has been implemented for characterizing the droughts on sub-seasonal time scales. A sample chart of the multi-scalar SPI drought over the Indian region is given below. The drought severity is labeled based on the classification defined by the World Meteorological Organization (WMO)

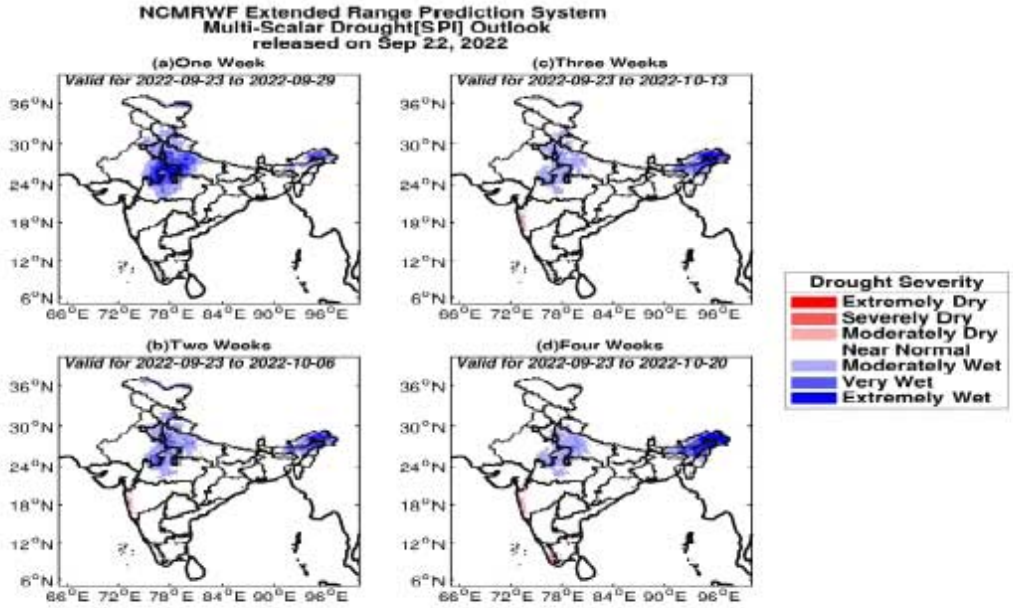


Fig. 2.7 Multi-scalar SPI drought index computed using the NCMRWF extended range prediction system. The drought chart released on 22 September 2022 (and will be updated weekly)

2.2.6 Improved Skill in the NCMRWF model Tropical cyclone forecasts over NIO

A new NCMRWF study documents the improved skill of NCUM-G in forecasting the North Indian Ocean (NIO) TCs during 2015–2019, based on a collection of 1810 forecasts involving 22 TC cases. The study highlights three significant changes in the modelling system during the recent five years, namely (i) increased grid resolution from 17 to 12 km, (ii) use of hybrid 4D-Var data assimilation (DA), and (iii) increased volume of assimilated data. The study results indicate a consistent improvement in the NCUM-G model forecasts during the pre-monsoon (April–May, AM) and post-monsoon (October–December, OND) TC seasons. In addition to a 44% reduction in the initial position error, the study also reports a statistically significant decrease in the direct position error (DPE) and error in the intensity forecast, resulting in a forecast gain of 24 hrs. Comparing NWP models with IMDs official track error shows that NCUM-G and ECMWF model forecasts feature lower DPE than IMD in 2019, particularly at higher (96, 108, and 120 h) lead times.

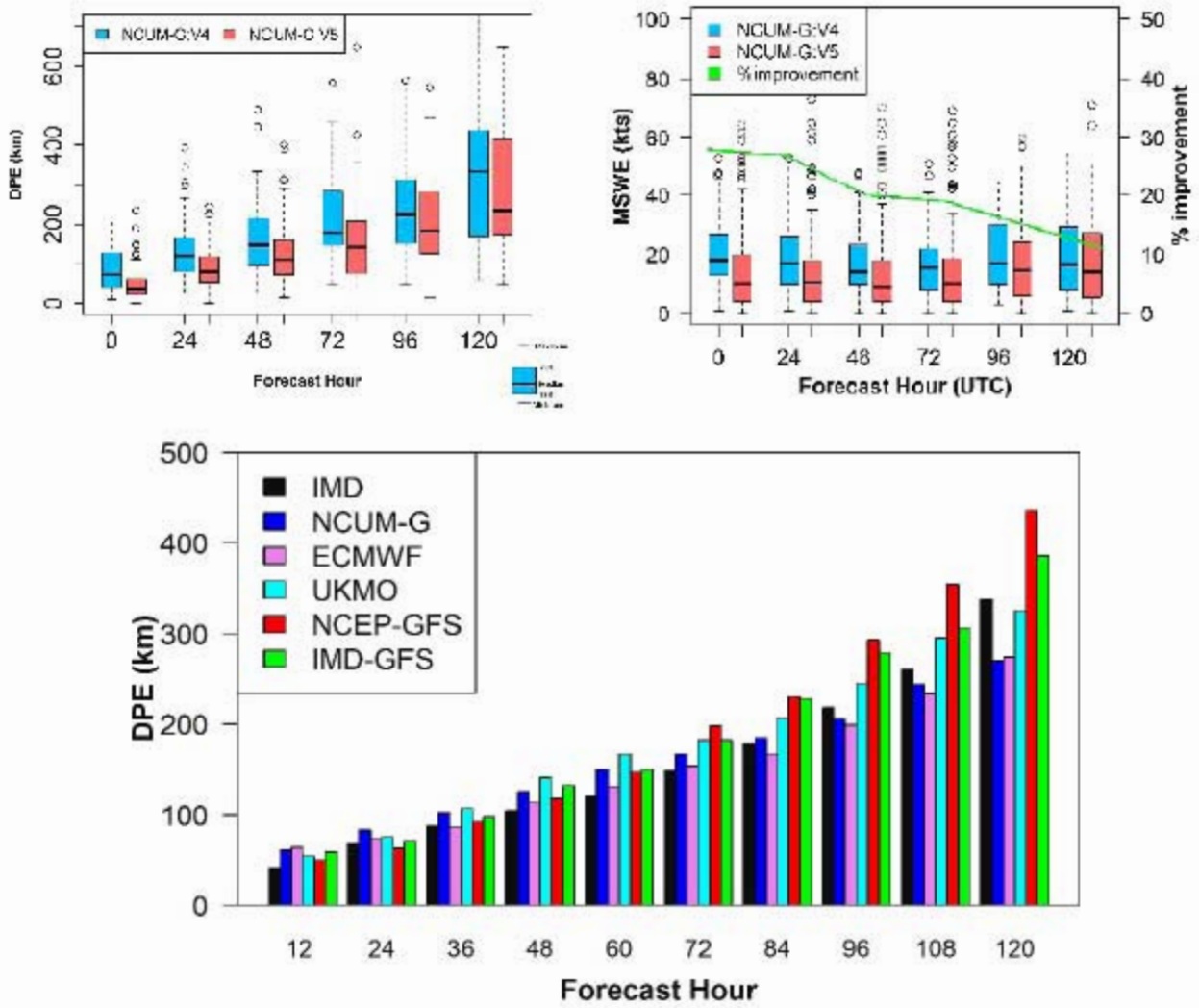


Fig. 2.8 Reduced errors in the tropical cyclone forecast positions (top left), Intensity forecasts (top right). An intercomparison of NCUM-G forecast positions errors with other global NWP centres (bottom).

2.2.7 Ocean Data Assimilation and Forecast System

NCMRWF produces the ocean analysis and forecast using the global NEMO model. In model, the Sea Level Anomaly (SLA) is computed by subtracting the measured Sea Surface Height (SSH) from the long term mean (2016-2021). The SLA is defined by the height of water over the mean sea surface in a given time and region. Figure 2.9 shows the SLA from the NEMO analysis and forecast against the satellite-derived SLA data for 24Oct2022. The satellite-derived SLA data is available from the multimission altimeter data. The cyclone track (IMD best track) is also overlaid. The comparatively small, short-lived eddies circulation is observed in the ocean similar to weather patterns in the atmosphere.

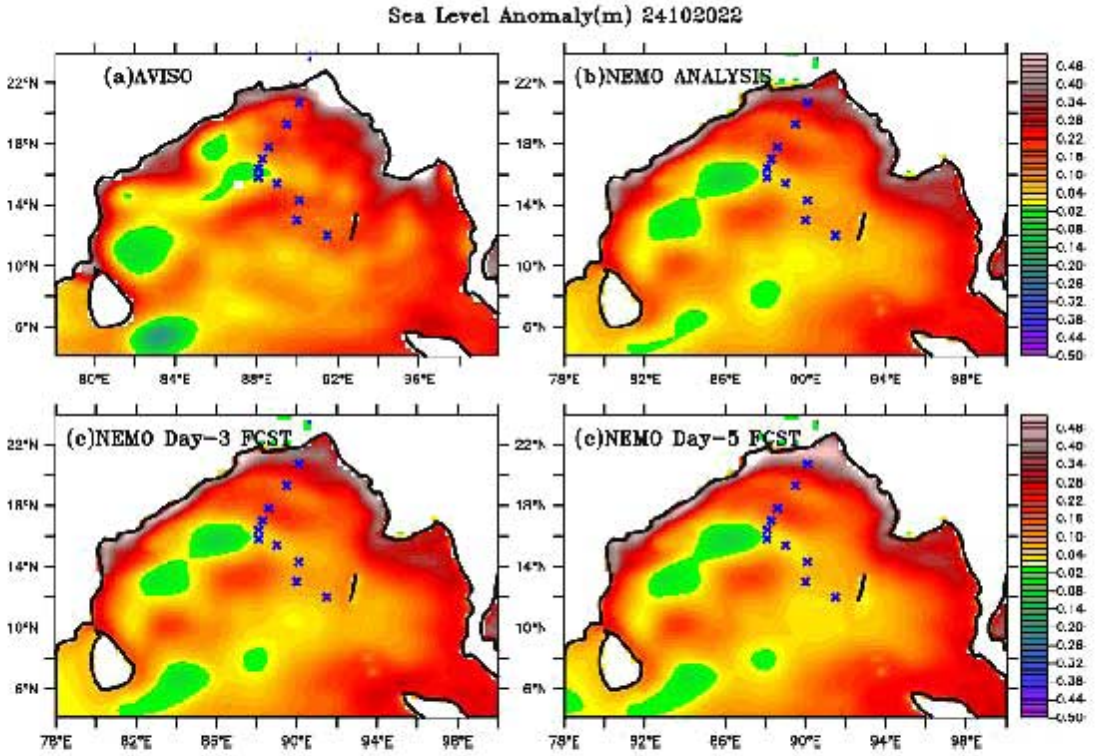


Fig. 2.9 Sea Level Anomaly (SLA) forecast from the NEMO model with respect to the satellite-derived SLA data for 24 Oct 2022. IMD best track is also overlaid.

2.3 Global and Regional modelling at IMD

2.3.1 Global Forecasting System

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

well as satellite observations including radiances from different polar orbiting and geostationary satellites. The real-time outputs are made available to operational weather forecasters and various users through the national web site of IMD. Figure 2.10 shows the forecast and observed heavy rainfall event of 22nd August 2022 during south west monsoon 2022.

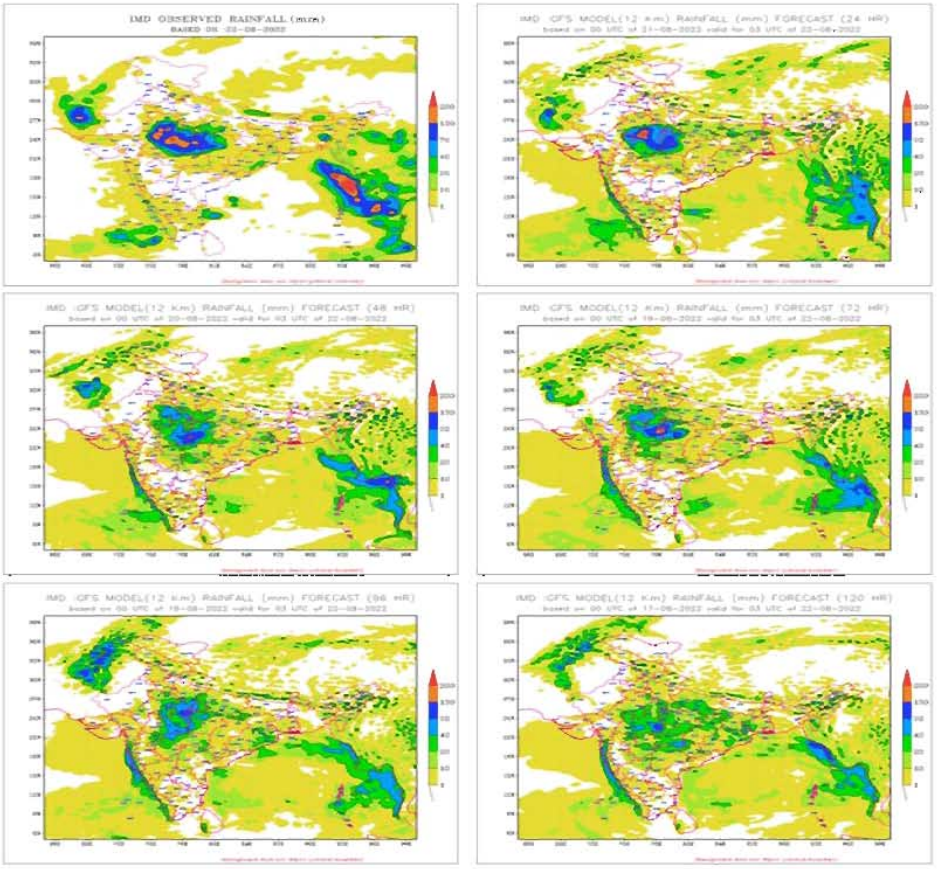


Fig. 2.10 (a) IMD Observed rainfall for 22nd August 2022 and IMD-GFS forecast for (b) 24 hours, (c) 48 hours, (d) 72 hours, (e) 96 hours and (f) 120 hours valid for 22nd August 2022.

2.3.2 Generation of Multimodel Ensemble (MME) forecast for Indian districts

IMD generates location based as well as area averaged forecast from six models also its MME in real time for decision support. The NWP model forecasts available with IMD is of different spatial resolution (Table 2.2).

Table 2.2 Operational Global models

	Operation Models	Agency	Resolution (km)
1.	GFS	IMD	12
2.	GEFS	IMD	12
3.	GFS	NCEP	25
4.	UM	NCMRWF	12
5.	GSM	JMA	25
6.	IFS	ECMWF	20

Five days of the area-averaged forecast of rainfall, maximum temperature, minimum temperature, wind speed, wind direction, relative humidity (at 3 UTC and 12 UTC), and cloud cover from each model is generated for Indian districts, followed by MME-mean forecasts have been generated. Currently, forecast over 734 districts are generated in real time. Over these spatial domains, forecast of rainfall distribution also calculated by estimating the percentage of grids reporting a rainfall amount greater than 2.5 mm/day.

These forecasts are disseminated to the operational forecasters at RMCs and MCs as a decision support while issuing forecast. These forecasts (as digital values) and figures are also available at NWP division's website. The district rainfall forecast from different NWP model and MME are evaluated against IMD observed rainfall during southwest monsoon-2022 and superiority in the performance of MME forecast is observed. A case study is presented in this report to evaluate the performance of MME forecast qualitatively over Indian districts. The extremely heavy rainfall reported at northeast states of India on 16th June 2022 is compared qualitatively with the MME forecast as shown in Fig. 2.11 The extremely heavy rainfall observed at northeast regions are well predicted in MME day 1, day 2 and day 3 forecast. Similar to MME district rainfall forecast met-

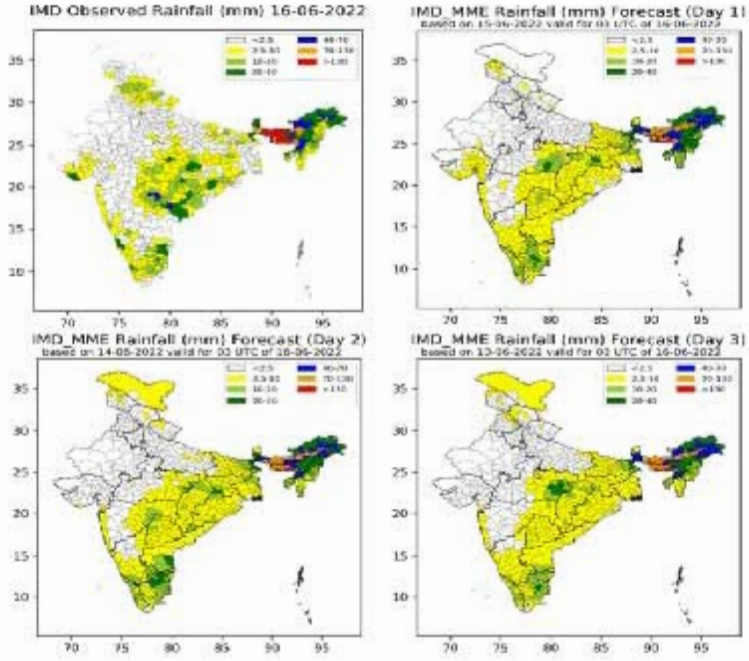


Fig. 2.11 Mean MME Forecasts

subdivision and location specific city forecasts based on MME are also generated in real-time and available at IMD-NWP website.

2.3.3 WRF model

During southwest monsoon season 2022, the WRF model (ARW) delivered hourly forecasts for 3 days at 3 km horizontal resolution updated four times daily at 00, 06, 12 and 18 UTC. The data assimilation component, regional GSI (Global Statistical Interpolation) takes global GFS analysis and all other conventional quality-controlled observations as its input and generates mesoscale (3 km) analysis. The model produced forecasts over a domain spanning about 5°S to 41°N in north-south and 49°E to 102°E in east-west directions respectively. Figure 2.12 represents the performance of the model during monsoon season in terms of categorical skill scores

of rainfalls forecast and spatial correlation coefficient with observed rainfall. The upper row of Fig. 2.12 portrays skill scores (a) critical success index and (b) Gilbert skill scores for different rainfall thresholds whereas lower row exhibits seasonal averaged spatial correlation coefficient for (c) 24 hours, (d) 48 hours and (e) 72 hours rainfall forecasts with observation.

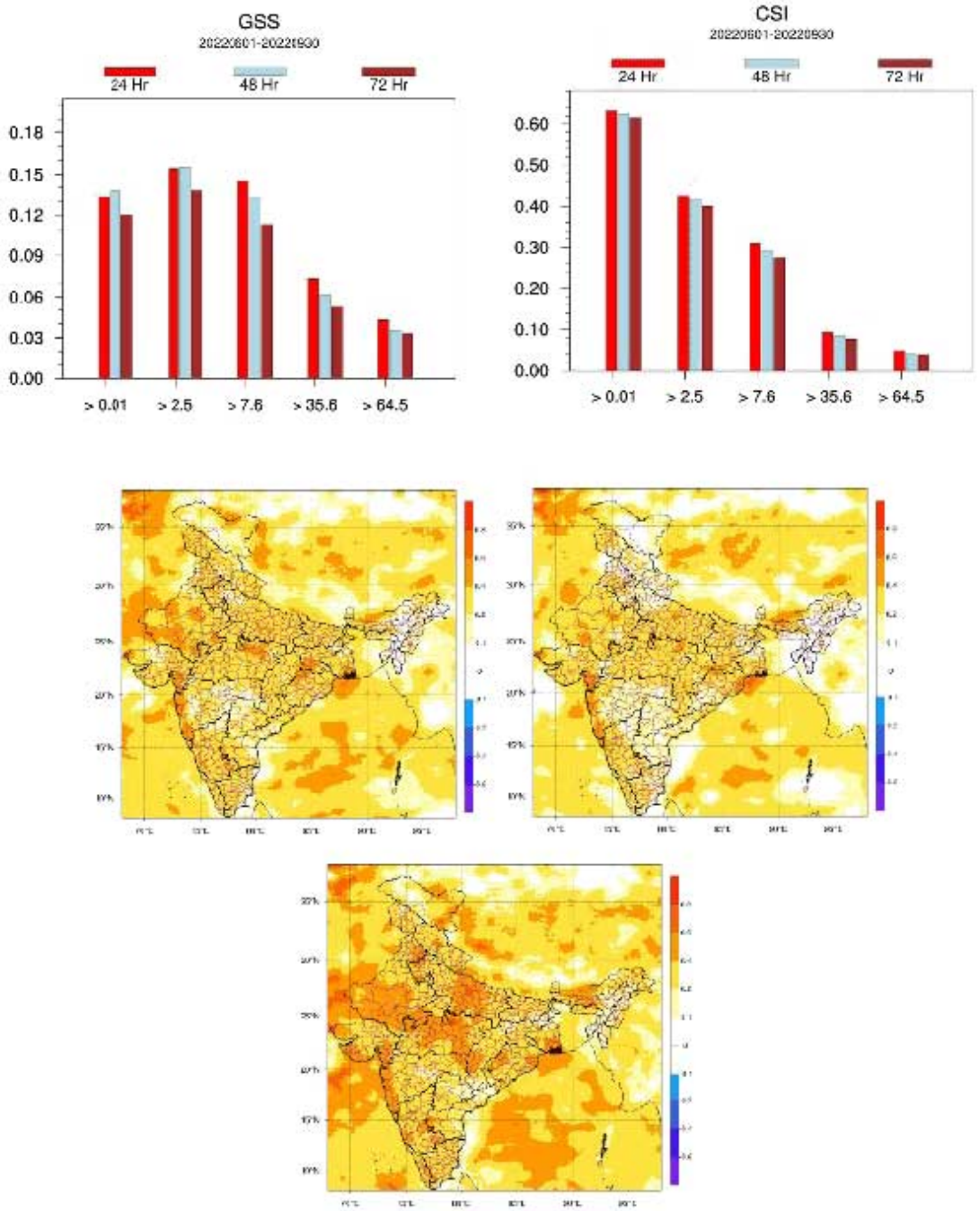


Fig. 2.12 (a) Critical Success Index, (b) Gilbert Skill Score & spatial correlation coefficient averaged over whole southwest monsoon season of 2022 for (c) 24 hours forecast, (d) 48 hours forecast and (e) 72 hours forecast of rainfall.

2.3.4 HWRF-Ocean (HYCOM/POM-TC) coupled model

During pre-monsoon cyclone seasons of 2022, the movable triple nested HWRF-Ocean (HWRF/POM-TC) coupled model with horizontal resolutions of 18 km, 6 km and 2 km delivered five days forecasts four times a day at 00 UTC, 06 UTC, 12 UTC and 18 UTC for tropical cyclone formed over north Indian Ocean (NIO). During pre-monsoon season of 2022 only one Severe Cyclonic Storm ASANI formed over Bay of Bengal. The data assimilation component of HWRF, regional GSI Data Assimilation, generated mesoscale analysis for intermediate and innermost nests which are then merged to generate analysis for all three domains. The model parent domain (18 km horizontal resolution) remained stationary whereas the intermediate domain (6 km horizontal resolution) and the inner most domains (2 km horizontal resolution) moved to track the storm centre. The performance of the model with 3 days lead time is satisfying operational requirements. Figure 2.13 represents the different product generated from operational HWRF-HYCOM coupled model for the Severe Cyclonic Storm (SCS) ASANI during May 2022.

2.3.5 High Resolution Rapid Refresh (HRRR) MODEL

The HRRR model is based on Weather Research and Forecasting (WRF) Model's ARW core and takes the initial and boundary condition from the IMD-GFS global model. Utilising the WRF Data Assimilation system (WRF-DA), the RADAR data is assimilated in HRRR model every 10-15 min over a 1-h period. The HRRR is hourly updated, cloud-resolving, convection-allowing atmospheric model, with horizontal resolution of 2km and provides reflectivity and rainfall forecast for next 12 hours. The HRRR model is run in cyclic mode every hour for

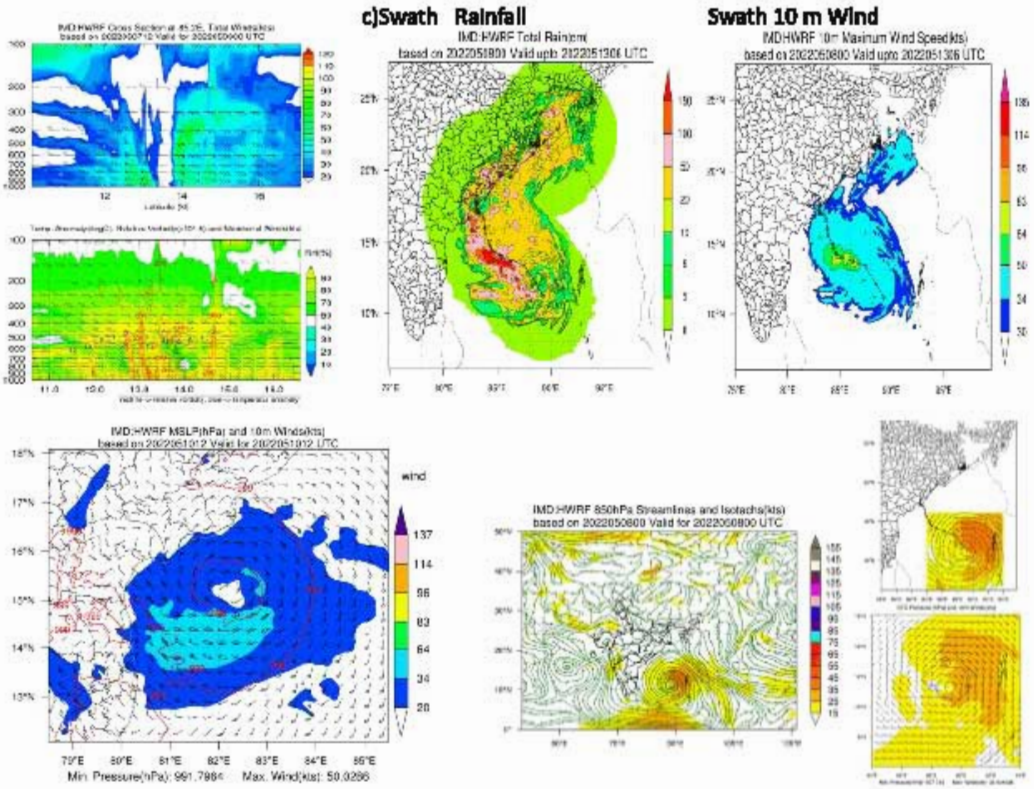


Fig. 2.13 SCS ASANI Zonal Cross-section of (a) Total wind & (b) Humidity and temperature, (c) Swaths of Rainfall & 10 m wind, (d) 10m wind and MSLP of 2 km core domain and (e) Streamlines and Isotachs of combine domain (18x6x2 km).

three domains covering entire mainland of India viz. North-West Domain, East & North-East Domain and South Peninsular India domain and forecast products are updated on the NWP website after every two hours. The forecast product from HRRR model is shown in Figure 2.14.

2.3.6 E-WRF Operationalization

Recently during March 2022, IMD NWP division has

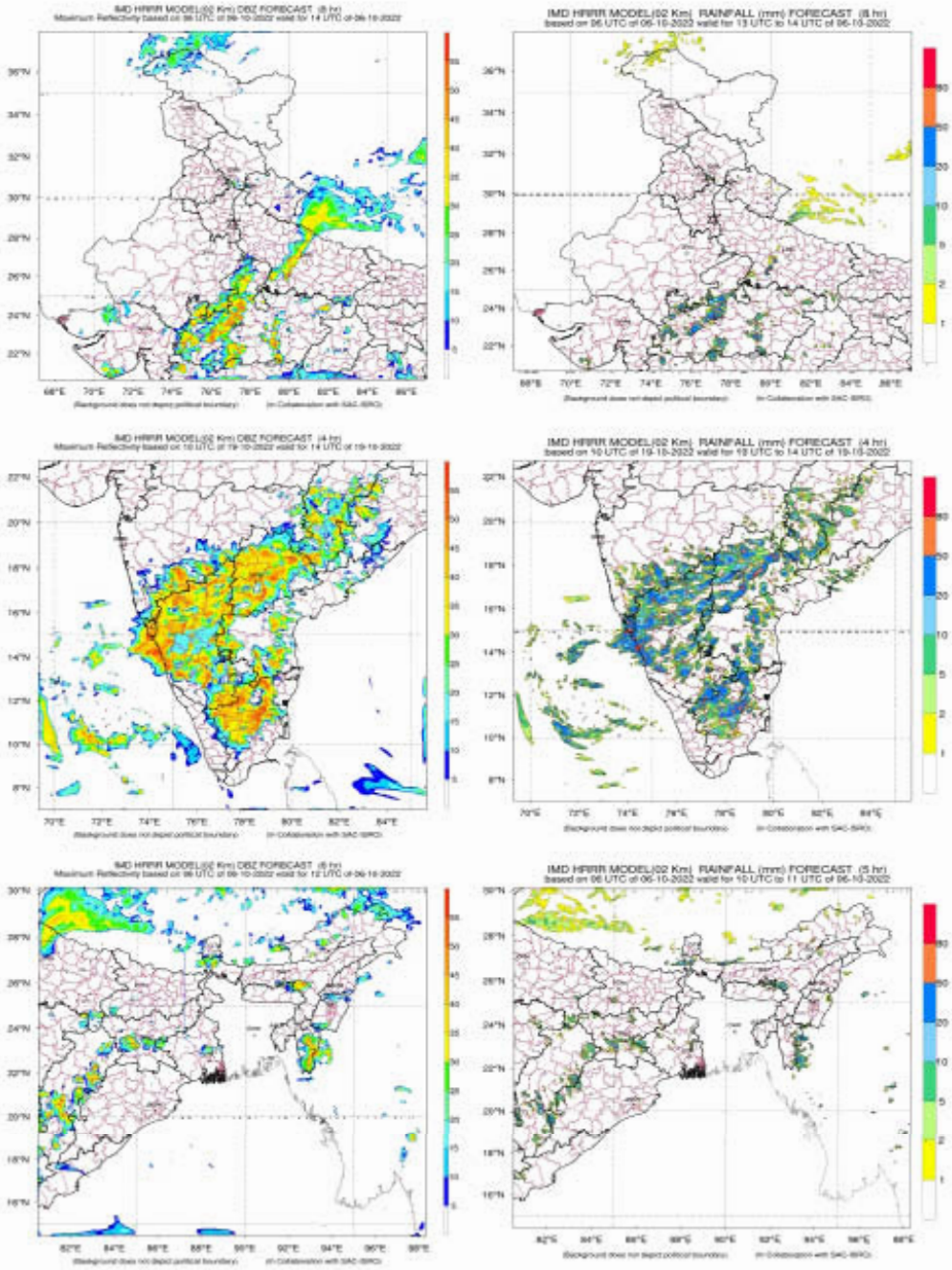


Fig. 2.14 The left column figures show the Reflectivity forecast product for North West, South and East & North-East India from HRRR model from top to bottom respectively. The right column figures shows the rainfall forecast product for North West, South and East & North-East India from HRRR model from top to bottom respectively

operationally implemented the model EWRF. Presently three different products (Lightning Flash Density, Max Reflectivity and Hourly rainfall) from the Electric-WRF model have been updated in the IMD NWP internal website on the experimental basis for the kind feedback of forecasters. In case of E-WRF model run, ground-based lightning flash rate is assimilated in the model. Presently due to the limitation of the computational resources, we are running the model at three different times in a day to cover the entire 24 hours of the day. Early Run is based on the 00 UTC IMD-GFS initial conditions with the validity of the forecast being for 12 hours at hourly intervals (01 UTC to 12 UTC). The Early run products will be available on the website around 0600 UTC (1130 IST). Update Run is based on the 00 UTC IMD-GFS initial conditions, with the validity of the forecast being for 18 hours at hourly intervals (07 UTC to 00 UTC of next day). Third run is based on the IMD-GFS 12 UTC initial condition with the validity of the forecast being for 21 hours at hourly intervals (13 UTC to 09 UTC of next day). The Third run products will be available on the website around 1830 UTC (0000 Night). This Electric WRF model is based on the proper and explicit cloud electrification physics mechanism through which the model generates the electric field over the different grid points of the domain. This electrification mechanism has separate charging and discharging schemes based on different laboratory experiments. In the charging mechanism, Inductive and no-inductive processes have been introduced.

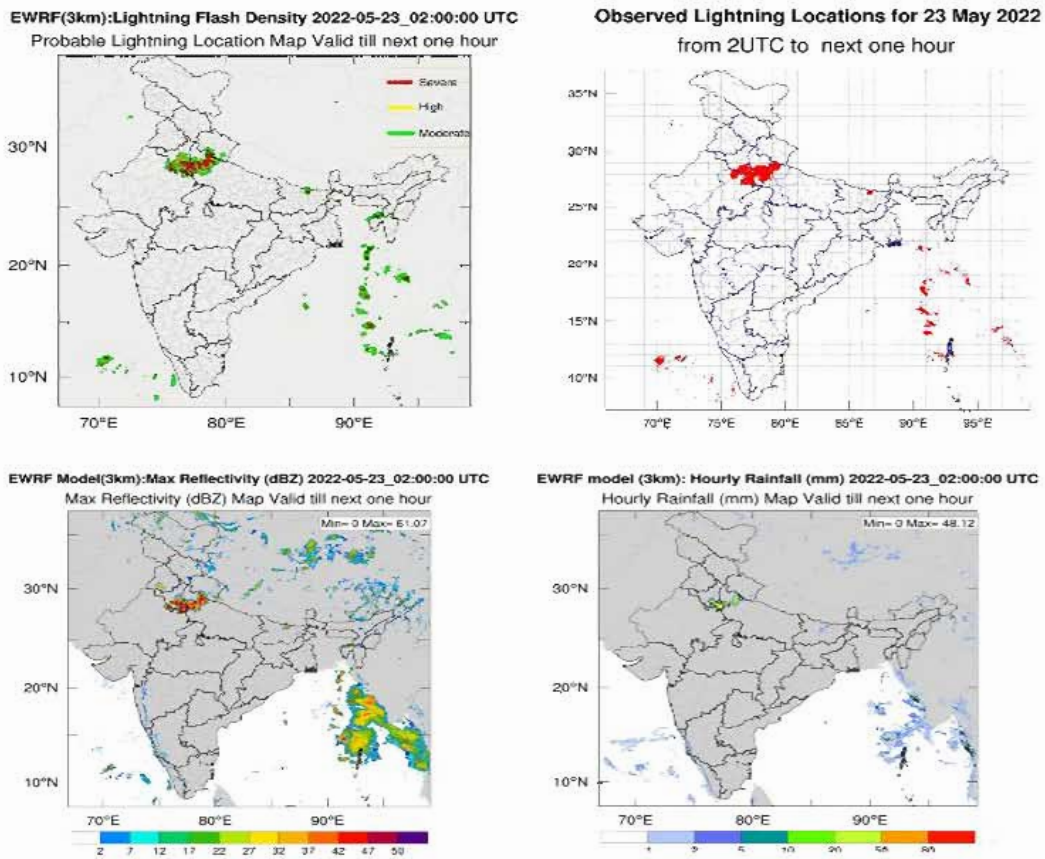


Fig. 2.15 EWRF simulated Lightning Flash Origin Density (top left), Max Reflectivity (bottom left), Rainfall (bottom right) and observed Lightning (top right) for 23 May 2022

2.3.7 Extended Range Forecast (ERF)

A coupled model with a suite of models from CFSv2 coupled model has been developed, implemented and operationalized in IMD in 2017 for generating operational Extended Range Forecast products for different users. This suite of models are (i) CFSv2 at T382 (≈ 38 km) (ii) CFSv2 at T126 (≈ 100 km) (iii) GFSbc (bias corrected SST from CFSv2) at T382 and (iv) GFSbc at T126. The Multi-model ensemble (MME) of the above suite is run operationally for 32 days based on every Wednesday initial condition with 4 ensemble members to give forecast for 4 weeks for days 2-8 (week1; Friday to Thursday), days 09-15 (week2; Friday to Thursday), days 16-22 (week3; Friday to Thursday) and days 23-29 (week4; Friday to Thursday). Figure 2.16 shows observed rainfall anomaly and anomaly in rainfall forecasts of lead time week1, week 2, week3 and week4 valid for the period August 26-September 1, 2022. It can be seen that forecasts of week 1 and week 2 shows better match with observations than week 3 and week 4.

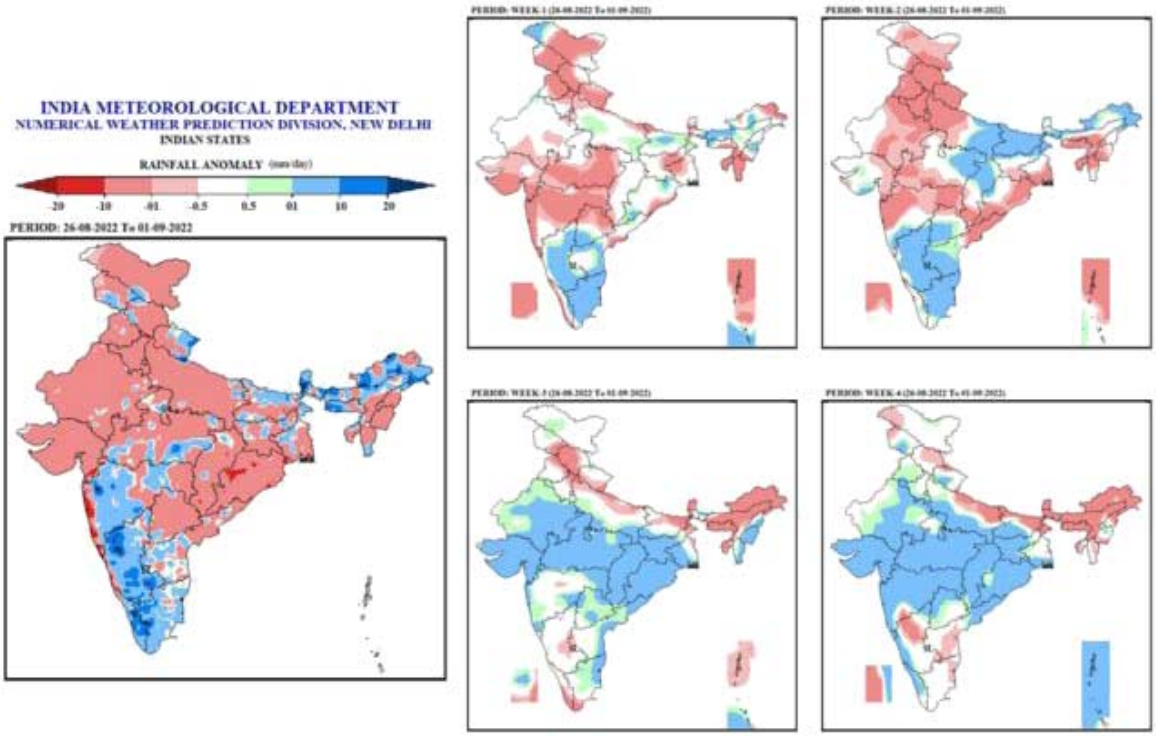


Fig. 2.16 Rainfall anomaly in observations and forecasts of lead time week1, week 2, week 3 and week 4 valid for the period 26 August to September 1, 2022.

2.4 Monsoon Mission

2.4.1 Extended Range Prediction

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, revised SAS (simplified Arakawa Schubert scheme) with modified shallow-convection, and microphysics schemes have 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. Therefore, for ERPv2, we have three initial condition perturbed ensemble members (control + two) each for six multi-physics combinations, thus total 18 ensembles (3 initial condition perturbation X 6 physics perturbation). The experimental forecasts based on this new system, i.e., ERPv2, are being generated from May 2022 and are updated

every Thursday on a real-time basis on the ERPAS website, https://www.tropmet.res.in/erpas/ of IITM. A thorough analysis on the real-time performance of ERPv2 in predicting the Indian summer monsoon rainfall of 2022 monsoon indicates that the prediction system has remarkable skill in predicting the intraseasonal fluctuations within the season remarkably well upto 3 weeks over all homogenous regions, though the skill is comparatively less for northeast India at week 3 lead (Figure 2.17).

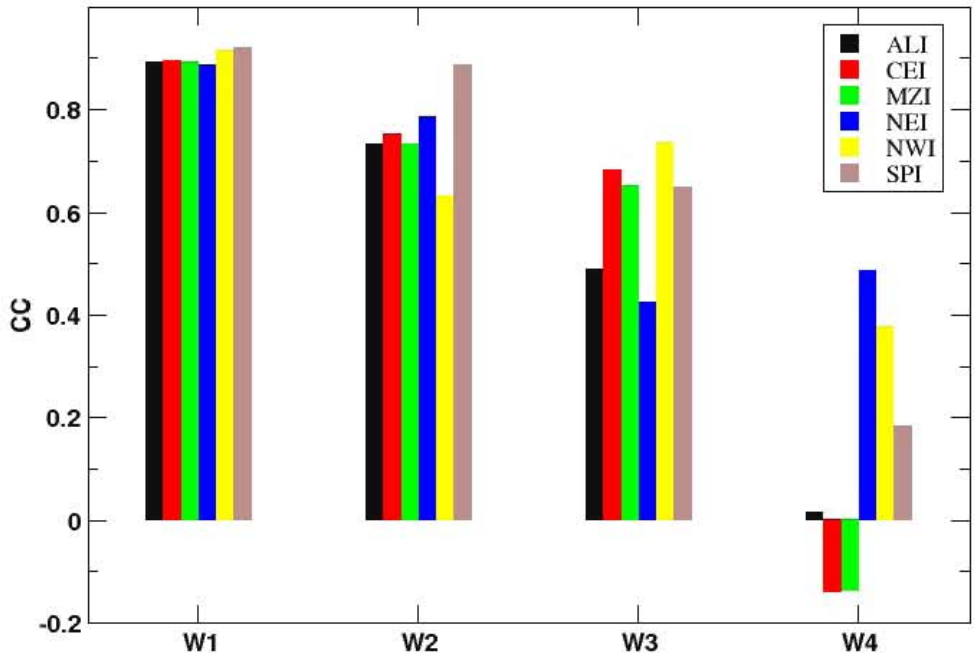


Fig. 2.17 Rainfall prediction skill of ERPv2 during the summer monsoon of 2022 over the various homogenous regions (ALI – all India, CEI – central India, MZI – Monsoon Zone of India, NEI – Northeast India, NWI – Northwest India, SPI – South Peninsular India) over India for Week 1 (W1) to Week 4 (W4).

2.4.2 Short range Global Ensemble Forecast (GEFS)/ Global Forecast System(GFS) for Short Range Forecast :

The GEFS T1534 based ensemble forecasts have provided accurate forecast of genesis, ensemble tracks, strike probability, intensity for the Deep Depression over the southeast Bay of Bengal during 20-23 March, 2022, for the tropical cyclone "ASANI" over the Bay of Bengal during 7-12 May, 2022 and the cyclonic storm, "SITRANG" formed over the Bay of Bengal during 20-24 October 2022. The GEFS based cyclone tracker could capture these events as early as from the depression stage. The forecast skill of rainfall during the monsoon months (JJAS) of 2022 has improved when compared to 2021 in both GEFS and GFS. The categorical skill scores from GFS have shown improvement especially for longer lead times. The forecast skill of GEFS is assessed using various diagnostics such as Relative Operating Characteristic (ROC) and Reliability diagram. The skill obtained from ROC and reliability diagram (Figure 2.18) for Day 3 forecast of JJAS 2022 is equivalent to the Day 2 forecast of JJAS 2021 thus increasing or gaining the skill by one day.

2.4.3 Development of IITM high resolution global forecast Model (HGFM):

IITM high-resolution global forecast Model (HGFM) was inaugurated on the 60th foundation day of IITM on 17th November 2022. Due to the exponential

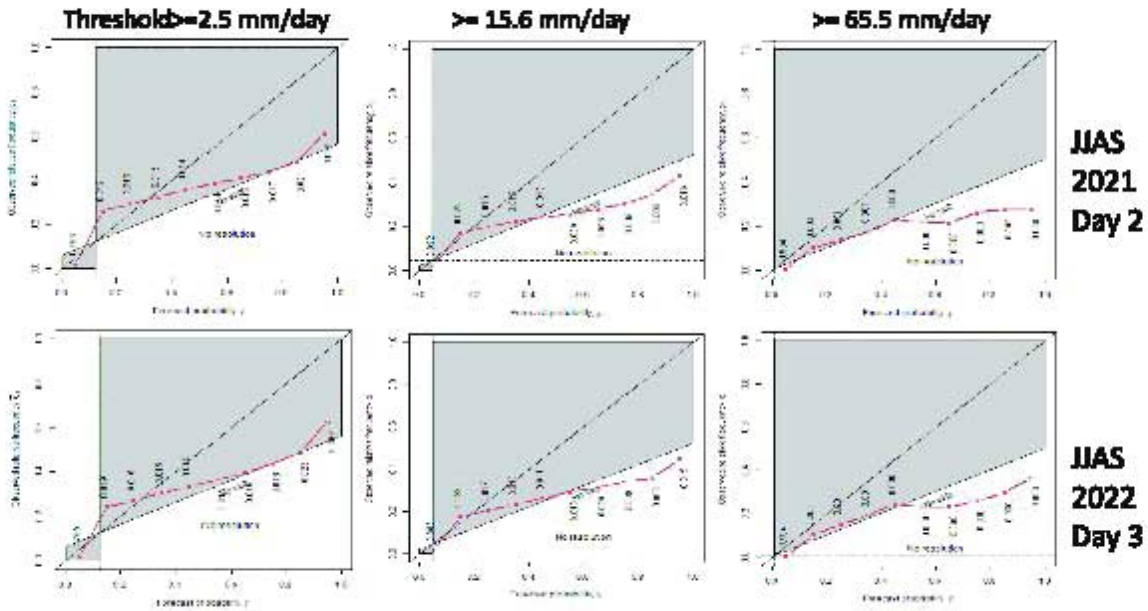


Fig. 2.18 Reliability Diagram for Day 2 rainfall forecast of JJAS 2021 (top row) and for Day 3 forecast of JJAS 2022 (bottom row) from GEFS T1534 for different rainfall thresholds (columns).

rise in the number of smaller-scale weather extremes, the development of a higher resolution (6 km) location-specific weather prediction model was proposed in the MoES ACROSS program. A scientific strategy is adopted by using Triangular Cubic Octahedral (Tco) grid which is very scalable and is being run on the Pratyush HPC system. The model is being developed from a basic version to a full physics version at IITM Pune and is completely indigenously and with in-house resources. While the current GFS (12 km) model helps to generate block level forecast, this indigenous IITM HGFM will help to reach forecast to a scale smaller than block level. This "Make in India" Model has been run in real-time daily since June 2022 on an experimental basis. After a thorough validation and performance evaluation, the model will be handed over for operational Implementation to India Meteorological Department.

2.5 Centre for Climate Change Research

2.5.1. IITM Earth System Model (ESM)

Since the development of IITM ESM v2, efforts are being made to develop the next version of IITM

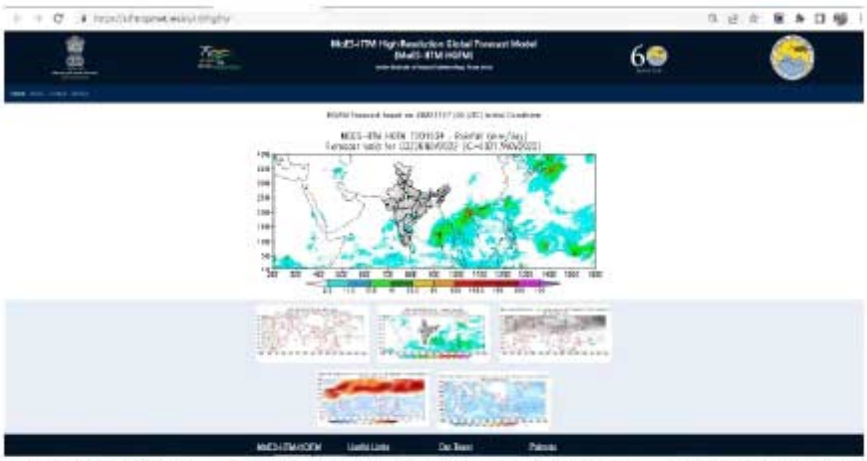


Fig. 2.19 Newly launched website https://srf.tropmet.res.in/srf/hgfm/ for high resolution global forecast Model (HGFM)

Earth System Model (ESM) by incorporating an interactive land-ice model and a new spectral dynamical core. In addition to the development of the ESM, studies are being carried out to understand climate change using the ESM. For example, a recent study was focused on the extreme sea level rise along the Indian Ocean coastline. Presently, observations show that extreme sea level (ESL) have become more frequent, longer lasting and intense along the Indian Ocean coastline (Fig 2.20a). Utilizing the likely range (17th-83rd percentile as the spread) of IPCC mean sea level projections with considerable inter-model spread, the study showed that the Indian Ocean region will be exposed annually to the present-day 100-year ESL event by 2100, irrespective of the greenhouse-gas emission pathways, and by 2050 under the moderate-emission-mitigation-policy scenario as shown in (Fig. 2.20b and 2.20c). The study provides a robust regional estimate of ESL and its progression with rising mean sea level, which are important for framing climate change adaptation policies.

2.5.2 Observational studies at CCCR

CCCR has also been involved in several climate related observations over the last year. For example, oxygen isotope ($\delta^{18}O$) variations of stalagmites samples collected from karst caves located in the

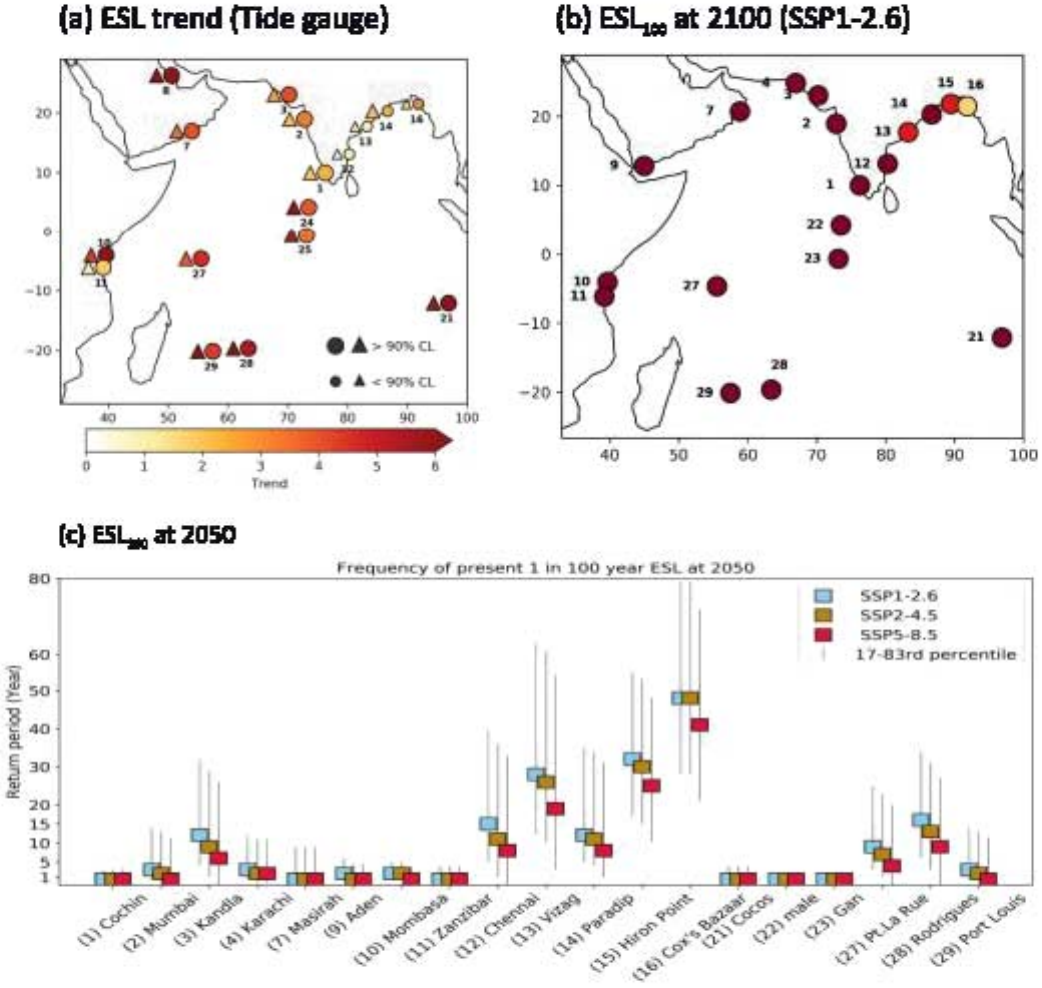


Fig. 2.20 (a) Annual trend in ESL intensity (mm yr^{-1}, circles) and ESL duration (hr yr^{-1}, triangles) from tide gauge data since 1970. The projected return period of the present-day ESL_{100} along the Indian Ocean coastline (b) at 2100 using SSP1-2.6 and © at 2050 based on three shared socio-economic pathways (SSP) used in IPCC Ar6.

remote regions of Kadapa, Andhra Pradesh were studied. The analysis shows that the Indian mainland witnessed several prolonged droughts and flood events during the last 3200 years **(Figure 2.21)**. This is the now highest temporal resolution paleo-record of monsoon available over India.

In addition to the paleo monsoon record, scientists at CCCR have been involved in the MetFlux India study, which aims at understanding carbon fluxes over the Indian subcontinent. As a part of this they have been carrying out carbon flux observations over several location, which are essential to understanding the carbon budget during different seasons, and the drivers for carbon exchange. This project enables identification of the sources and sinks of greenhouse gases covering different ecosystems. Observations on soil moisture have also been conducted regularly across several stations in India to contribute to water resource information and outlooks for sustainable water use.

Scientists at CCCR also participated in the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAIC) expedition, and showed that Iodine is the second highest contributor to the loss of surface ozone in the Arctic, which is a change in the current paradigm on ozone loss.

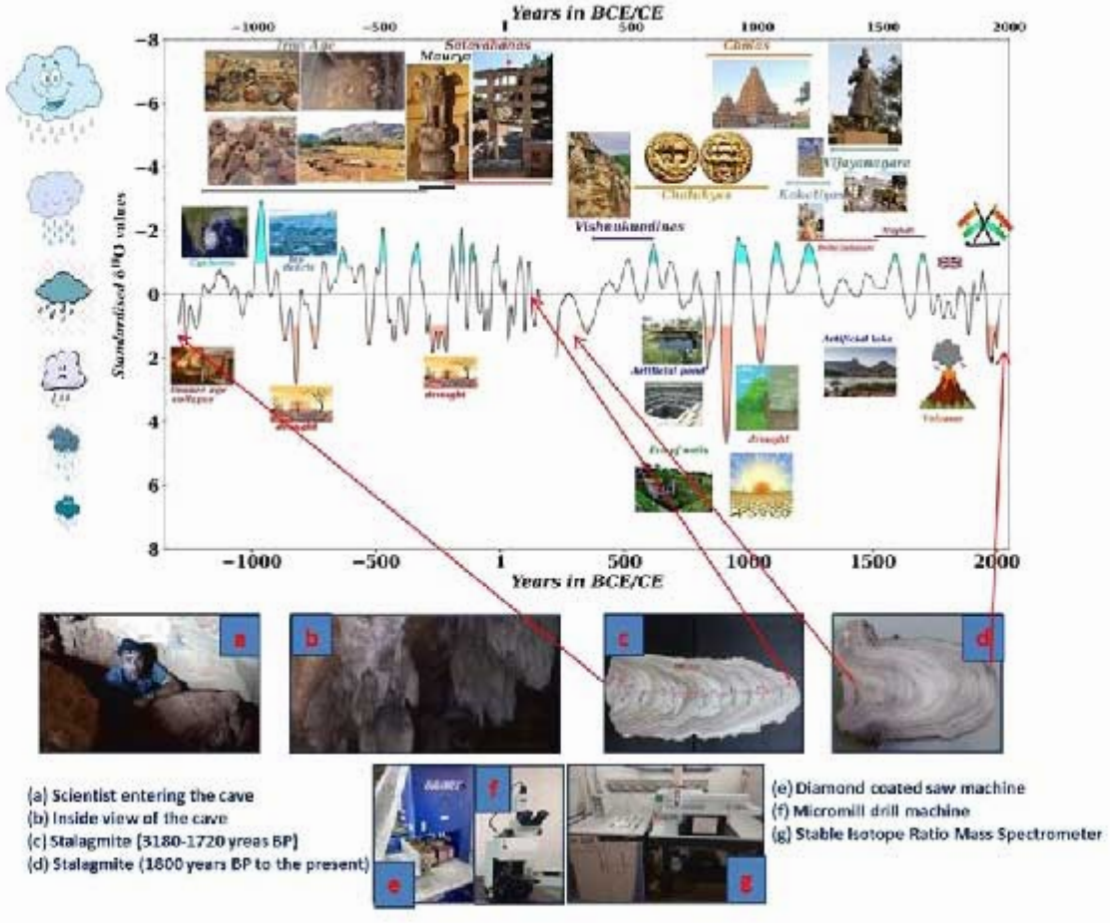


Fig. 2.21 $\delta^{18}O$ values of two stalagmites covering 3200 years from the present. More negative values of $\delta^{18}O$ represent higher rainfall and vice versa. Drought (flood) events are marked with brown (cyan) colour. This is the now highest temporal resolution paleo-record of monsoon available over India.

A new global seawater climatology for climatic trace gas dimethyl sulphide (DMS) was published. This is the first time that a global emission inventory has been created by any group from India.

2.6 Southwest Monsoon 2022

The forecast for the date of monsoon onset over Kerala was issued on 13th May, 2022 that monsoon will set in over Kerala on 27th May with a model error of ±4 days. This year, it was forecasted that the onset of southwest monsoon over Kerala is likely to be slightly early as compared to normal date of onset. The actual monsoon onset over Kerala was on 29th May with a model error of ± 4 days.

1st stage Long Range Forecast of Monsoon Season rainfall was issued on 14 April, 2022, stating that Southwest monsoon seasonal (June to September) rainfall over the country as a whole is most likely to be normal [96 to 104 % of Long Period Average (LPA)]. Updated Long Range Forecast of Southwest Monsoon Season (June - September), was issued on 31st May, 2022 , stating that Southwest monsoon seasonal (June to September) rainfall over the country as a whole is most likely to be normal [96 to 104% of Long Period Average (LPA)]. The silent features of southwest monsoon rainfall are given below :

- Observed monsoon seasonal rainfall during June to September for the country as a whole had been above normal (105 -110% of Long Period Average (LPA)). Quantitatively, all India monsoon seasonal rainfall during 1 June to 30 September 2022 had been 92.5 cm against the Long Period Average of 87.0 cm based on data of 1971-2020 (106% of its LPA).
- The Southwest monsoon seasonal (June to September) rainfall had been above Normal over South peninsula (122% of LPA) and Central India (119 % of LPA); normal over Northwest India (101%) and Below Normal over East and Northeast India (82%).
- The southwest monsoon seasonal (June to September) rainfall over the monsoon core zone, which consists of most of the rainfed agriculture regions in the country had been above normal (120% of LPA).
- Out of the total 36 meteorological subdivisions, 12 subdivisions constituting 40% of the total area of the country received excess, 18 subdivisions (43% of the total area) received normal rainfall and 6 subdivisions (17% of the total area) received deficient season rainfall. These 6 Met subdivisions which got deficient rainfall are West Uttar Pradesh, East Uttar Pradesh, Bihar, Jharkhand, Gangetic West Bengal, and Nagaland, Manipur, Mizoram & Tripura (NMMT).
- The rainfall over the country as a whole was 92%, 117%, 104% and 108% of LPA during June, July, August and September respectively.

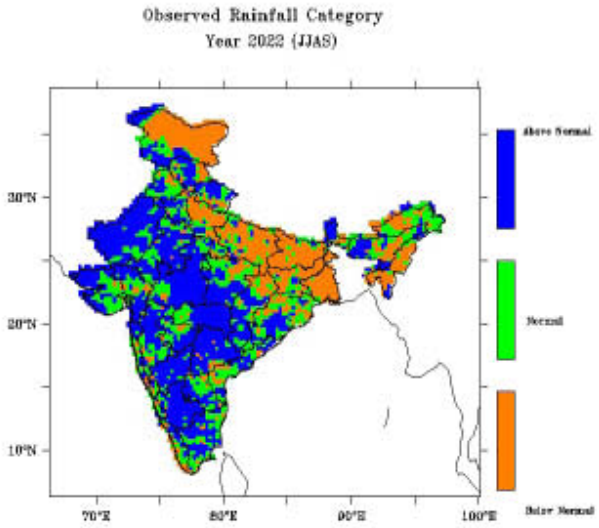


Fig. 2.22 Observed Rainfall categories (below normal, normal, and above normal) over India during monsoon season (June -September), 2022.

2.7 Tropical Cyclone Monitoring and Prediction 2022

Salient features of the cyclonic activity over the North Indian Ocean (NIO) during 2022 are mentioned below :

Verification of Long Range Forecast of SW Monsoon 2022

Region	Period	Forecast (% of LPA)		Actual Rainfall
		14th April	31st May	(% of LPA)
All India	June to September	Normal (96-104% of LPA) 99± 5 of LPA	Normal (96-104% of LPA) 103± 4 of LPA	106
Northwest India	June to September		Normal (92-108% of LPA)	101
Central India	June to September		Above Normal (>106% of LPA)	119
Northeast India	June to September		Normal (96-106% of LPA)	82
South Peninsula	June to September		Above Normal (>106% of LPA)	122
Monsoon Core Zone	June to September		Above Normal (>106% of LPA)	120
All India	July (issued on 1st July)		Normal (94-106% of LPA	117
All India	August (issued on 1st Aug.)		Normal (94-106% of LPA	103
All India	August to September (issued on 2nd Aug.)		Normal (94-106% of LPA)	105
All India	September (issued on 1st Sep.)		Above Normal (>91-109% of LPA)	108

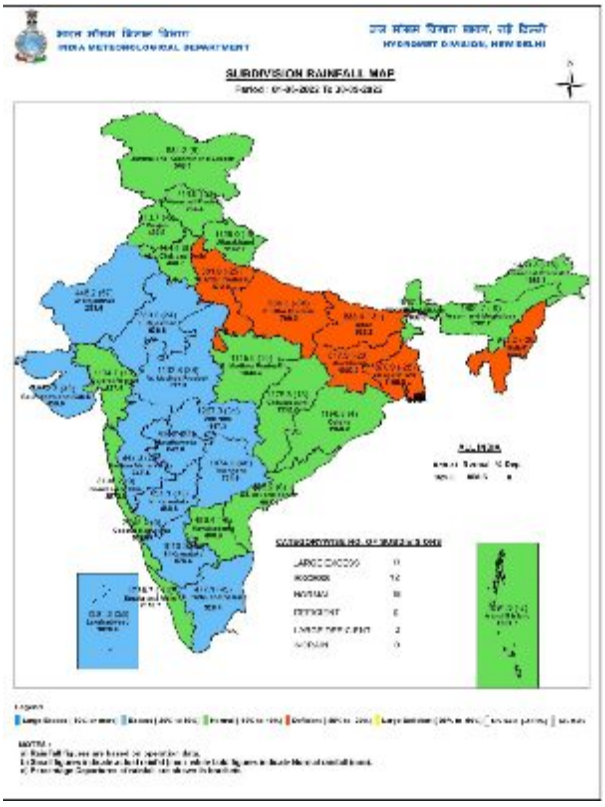


Fig. 2.23 Sub-division wise observed rainfall during the monsoon season of 2022

Fifteen (15) Cyclonic disturbances (CDs-Depressions and cyclonic storms put together) developed over the North Indian Ocean (NIO) which includes 11 over the Bay of Bengal (BoB) and 4 over the Arabian Sea (AS) during the year 2022 against the normal of 11 CDs per year over the NIO for the period 1961-2020. Out of these, 3 intensified in to cyclonic storms (CS) (maximum sustained wind speed (MSW) ⩾ 34 kt) against the normal of 4.8 CS per year over the NIO for the period 19610-2020. In this 3 two intensified in to severe category storms (MSW⩾50kt).

(i) Deep depression over Bay of Bengal during 03-06 March, 2022

(ii) Deep depression over North Andaman Sea during 20-23 March, 2022

(iii) Severe cyclonic storm Asani over Bay of Bengal during 07-12 May, 2022

(iv) Depression over Bay of Bengal during 20-21 May, 2022

(v) Depression over Arabian Sea during 16-18 July, 2022

(vi) Depression over coastal Odisha during 09-10 August, 2022

(vii) Depression over Arabian Sea during 12-13 August, 2022

(viii) Depression over Bay of Bengal during 14-16 August, 2022

(ix) Deep depression over Bay of Bengal during 19-23 August, 2022

(x) Depression over South Odisha during 11-12 September, 2022

(xi) Cyclonic Storm Sitrang over Bay of Bengal during 22-25 October, 2022

(xii) Depression over Bay of Bengal during 20-22 November, 2022

(xiii) Severe Cyclonic Storm Mandous over Bay of Bengal during 06-10 December, 2022

(xiv) Deep Depression over Arabian Sea during 14-17 December, 2022

(xv) Depression over Bay of Bengal during 22-25 December, 2022

2.7.1 Severe Cyclonic Storm ASANI over the Bay of Bengal (7th - 12th May, 2022)

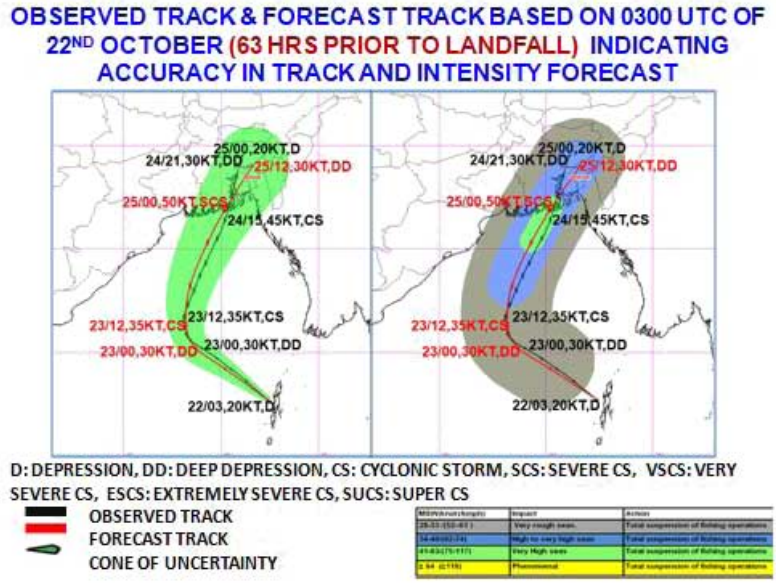
A low pressure area formed over South Andaman Sea and adjoining Southeast Bay of Bengal in the morning (0830 hrs IST) of 6th May, 2022. It laid as a well marked low pressure area over Southeast Bay of Bengal and adjoining south Andaman Sea in the early morning (0530 hours IST) of 7th May. Under favourable environmental conditions, it concentrated into a depression over the same region around noon (1130 hrs IST) of the same day, the 7th May, 2022. It moved northwestwards and intensified into a deep depression over southwest Bay of Bengal in the same evening (1730 hrs IST) of 7th May. Continuing to move northwestwards, it intensified into the cyclonic storm "ASANI " in the early morning (0530 hrs IST) of 8th May and into a severe cyclonic storm in the same evening (1730 hrs IST) over southeast Bay of Bengal. Continuing to move northwestwards, it reached peak intensity of 55 knots (100-110 kmph gusting to 120 kmph) on 9th early morning (0530 hrs IST). It maintained its peak intensity till 10th noon (1130 hrs IST), thus for 30 hrs. From 10th evening, it started gradually moving north-northwestwards and weakened into a cyclonic storm over west central Bay of Bengal about 60 km south-southeast of Machilipatnam in the early hours (0230 hrs IST) of 11th May. Thereafter, it started moving nearly northwards with a very slow speed and weakened into a deep depression over west central Bay of Bengal close to Andhra Pradesh coast in the evening (1730 hrs IST) of 11th May. It crossed Andhra Pradesh coast near latitude 16.3°N and longitude 81.3°E between Machilipatnam and Narsapur during 1730-1930 hours IST of 11th May, 2022 as a deep depression with maximum sustained wind speed of 55-65 kmph gusting to 75 kmph. It then moved slowly west-southwestwards and weakened into a depression in the early morning (0530 hrs IST) and further into a well marked low pressure area in the morning (0830 hrs IST) of 12th May over coastal Andhra Pradesh. The observed track of the system is presented in Figure 2.24.

Fig. 2.24 Observed track of severe cyclonic storm "ASANI" over the Bay of Bengal during 7th - 12th May, 2021

2.7.2 Cyclonic Storm SITRANG over the BoB (22nd-25th October, 2022)

A low pressure area formed over North Andaman Sea and adjoining areas of south Andaman Sea & Southeast Bay of Bengal (BoB) in the early morning (0530 hrs IST/0000 UTC) of 20th October, 2022. It laid as a well marked low pressure area over north Andaman Sea and adjoining southeast BoB in the

Fig. 2.25 Observed track of cyclonic storm 'SITRANG" over the BoB during 22nd - 25th October, 2022



evening (1730 hours IST/1200 UTC) of 21st October. Under favourable environmental conditions, it concentrated into a depression over southeast and adjoining eastcentral BoB close to Andaman Islands in the forenoon (0830 hrs IST/0300 UTC) of 22nd October, 2022. It moved northwestwards and intensified into a deep depression over westcentral BoB in the early morning (0530 hrs IST/0000 UTC) of 23rd October. Thereafter, it moved nearly northwards and intensified into the cyclonic storm (CS) "SITRANG" in the evening (1730 hrs IST/1200 UTC) of 23rd October. It then gradually recurved north-northeastwards and crossed Bangladesh coast between Tinkona and Sandwip close to Barisal (near 22.15°N/90.35°E) in the night of 24th October during 2130 to 2330 hours IST/ 1600 to 1800 UTC of

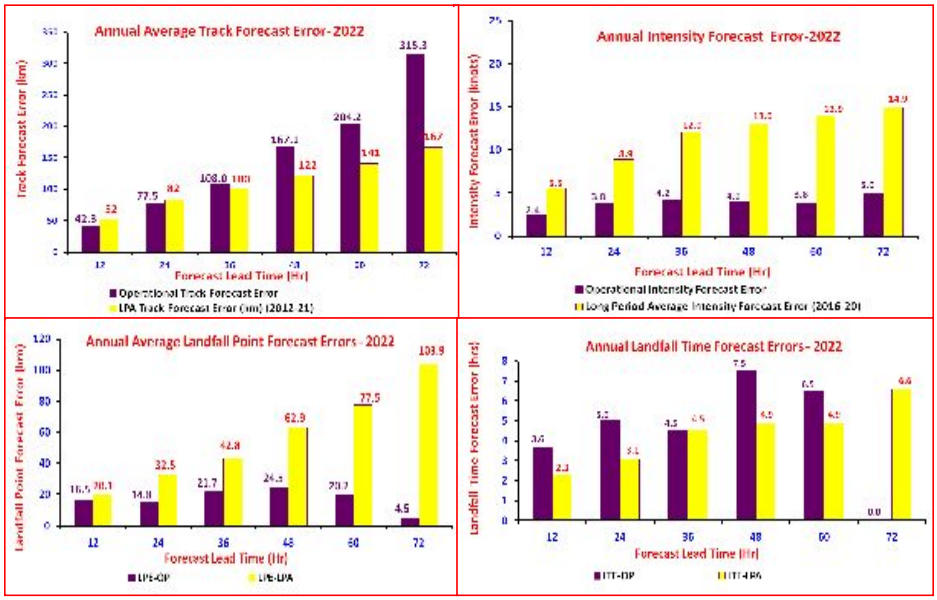


Fig. 2.26 The annual average track, intensity, landfall point and landfall time forecast errors during 2022.

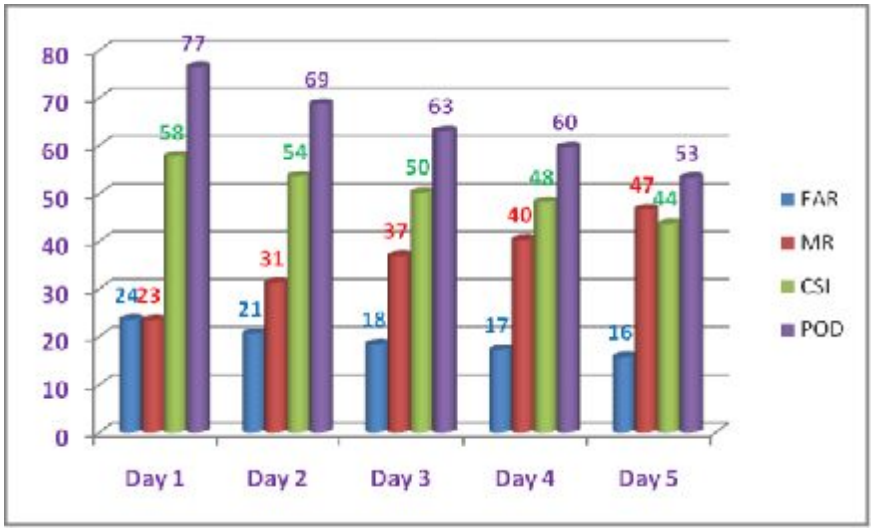


Fig. 2.27 All India southwest Monsoon (June to September) 2022 heavy rainfall skill scores from Day 1 to Day 5

24th October as a cyclonic storm with maximum sustained wind speed of 80-90 kmph gusting to 100 kmph. Continuing to move north-northeastwards, it weakened into a deep depression over northeast Bangladesh in the early hours (0230 hours IST of 25th/2100 UTC of 24th), into a depression over interior Bangladesh in the early morning (0530 hours IST/ 0000 UTC) of 25th October and into a well marked low pressure area over northeast Bangladesh & adjoining Meghalaya in the forenoon (0830 hours IST/0300 UTC) of 25th October, 2022. The observed track of the system is presented in Figure 2.25.

2.7.3 Performance of Cyclone landfall, track and intensity forecast during 2022

Annual Performance of cyclone landfall, track and intensity forecast during 2022

Track forecast performance: Annual average track forecast errors in 2022 have been 42.3 km, 77.5 km

Table 2.3 Skill Scores for 24 hour Thunderstorm IOP Verification for FDP STORM – 2022 (March to June)

Month	Probability of Detection (POD)	False Alarm Ratio (FAR)	Critical Success Index (CSI)	Equitable Threat Score (ETS)
March	0.73	0.66	0.30	0.25
April	0.84	0.37	0.56	0.38
May	0.91	0.39	0.58	0.27
June	0.92	0.38	0.59	0.22
FDP STORM-2022	**0.89**	**0.40**	**0.55**	**0.35**

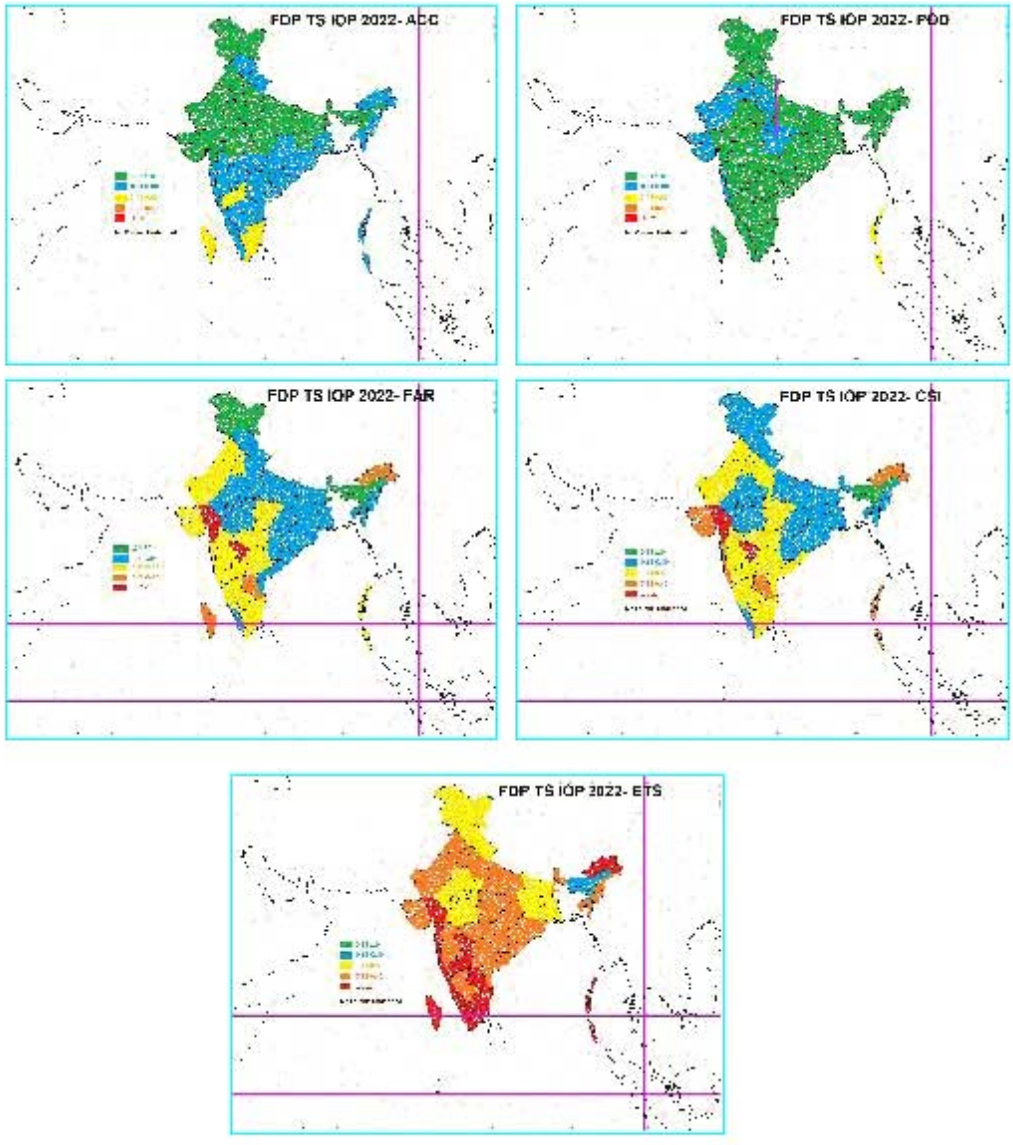


Fig. 2.28 The Sub-division wise verification scores in pictorial form for 24 hour Thunderstorm IOP Verification during FDP STORM-2022

and 108.0 km, respectively for 12, 24 and 36 hrs against the long period average (LPA) errors of 51.7, 82.4 and 100.3 km based on data of 2012-2021. The forecast accuracy since 2003 indicates an improvement at the rate of 5.8 km/year (58 km in 10 years) for 24 hrs lead period. The accuracy in track prediction registered an overall improvement of 20-25% upto 120 hours lead period during 2018-22.

Intensity forecast performance: The annual average absolute error (AE) in intensity forecast error has been 3.8 knots, 4.0 knots and 5.0 knots against the LPA (2012-21) errors of 8.9, 13.0 and 14.9 knots for 24, 48 and 72 hrs lead period respectively. The intensity forecast accuracy since 2005 indicates an improvement at the rate of 0.52 knots/year (5.2 knots in 10 years) for 24 hrs lead period. The accuracy in intensity prediction registered an overall improvement of 20-30% upto 72 hours lead period during 2018-22.

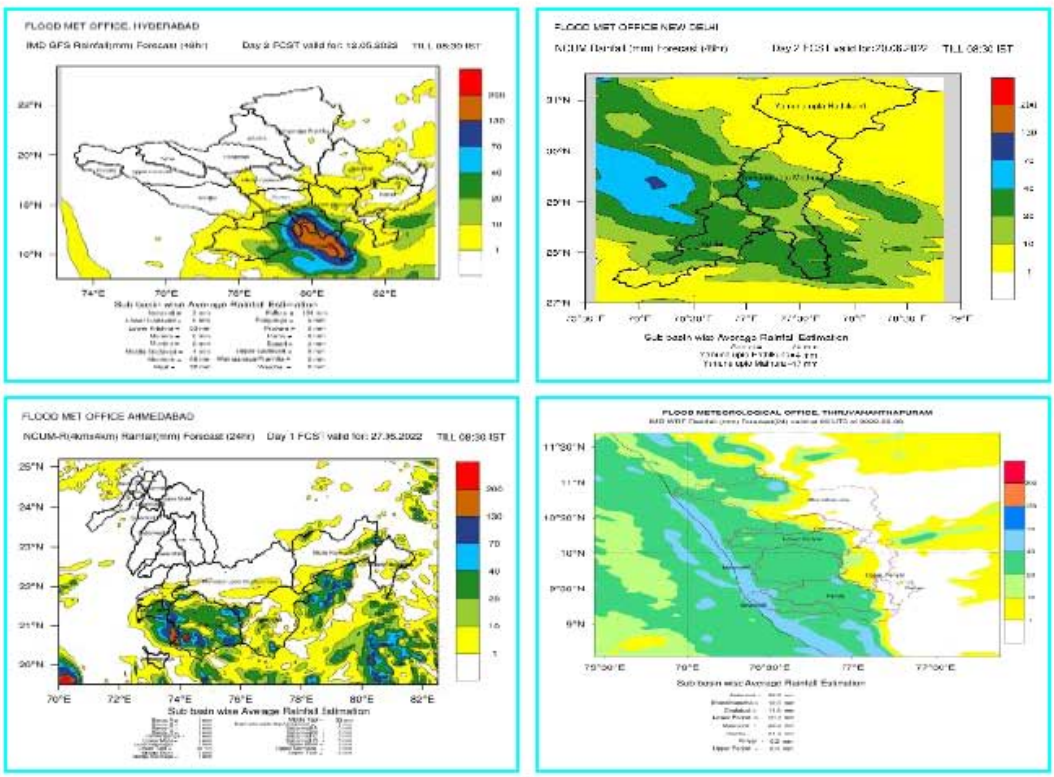
Landfall point forecast performance: The annual average landfall point forecast errors for the year 2022 have been 14.8 km, 24.5 km and 4.5 km against the LPA (2012-21) errors of 32.5 km, 62.9 km and 103.9 km for 24, 48 and 72 hrs lead period respectively. The landfall point forecast accuracy since 2003 indicates an improvement at the rate of 14.4 km/year (144 km in 10 years) for 24 hrs lead period since 2003. The accuracy in landfall point prediction registered an overall improvement of 40-70% upto 72 hours lead period during 2018-22.

2.8 Forecast Verification of Extreme Events

2.8.1 Heavy rainfall warning skill of southwest monsoon 2022

Probability of Detection (POD) for heavy rainfall warning varies between 77% to 53% from Day 1 to Day 5. Critical Success Index (CSI) varies between 58% to 44% from Day 1 to Day 5. False Alarm Rate (FAR) is between 24% to 16% and Missing Rate (MR) is between 23% to 47% from Day 1 to Day 5.

Probability of Detection (POD) for heat wave warning varies between 98% to 50% from Day 1 to Day 5. Critical Success Index (CSI) varies between 62% to 34% from Day 1 to Day 5. False Alarm Rate



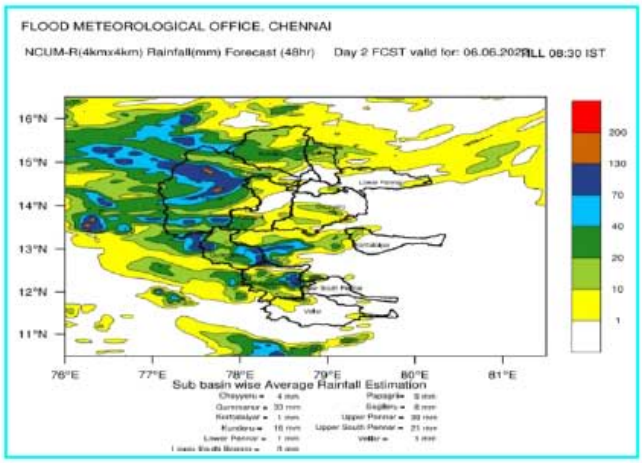


Fig. 2.9 River Sub-basin-wise average rainfall estimation of deterministic NWP models (WRF, NCUM-R, GFS, NCUM-G)

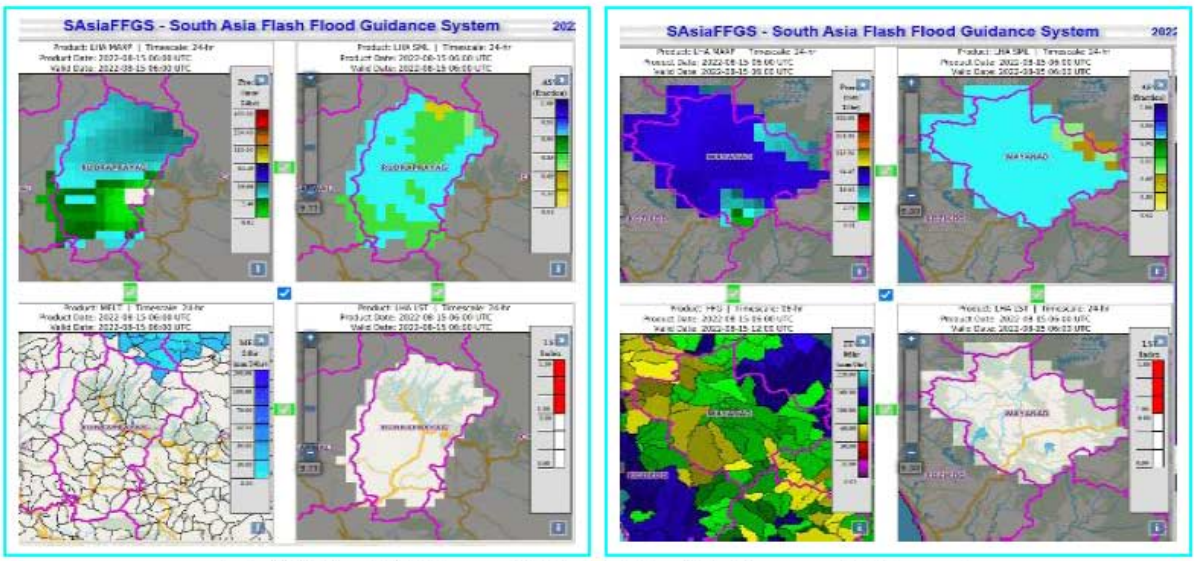


Fig. 2.30 Landslide Susceptibility Module of Rudraprayag & Wayanad

(FAR) is between 7% to 6% and Missing Rate (MR) is between 2% to 50% from Day 1 to Day 5 (Figure 2.27)

2.8.2 Thunderstorm Nowcast

During the year 2022, about 36 stations were added to the All India Nowcast list. Thus the total number of stations for the three hourly nowcast has gone upto 1124 in 2022 (till September).

(A) 24 hour Thunderstorm IOP Verification: The skill scores pertaining to thunderstorms predicted during FDP period is given in Table 2.3 and sub-divisionwise verification scores in pictorial form in the **Figure 2.28.**

2.9 Flood Meteorological Services

Flood Meteorological Offices (FMOs, 15 in all over India) of India Meteorological Department (IMD) provide Meteorological support in the of Quantitative Precipitation Forecast for 153 sub-basins to Flood Forecasting Divisions (FFDs) of Central Water Commission (CWC) to help them issue "Flood warnings/Flood alerts". The meteorological support is provided in terms of sub basin wise 'Quantitative Precipitation Forecast (QPF)' and 'Probabilistic Quantitative Precipitation Forecast (PQPF)' in different categories through Hydromet Bulletins. Forecast for a lead time of 7-days (forecast for 5 days and outlook for subsequent

Fig. 2.30 Farmers Awareness Program

2 days) are issued daily during flood season.

Sub basin-wise Quantitative Precipitation Estimate for Day-1, Day-2, Day-3 using WRF ARW (9km x 9km) based on 00 UTC, for Day-1 to Day-5 using MME (0.25°x 0.25°) based on 00 UTC and Day-1 to Day-7 using GFS (0.12°x 0.12°) based on 00 UTC run by IMD are computed and uploaded on IMD website operationally. Similarly, new sub-basin-wise products of the NCUM (0.12°x 0.12°) model based on 00 UTC data for Day1 to Day 7 were made operational and uploaded in the IMD website. Sub-basin wise probabilistic QPF based on dynamical model GEFS and NEPS was made operational in the IMD website. Operational run of dynamical model GFS, MME, NCUM & WRF for estimation of sub basin wise QPF and GEFS & NEPS based Categorical Probabilistic QPF which are uploaded in IMD website. Joint Advisories of IMD, CWC and NDRF for the flood situation in the country operationalised during the southwest monsoon season 2022.

Enhanced capabilities of Flash Flood Guidance Services:

1) Landslide Susceptibility Module :

Integration of Landslide Susceptibility Module into Flash Flood Guidance System for better predictability of landslide associated flash floods in the vulnerable hilly regions of Indian Subcontinent has been completed for Rudraprayag district of Uttarakhand and Wayanad district of Kerala jointly by GSI, NRSC, IMD and HRC.

A virtual training was conducted on 29th June 2022 on Landslide Susceptibility Module of Rudraprayag and Wayand and the module was operationalised successfully.

2.10 Agro-Meteorological Advisory Services under Gramin Krishi Mausam Seva (GKMS)

Presently, 329 Agromet Units (199 DAMUs along with the existing 130 AMFUs) prepare medium range weather forecast based bi-weekly Agromet Advisory Service (AAS) bulletins at district and block level. At present these bulletins are issued for 700 districts and ~3000 blocks in the country. For comprehensive and quicker dissemination of Agromet Advisories, 16,211 WhatsApp groups have been formed covering 1,20,507 villages of 3,622 blocks reaching 13,66,103 farmers. In collaboration with CRIDA, ICAR, Hyderabad, Extended Range Weather Forecast based AAS bulletin is also issued on every Friday. Biweekly AAS bulletin is also issued from North Karnataka Agromet Forecasting & Research Centre (NKAFC) jointly by University of Agriculture Sciences (UAS), Dharwad, Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bengaluru and India Meteorological Department (IMD) covering 13 districts of North Karnataka on every Tuesday and Friday. Weather and agromet inputs are also communicated to DD Kisan Channel, New Delhi and for Krishi Darshan Programme of DD National channel, New Delhi for "Crop Specific Weather Based Agromet Advisories" for the country on every Tuesday and Friday. A YouTube channel named IMD-GKMS was created during the year to showcase various activities being carried out under GKMS scheme. So far, around 379 short videos under GKMS have been uploaded in the channel.

2.11 Environmental Meteorology Services

IMD conducts monitoring and research related to atmospheric constituents that are capable of forcing change in the climate of the Earth, and may cause depletion of the global ozone layer, and play key roles in air quality from local to global scales. IMD also provides specific services to Ministry of Environment and Forest & Climate Change and other Government Agencies in the assessment of air pollution impacts. IMD contributes in the field of atmospheric environment to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) programme. The main objective of GAW is to provide data and other information on the chemical composition & related physical characteristics of the atmosphere and their trends, required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere. IMD has established following nationwide networks under this program :

Ozone Monitoring Network, Precipitation and Particulate Matter Chemistry Monitoring network and Aerosol Monitoring Network which consists of following sub-networks: (i) Sun-Sky radiometer Network, (ii) Black Carbon Aerosol Monitoring Network, (iii) Multi-wavelength Integrating Nephelometer Network, and (iv) Chemical Characterization of Aerosols.

2.12 Air Quality Early Warning System (AQEWS) and Decision Support System (DSS) for Delhi

One of the biggest environmental risks that many large cities across the world confront is air pollution. This also applies to New Delhi, the capital of India. Especially in the colder and calmer winter months, the Delhi's air quality deteriorates to dangerous proportions. IITM, IMD, and NCAR developed the Air Quality Early Warning System (AQEWS), which has been providing early warnings about potential severe air pollution events occurring in Delhi-NCR since 2018. We added a Decision Support System (DSS) to this architecture last year with the ability to give source attribution data along with a variety of emission reduction scenarios. The team has developed a chemical data assimilation system that integrates satellite aerosol optical depth (AOD) retrievals at 3 km resolution, surface data from 320 air quality monitoring stations in India and high-resolution emissions from various anthropogenic

and natural sources (including dust and stubble burning). This extensive modelling framework has resulted in a phenomenal increase in prediction skill of extreme air quality episodes up to 3-days in advance at a city-scale to street level. IITM has further developed a very high-resolution (400 metre) operational modelling system 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. The operational and public dissemination system (https://ews.tropmet.res.in) was developed under the Smart Cities Mission (NP15) of the Govt. of India and the same is being used operationally by IMD, MoES, CPCB, MoEFCC, and DPCC. 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, 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.

The measurements of fine particulate matter (PM2.5) mass concentration over 39 observational locations in Delhi, maintained by the Central Pollution Control Board (CPCB) and the Delhi Pollution Control Committee (DPCC), show an identifiable peak (PM2.5 > 500 ug/m3, red line figure 2.32) during the evening to night hours of the 24th October 2022 (the evening of Laxmi Pooja). However, the peak concentrations only persisted for a little time. Immediately on the next day (25th October 2022), the concentrations were reduced to around 150-200 ug/m3. On the following days, while there was a weak build-up of the PM2.5 concentrations, the hourly mean values remained less than 300 ug/m3. The simulated AQI rose to the 'very poor' category on the Diwali night and reduced after that to reach the lower end of the same category. The model also captured a slow build-up

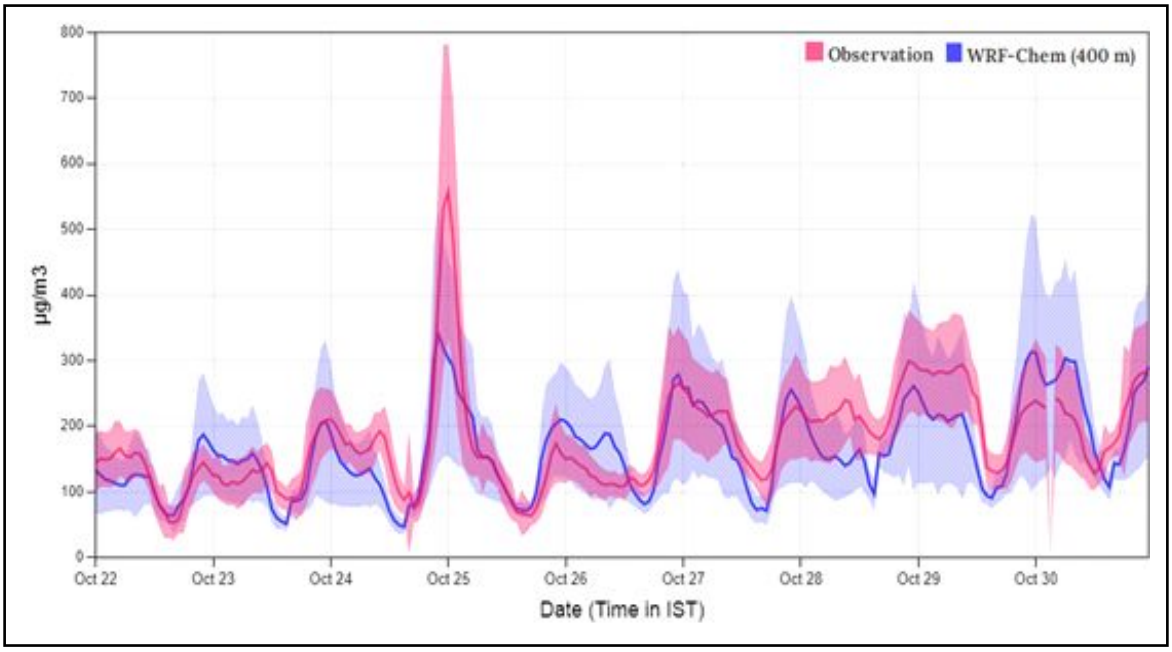


Fig. 2.32 Hourly mean PM2.5 mass concentration over Delhi for 22nd October 2022 to 30th October 2022. The observations and WRF-Chem simulated PM2.5 are averaged over the 39 observational stations across Delhi. The curves show the mean values, while the shading indicates the one-standard deviation range.

of the AQI after 26th October 2022. Overall, the model correctly predicted the category of AQI during this pollution event; however, the magnitude of AQI was missed by the model. The Decision Support System (DSS) developed by the IITM, MoES, quantifies the contribution from local and non-local sources to the pollution load in Delhi. The DSS simulated local and non-local contribution for the same period (22nd October 2022 to 30th October 2022) shows a daily mean contribution of around 30-35% from the local sources within Delhi to its pollution load.

2.13 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. The field experiments involved extensive suites of in-situ instruments and gathered simultaneous observations of micro-meteorological conditions, radiative fluxes, turbulence, droplet/aerosols microphysics, aerosol optical properties, fog water-chemistry, and vertical thermodynamical structure to describe the environmental stability in which fog develops. An operational modeling framework, the WRF model, was set up to provide fog predictions during the measurement campaign. A new 21 member Ensemble Probability Forecast System (EPFS; 21 member) has been developed for fog and made operational for winter 2020-2022. The EFS framework comprises the WRF model with a 4 km horizontal resolution, initialized by 21 ICs/BCs. The advantages of probabilistic fog forecasting have been demonstrated by comparing control (CNTL) and ensemble-based fog forecasts. The forecast is verified using fog observations from the Indira Gandhi International (IGI) airport during the winter months of 2020–2021 and 2021–2022. The results show that with a probability threshold of 50%, the ensemble forecasts perform better than the CNTL forecasts. The skill scores of EFS are relatively promising, with a Hit Rate of 0.95 and a Critical Success Index of 0.55; additionally, the False Alarm Rate and Missing Rate are low, with values of 0.43 and 0.04, respectively. The EFS could correctly predict more fog events (37 out of 39) compared with the CNTL forecast (31 out of 39) and shows the potential skill. Furthermore, EFS has a substantially reduced error in predicting fog onset and dissipation (mean onset and dissipation error of 1 h each) compared to the CNTL forecasts.

Chapter – 3
OCEAN SERVICES, MODELLING, APPLICATION, RESOURCE AND TECHNOLOGY (O-SMART)

The OSMART scheme focusses on oceanographic research and technology development activities for the nation. This schemes primarily address the objectives for providing forecast and services based on the continuous observation of our oceans, development of technologies and exploratory surveys for sustainable harnessing of our oceanic resources (both living and non-living) and promotion of front-ranking research in ocean sciences. The scheme encompasses seven sub-schemes namely Ocean Technology, Ocean Modelling and Advisory Services (OMAS), Ocean Observation Network (OON), Ocean Non-Living Resources, Marine Living Resources and Ecology (MLRE), Coastal Research and Operation and Maintenance of Research Vessels. These sub-schemes are being implemented by autonomous/attached institutes of the Ministry, viz. National Institute of Ocean Technology (NIOT), Chennai; Indian National Center for Ocean Information Services (INCOIS), Hyderabad; National Centre for Polar and Ocean Research (NCPOR), Goa, Center for Marine Living Resources and Ecology (CMLRE), Kochi; and National Centre for Coastal Research (NCCR), Chennai as well as involving other national institutes. A fleet of oceanographic and coastal research vessels of the Ministry provide required support for the scheme.

3.1 Ocean Sciences and Services

The activities related to ocean services stated in the following sub sections are primarily conducted by Indian National Center for Ocean Information Services (INCOIS), Hyderabad.

3.1.1 Tsunami Early Warning services

Indian Tsunami Early Warning Centre (ITEWC) monitored 16 earthquakes of magnitude ≥ 6.5 during the period January 2022 to September 2022 in the Indian & global oceans (Fig. 3.1). Out of these 16 earthquakes, only 2 earthquakes occurred in the Indian Ocean region. ITEWC assessed the situation carefully during each of the earthquakes in the Indian Ocean and declared no possibility of causing tsunami.. Being the Tsunami Service Provider (TSP) for the Indian Ocean, the necessary bulletins were also provided to 25 Indian Ocean rim countries and Inter governmental oceanographic commission IOC.

24th Communications (COMMs) test of the

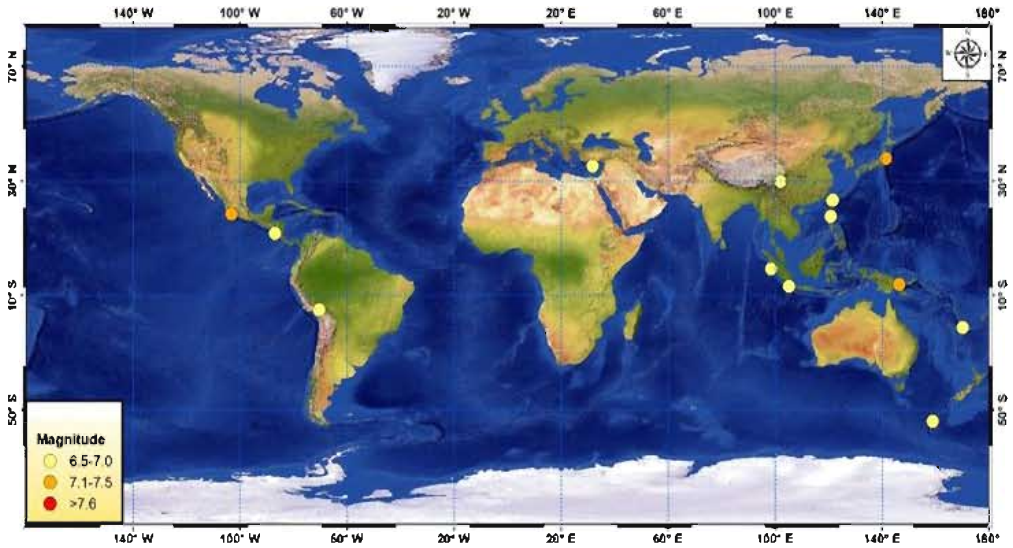


Fig. 3.1 Locations of earthquakes with magnitude ≥ 6.5 Mw occurred in the Indian & global oceans.

Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) was conducted on 08 June 2022 to validate the TSP's (Tsunami Service Providers) dissemination process to NTWCs (National Tsunami Warning Centres), validate the dissemination processes for tsunami notification messages with national disaster management contacts, reception of the notification messages by NTWCs. During the COMMs test, the scenario of M9.2 at Northern Sumatra, Indonesia was evaluated. ITEWC disseminated notification messages using email, fax, GTS, SMS and website to 25 NTWCs and including two TSPs (Australia & Indonesia) in the Indian Ocean Region.

The UNESCO-IOC Tsunami Ready start-up program was conducted for the Alappad community at Amritapuri, Kollam Dist., Kerala on 09 June 2022 in coordination with Amrita Vishwa Vidyapeetham and Kerala Disaster Management Authority (KSDMA). Tsunami Evacuation Planning (TEP) workshop conducted at INCOIS on 13 September 2022 as part of IOC-UNESCO and UNESCAP project "Strengthening Tsunami Early Warning in the Northwest Indian Ocean Region through Regional Cooperation" for northwest Indian Ocean Region.

3.1.2. Potential Fishing Zones and Tuna Advisories

The advisories on Potential Fishing Zones (PFZ) generated using the satellite-derived Sea Surface Temperature (SST), chlorophyll concentration, water clarity and sea level. The advisories were disseminated in smart map and text form on a daily basis, except during the fishing-ban period and adverse sea-state conditions. During the period 01 January 2021 to 30 September 2022, multilingual Potential Fishing Zones (PFZ) advisories and Yellowfin Tuna advisories were provided respectively for 251 and 108 days out of 273 days (Fig. 3.2).

3.1.3 Coral Bleaching Alert System

Coral Bleaching Alert System (CBAS) provided 90 advisories from January to September, 2022. These advisories comprise Hot Spots (HS) and Degree of Heating Weeks (DHWs) estimated using SST anomalies derived from satellite data on a bi-weekly basis. 8 watch alerts of hotspots were observed (4 at

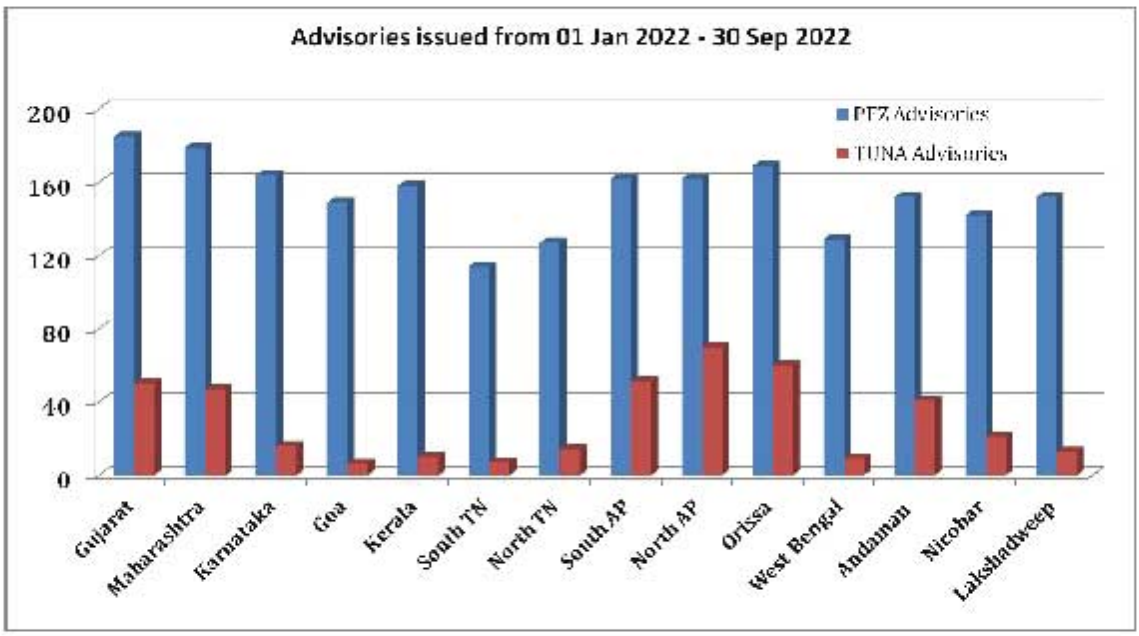


Fig.3.2 Number of PFZ and Tuna PFZ advisories issued during Jan-Sep, 2022.

Andaman, 3 at Lakshadweep and 1 at Nicobar.

3.1.4. Algal Bloom Information Services

INCOIS Algal Bloom Information Services (ABIS) uses MODIS-Aqua retrieved ocean colour data to provide near-real time status of algal bloom in the northern Indian Ocean waters in a daily basis. Based on historical frequent occurrences four bloom hotspots (NE Arabian Sea, Kerala Coast, Gulf of Mannar and Coast of Gopalpur) have been identified and are being monitored using ABIS. During January to September, 2022 ABIS alert were issued for 26 days.

3.1.5 Ocean State Forecast

Daily operational forecasts has been continued to be seamlessly issued covering the parameters of waves, winds, currents, tides, Sea Surface Temperature (SST), Mixed Layer Depth (MLD), Depth of 20°C isotherm (D20) for various regional and coastal domains. Daily ocean state forecast (OSF) data was issued to Sri Lanka, Maldives, Seychelles, Comoros, Mozambique and Madagascar. Cyclone/depression conditions was monitored and joint INCOIS-IMD bulletins were issued for dissemination the warnings through multiple modes to the user communities.

3.1.6. Oil-spill trajectory advisories

Oil-spill trajectory advisory was provided for MV Princess Vessel in June 2022. Based on the request from Karnataka State Disaster Management Authority (KSDMA), model simulated oil drift patterns was issued (Fig. 3.3) on regular intervals (starting from 21 June 2022 to 04 July 2022) from the spill location 12° 45.5'N, 74° 51.1'E of the wrecked vessel MV Princess which had 220 Tons of Fuel oil on board. Initially, the drift pattern was towards the East and North. Later, the drift pattern was changed to southward. These periodical advisories were sent to the Indian Coast Guard, KSDMA, Pollution Control Boards, Coastal Police, Fishing department, Mangalore Refineries, New Mangalore Port Authority, etc.

3.1.7 Storm Surge and early Warning Services

One cyclone and three deep depression systems was monitored and timely storm surge and inundation advisories were issued through Indian Meteorological Department (IMD). A total of 400 High Wave Alerts/Warnings were issued to caution the users on the impending high waves on the coast from January to September, 2022.

Advisory services have been provided to specific

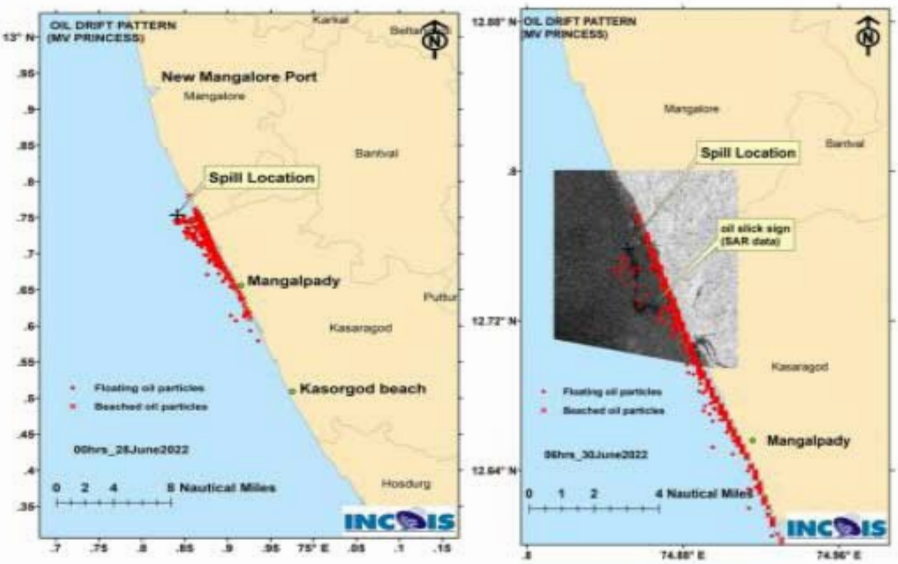


Fig. 3.3 Model simulated of oil drift patterns of MV Princess vessel and its validation.

users like disaster management authorities, fishermen, ports and harbours, ships plying in the seas, offshore industries and the defense authorities

3.1.8 Data Services

The data centre at INCOIS acquired and archived real-time data from various ocean observing systems. The data center also receives and archives delayed mode data from various observing systems such as XBT/XCTD observations, Met observations (NODPAC), OMM cruise data, ADCP data, OMNI hard-disk data, etc. INCOIS established three Ground stations to meet the in-house operational advisory services and acquire data from AVHRR (Metop-A, NOAA-18 & NOAA-19), VIIRS (Soumi-NPP), MODIS (AQUA & TERRA) & OCM (Oceansat-2) sensors. Remote sensing data products such as Sea Surface Temperature, Chlorophyll-a, etc. are regularly archived by the data centre.

3.1.9 Deployment of autonomous coastal water quality observatory

"Coastal Observatories" at off Kochi and Visakhapatnam along the Indian coast was established in May 2022. Buoy was deployed at approximately ~30 m water depth and ~6-8 km from the coast, housing multiple sensors for physical (temperature, salinity, depth, surface current) and water quality (dissolved oxygen, nutrients, chlorophyll, turbidity, pH, pCO_2) parameters. The buoy based autonomous observatory which was inaugurated by the Hon'ble Minister for Ministry of Earth Sciences on the 16th Foundation Day of MoES on 27th July 2022 at Prithvi Bhavan, New Delhi will lead to the initiation of water quality nowcast service (Fig. 3.4 (a)).

3.1.10. Ocean Modeling and Data Assimilation

A regional coupled ocean-ecosystem model for the Indian Ocean region has been developed following the Regional Carbon Cycle Assessment and Processes Phase 2 (RECCAP-2) Ocean Modeling Protocol (Fig. 3.5) The model simulated data for a period from 1980 to 2019 has been submitted to the MPI-BGC data server.

3.1.11 Ocean Observation Network

To serve the need for operational forecast and advance the predictive understandings of multi-scale physical, biogeochemical, and ecosystem processes and interactions among them, the following observation platforms have been deployed:

- An extensive network of 75 Argo floats in the Indian Ocean is maintained including 48 core

Fig. 3.4 (a) Inauguration of Water Quality Nowcast Service of INCOIS. (b) Coastal autonomous water quality observatory off Kochi

Argo floats (CTD sensor only) and 27 BGC floats (CTD sensor plus biogeochemical sensors).

- As a contribution to the Global drifting buoy programme 26 drifters were deployed, which measure near-surface atmospheric and oceanographic parameters in the Indian Ocean in collaboration with national agencies.
- Maintained a network of 16 Waverider Buoy (WRB) during the reporting period to monitor

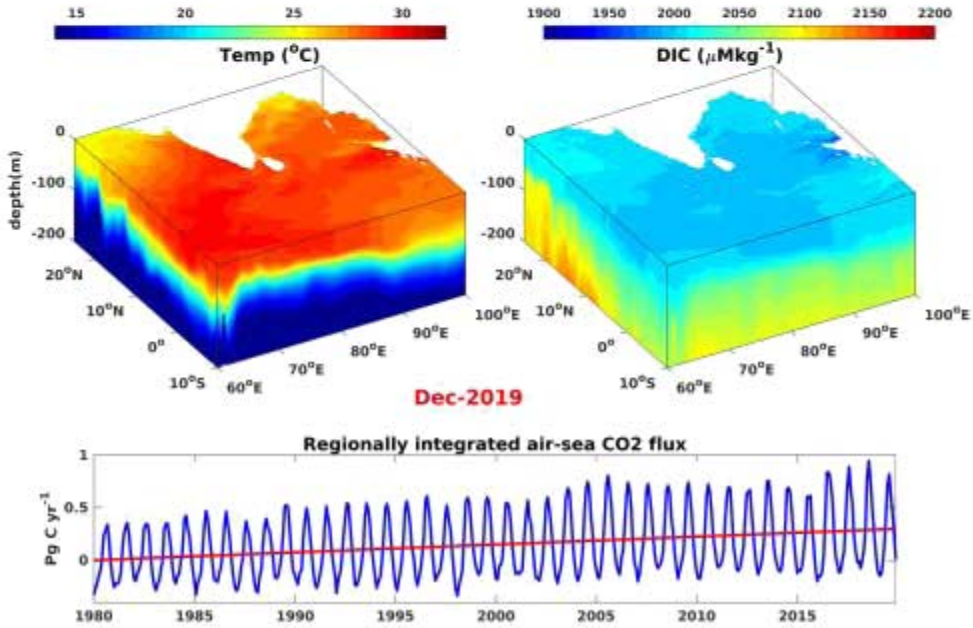


Fig. 3.5 Model simulated upper ocean structure of temperature (°C) and dissolved inorganic carbon (μM/kg) in Dec 2019 (top panels). Time series evolution of the regionally integrated air-sea CO_2 flux for the Indian Ocean from 1980 to 2019 (bottom panel).

are equipped with sea surface temperature and barometric pressure in the north Indian Ocean

- 17 ADCP moorings (13 slope moorings and four shelf moorings) along the entire Indian coast and 3 ADCP moorings along the equator are maintained in collaboration with CSIR – National Institute of Oceanography (NIO),.
- Real-time data from 36 tide gauges were received at ITWEC through INSAT and GPRS modes of communication. The radar Tide gauge system at Gopalpur port with GPRS communication has been accomplished. A network of Tsunami Buoys deployed close to the tsunamigenic source regions in the Bay of Bengal and the Arabian Sea,
- Network of 34 Automatic Weather Stations (AWS) in ships and offshore platforms to the ocean wave characteristics along the Indian coastal waters, and the propagation of southern ocean swells to the north Indian Ocean in near-real-time.

Regular calibration of the systems in recommended intervals has been performed to ensure the quality of data from these networks. The construction of the recording room for the installation of emergency communication, with co-located SMA, GPS, and meteorological sensors with real-time VSAT connectivity, has been completed at 32 stations.

3.2 Studies in Marine Living Resources (MLR)

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

3.2.1. Ecosystem Processes and biological response

Under the ecosystem process studies, intra-annual variation and dynamics of the oxygen minimum zones (OMZs) were mapped along the off-shore regions of eastern Arabian Sea. The Oxygen Minimum Zones (OMZ) of the Arabian Sea (EAS) is the thickest and second-most intense OMZ formed primarily due to poor ventilation and high biological respiration rates. The OMZ (<20 µM oxygen) in the EAS varied between 60 and 1350 m and its thickness decreased from north to south. A significant seasonal and sub seasonal variability was observed in the vertical extend of upper OMZ during upwelling and winter convective mixing processes. The convective mixing in the north EAS during the winter monsoon resulted in deepening of upper OMZ and core OMZ up to 200m depth. However, the shoaling of OMZ associated with upwelling was noticed during the summer monsoon which significantly reduced the dissolved oxygen in the upper layers Subsequently, the average dissolved oxygen levels in the upper 100m reached up to ~40 µM in the central EAS

The influence of physical processes on oscillations in the nitracline depth has been studied. The upper boundary of thermocline (26C isotherm), which oscillates with the seasonal physical forcing was found positively aligned (Fig. 3.6) with the depth of nitracline (depth of ≥ 3 µM NO_3^-). This implies that the depth of 26oC isothem can be used as proxy to desire the nitracline depth, which is highly useful for training the bio geochemical models. Mixed layer nutrient availability varied with the depth of nitracline and relatively faster nitrogen exhaustion than phosphorus during the nutrient enrichment events viz. upwelling and convective mixing yielded low N/P ratios. With continued uptake of nutrients by the plankton the system during oligotrophic inter-monsoons became nitrogen-limited with surplus (excess) phosphate (P*), resulting in the lowest N/P ratios (1.5±0.7) in the mixed layer. The reduction in P* along with high cyanobacterial abundance towards the late phase of summer monsoon and fall inter-monsoon (high zeaxanthin concentrations) indicate the dominance of diazotrophy.

The vertical structure of dynamic stability and chlorophyll was established from the monthly time series observations along the Eastern Arabian Sea. Generally, the northern region of Eastern Arabian Sea was always unstable or neutrally stable while the southern region was relatively stable. During winter, the entire coastal region was unstable to neutrally stable (N^2~0-5 cph) conditions, while in the offshore highly stable layers from the surface to 100 m depth in the south and unstable waters in the north up to 100 m was observed. The study also suggested that dynamic stability (Brunt-Vaisala frequency) has marked control on the formation of deep chlorophyll maximum (DCM) layers when the latter occurs in shallow euphotic zone. The mean structures of dynamic stability and chlorophyll profiles during summer and winter showed good statistical correlation between DCM and Deep Stability Maxima (Fig. 3.6)

In the, phytoplankton biomass Chlorophyll-a and primary production were moderate and comparable during both the north east (NEM) and south west Monsoon SWM. Due to significant surface stratification, the south (SEAS) was oligotrophic during the NEM, but, was productive during the SWM due to coastal upwelling along the shelf waters The SWM along the shelf waters in the EAS favoured the growth of larger micro- and meso-phytoplankton whereas the NEM in the entire NEAS favored the growth of nano-phytoplankton.

Role of mesoscale eddies, both propagating and non propagating in the sustenance of high biological productivity in North EAS during the winter-spring transition period has been well understood. In the non-eddy areas, where convective mixing is active, diatoms (96.74%) dominated over the dinoflagellates (3.14%). Extensive blooms of the dinoflagellate green Noctiluca *(N. scintillans)* contribute to the very high cell density in the periphery of the Cold Core Eddy, where the currents

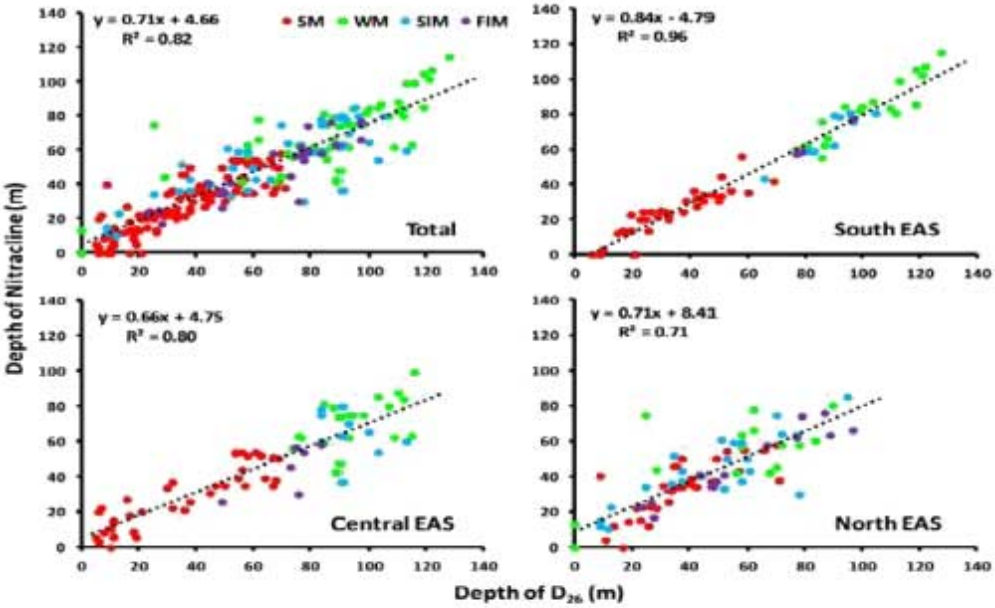


Fig.3.6 Relationship between depths of nitracline and 26C isotherm in the eastern Arabian Sea, which is strongest in the stratified south than the weakly stratified north.

were comparatively weak, and water column was more stable. Active mixing is associated with diatom dominance, followed by Noctiluca when the mixing slackens, making use of the available nutrients and supported by regenerated production Fig. 3.7). The Noctiluca bloom (mid-March) is succeeded by Trichodesmium (April-May), in the stratified nutrient depleted, abundant light environment which propagated southwards.

3.2.2 Biodiversity and Ecology

Under the biodiversity studies, taxonomic information of marine (reef-associated and deep-sea) organisms collected on-board FORV Sagar Sampada within the Indian EEZ yielded five new species of decapod crustaceans *(Intesius brevipes,* Guyanacaris keralam, Munida samudrika, Paramunida travancorica and Munidopsis bhavasagara), one new species of fish *(Himantolophus kalami)* and two new species of polyclad flatworms *(Pseudoceros bipurpurea, Pseudoceros galaxea)* (Fig 3.8). In addition to the above, two decapods, three deep-sea fishes and one polyclad species were documented as new zoo-geographical record from the Indian EEZ.

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 3,311 voucher specimens categorized under 23 faunal groups representing 8 animal phyla (Annelida – 915, Arthropoda – 886, Chordata – 729, Echinodermata – 520, Mollusca – 120, Nematoda – 100, Platyhelminthes – 36 and Cnidaria – 5) have been deposited at the CMLRE

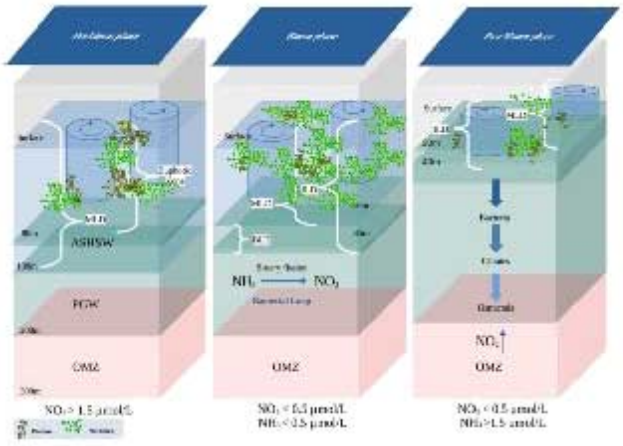


Fig 3.7 Schematic representation of the dynamics of the green Noctiluca bloom in the North Eastern Arabian Sea.

repository and the digital data has been disseminated through IndOBIS data portal. ***Seven deep-sea taxonomic catalogues based on the deep-sea specimens collected through FORV Sagar Sampada expeditions were published for outreach activities (Fig.3.9).***

stretch of Indian coastline are monitored for the various physicochemical, biological and microbiological characteristics of seawater and sediments to detect the periodical changes in the seawater quality. Two cruises from West Bengal to Goa were undertaken during February 2022 to April

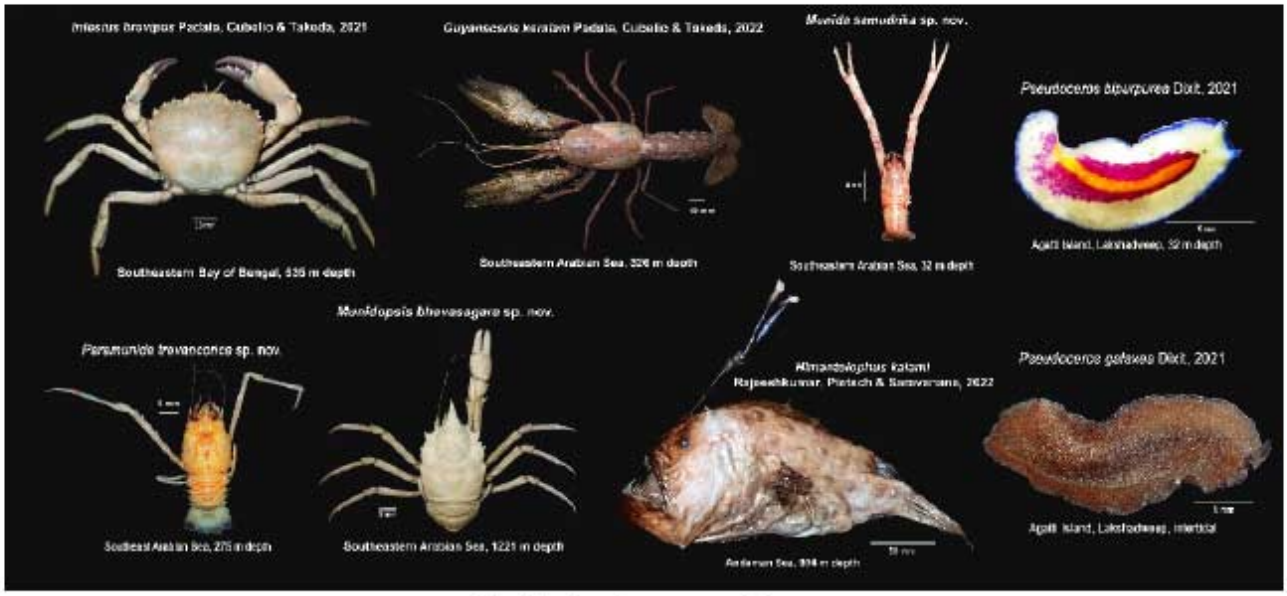


Fig 3.8: Species new to science

3.3 COASTAL RESEARCH

The activities related to coastal research in the following sections are carried out by National Centre for Coastal Research (NCCR), Chennai.

3.3.1 Marine and Coastal Pollution

Under Seawater Quality Monitoring (SWQM) program, 50 coastal locations covering entire

2022 to assess the coastal water quality. Based on our observations, the coastal water quality index (CWQI) was calculated and it is observed that most of the locations are in moderate condition. The eDNA (environmental DNA) analysis was carried out at Tuticorin bay to understand the abundance of antibiotic and metal resistance bacteria at

Fig. 3.9 Deep-sea taxonomic catalogues

nearshore (1km) and offshore (5km) waters (Fig. 3.10 a & b). The dominance of resistomes gradually decreased from near shore to offshore waters. The dominant metal resistance gene like Multicopper Oxidases (MCO), antibiotic resistance gene Multidrug export protein (AcrF) and serine beta-lactamase (blaEC) are highly abundant at 1 km waters. Ferrous ion-efflux transporter (FieF) and organomercurial transporter (MerC) are predominant at Tuticorin Thermal power plant coolant water discharge region.

The high-resolution observation and prediction system are conducted through automated buoys equipped with meteorological and water quality sensors and deployed along the Chennai and Puducherry coast water at 12 m depth. A numerical

as Marina, Elliot, and Thiruvanmiyur are being disseminated through the "Clean Coast" mobile digital application platform as part of the "Clean Seas Mission".

Coastal clean-up programs are conducted at regular intervals as a part of the "Clean Seas Program (Swachha Sagar)" to create awareness on marine litter. In the context of "Azadi Ka Amrit Mahotsav", MoES launched the "Swachh Sagar, Surakshit Sagar" campaign to clean-up India beaches all across India and raise awareness about the importance of a Clean and Safe Sea. A total number of 75 beaches covering the entire Indian coast were identified for creating awareness among the beach visitors, fishing communities, other coastal stake holders and general public on the ill effects of beach litter on

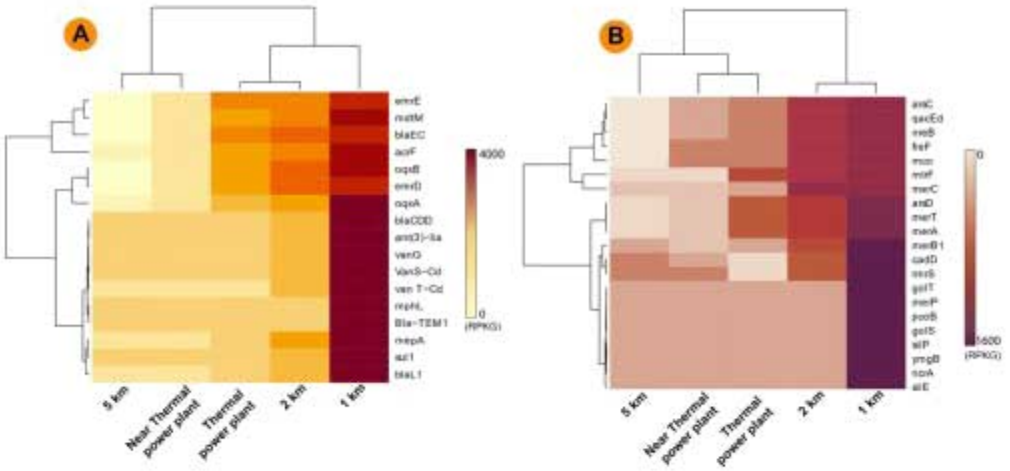


Fig. 3.10 Heatmap showing the Relative Abundance of (A) Antibiotic Resistance Genes and (B) Metal Resistance Genes in Tuticorin Coastal Waters.

model has been developed for both Chennai and Puducherry coastal waters to simulate and predict the water quality parameters viz., sea surface temperature, salinity, dissolved oxygen, chlorophyll-a, pathogens (faecal coliform, total coliforms, and Enterococci) using in-situ data, buoy data, and forcing boundary condition from the global models. At present, the model provide three day(s) forecast of the coastal water quality parameters. The water quality buoys data along with forecasted model output of water quality parameters for the three recreational beaches such

the marine environments (Fig.3.11). About 58,100 volunteers participated and collected a total of 64,714 kg marine litter from the coastal areas. The most of the litter collected during this event were of single use plastics such as polyethylene bags, water bottles, and food covers. International Coastal Cleanup 2022, with a theme 'Swachh Sagar, Surakshit Sagar' was organised and one such mega event was organised at Juhu Beach, Maharashtra (Fig. 3.12) through MoES participation. A mobile application and digital dashboard named "SS Sagar" was designed and developed. Data on marine litter

collected during the beach cleaning event were uploaded that allowed identifying the amount of litter in the different beaches along the Indian coast.

3.3.2 Coastal Processes and Hazards

As a part of shoreline management study, a total of 526 numbers of shoreline change maps has been generated using the standard protocol (1:25000 scale) for the entire Indian coast. A web-based GIS application was developed as a digital version comprising of all the shoreline change maps for the Indian coast (1990-2018), which will help various coastal agencies/stake holders for better management of the coast. The shoreline change map has been released in two volumes corresponding to the East and West coasts of India. The shoreline change maps for Lakshadweep Islands has also been prepared. In addition, the coastal geomorphology and structures were mapped along with their functional and structural performance for Tamil Nadu, Puducherry, and Kerala coast.

The coastal protection strategy for Chellanam Coast (Ernakulam district, Kerala) has been developed using numerical models based on long-term historical shoreline change, topographic and oceanographic observations. A detailed project report was prepared with hybrid solutions (seawalls, T groins and beach nourishment) and submitted to State Irrigation Department, Govt. of Kerala to abate coastal erosion due to high waves during the monsoon season. An MoU has been signed with the Kerala Government for preparation. of shoreline management plan for Kerala coast and coastal protection measures for 10 hotspot locations. Among them, the plans for Kollamkode, Varkala, and Shangumugham hotspots are in the final stage.

Fig. 3.11 The awareness rally during the ICC 2022 event at Mandavi Beach

Fig. 3.12 The Secretary of Ministry of Earth Sciences addressing ICC 2022 event at Juhu Beach, Mumbai.

Integrated Flood Warning systems (I-flows) for Chennai and Mumbai are presently in operation and are used to provide impact-based warnings by IMD. Flood inundation maps was also prepared from the actual rainfall data from a network of automatic rain gauges. The inundation maps along with details of inundation at ward level forms part of the IMD bulletin that is provided to the state government for their mitigation operations (Fig 3.13 a & b).

3.3.3. Coastal Habitats and Ecosystems

It is proposed to develop a modular framework to assess the ecosystem status of the Southeast coastal waters of India influenced by natural, anthropogenic, and climate change scenarios starting from Kalingapatnam in Andhra Pradesh to the Gulf of Mannar, which includes three critical habitats viz. Coringa - mangrove ecosystem, Pulicat - lagoon and Gulf of Mannar – coral ecosystem. For the assessment of ecosystem assessment of Pulicat lagoon a total of 54 indicators were quantified in which 14 pertaining to provisional services, 27 in regulating and 13 in cultural services.

Long term reef health monitoring is being carried out in the Gulf of Mannar since 2018 to assess the live and dead coral coverage, community structure of reef-building corals, species diversity, anthropogenic impacts, and emerging threats to the ecosystem. The Vedhalai Reef Site, Pillaimadam Reef Site, Taraval Reef Site, and Munaikadu Reef Site (Live reef with full of young coral colonies) were

Fig. 3.13 (a) I-flows-Chennai in operation during North East (NE) Monsoon in Chennai (b) Flood conditions in Chennai during NE Monsoon.

considered for the study and massive Scleractinia corals, sponges, ascidians, burrowing polychaetes, polyclads, gastropods, opisthobranchs, Echinodermata and reef fishes were observed (Fig.3.14 a to d).

3.3.4 Integrated Ocean Management

As part of the Indo-Norwegian Collaborations Marine Spatial Plans (MSP) are being developed for two pilot areas namely Puducherry and Chennai. A number of stakeholder meeting were held and their requirements were incorporated while developing the knowledge base for MSP for the pilot sites. A framework for integrated, ecosystem-based marine spatial planning in India would be developed which can be replicated in other coastal areas

A web GIS based decision support system "Digital Coast–India (D-COIN)" has been developed housing all datasets on coastal and marine pollution, marine litter, shoreline changes , coastal hazards, ecosystems etc generated through various projects of NCCR over the years. This long term spatial database would be an invaluable tool to the coastal administrators for effective decision making.

Fig. 3.14 (A) Scleractinian coral diversity in Palk Bay (B) Opisthobranchs and Polyclads recorded from Palk Bay (C) Benthic invertebrates in reef monitoring site (D) Artificial Reef associated biota in Thonithural Palk.

3.4 Ocean Technology

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

3.4.1 Energy and Fresh Water

Establishment of the OTEC powered desalination plant at Kavaratti is in progress. Bhoomi Pujan ceremony at site was performed on 31 March 2022 by Shri Praful Patel, Administrator, UT Lakshadweep, in the presence of Director, NIOT and members from both NIOT and Lakshadweep Administration (Fig. 3.15) A white paper on OTEC for policymakers and stakeholders was published by Ocean Energy Systems (OES) Technology Collaboration Program (TCP) under International Energy Agency (IEA).

Subsequent to MoES-NIOT successful establishment of Low Temperature Thermal Desalination (LTTD) plants at Kavaratti (2005), Minicoy and Agatti (2011).the task of establishing six more plants with capacity of 1.5 lakhs per day at Amini, Androth, Chetlat, Kalpeni, Kiltan and Kadamat Islands of UT Lakshadweep is in progress. Kalpeni and Amini Desalination plant (Fig. 3.16) generated fresh water in January 2020 and July 2022, respectively.

3.4.2. COASTAL AND ENVIRONMENTAL ENGINEERING

The Coastal Inlets Research Programme (CIRP) proposed, tourism, fishing, etc. Such Studies have been undertaken for Ennore creek, Cooum River estuary and Adyar estuary, to keep the inlets sustainably open to ensure higher dilution improved water quality and for navigation. A Workshop were conducted at Chennai and Thiruvananthapuram during the month of September for state coastal stakeholders to identify hotspots and priority locations which require sustainable opening.

Based on the request of the Kerala Government, scientific studies were carried out and constructing submerged detached breakwaters using geotextile tubes was recommended at Poonthura village, District Thiruvananthapuram to protect large scale erosion under Sustainable shore protection scheme. Design, deployment and monitoring of artificial reefs for fishery development along the Pulicat coast has been carried out. Artificial reef civil structures were designed with wide base for scour protection and placed at 10m water. A ready to use wave atlas for north Indian Ocean including Islands is developed using 27 years (1995 to 2021) of high resolution wind data as model input and

Fig. 3.15 Bhoomi Pujan ceremony performed by Shri Praful Patel, Administrator, Lakshadweep

Fig. 3.16 Amini LTTD Plant

validation from observations. North Indian Ocean Tide (N.I.O.T) mobile App was developed with observation data along the Indian Ocean.

3.4.3. OCEAN SCIENCE AND TECHNOLOGY FOR ISLANDS

Mycosporine like amino acids (shinorine, porphyra and glycine) with potential cosmetics application were extracted from cyanophycean algae viz. Synechococcus marinus, Spirulina major, Trichodesmium thieubautii, Phormidium sp. Nostoc sp.,. A maximum yield of 0.7 mg/g mycosporine like amino acids was recorded in Spirulina major. The bio-surfactant extracted from the marine bacteria Brevibacterium sp. was tested for dispersion efficiency and toxicity as per EPA standards and a maximum dispersion efficiency of 70% was achieved in the 1:10 crude oil concentration. Technology for production of recombinant ectoine (Fig. 3.17 a) from deep sea bacteria for cosmetic applications and bioremediation of petroleum hydrocarbon in marine environment by deep sea microbial consortia were transferred to industry through NRDC. The open sea cages were redeployed in the new location in Olaikuda, Rameswaram with the technical support of NIOT the Olaikuda fisher men self help group reinitiated open sea cage culture of. Organised a national virtual industrial meet iCEN-69 on technology for cage culture of marine fin fish.

3.4.4. MARINE SENSOR SYSTEMS

Development of indigenous Underwater Acoustic Telephone (UAT) to be used in manned submersible at 6000m depth is initiated. UAT which has been demonstrated using Single Sideband Suppressed Carrier (SSB) Modulation technique in laboratory scale in Acoustic Tank Facility (ATF) tank.

Design of sonar to provide high-resolution images (decimeter level) of the sea bed and objects for detection of image is undertaken. A low frequency range (4-12 kHz), 2x5 transducer array was realized with indigenously developed NIOT-BEL transducers. The array and other subsystems have been assembled in a tow body (Fig. 3.17 a) and experiments have been carried out in Acoustic Test Facility (ATF). Preliminary sea trials carried out off Chennai, generated images of sea bed and a known ship wreck. A networkable digital hydrophone array has been realized and successfully tested and demonstrated in the Acoustic Test Facility (ATF) (Fig. 3.17 b).

3.4.5. OCEAN ELECTRONICS

Significant achievements in three major areas such as Development of New Ocean Observation Technologies, Indigenization of Marine Instruments and satellite communication payloads developments using Indian satellites are as follows

- Indigenized the Drifting buoys with INSAT communication and technology was transferred to Indian industries.
- Development of Deep Sea Autonomous Underwater Profiler (DAUPD - operable up to 5000m) is progressing with indigenized 1000 CC variable buoyancy engine. Currently two proto

units integrated and tested for basic functionality at sea conditions and scheduled for field deployments.

- Development of Open Sea subsurface Fish Cage Culture system, auto feeder is in progress. A bio-mass estimation system using Machine Learning algorithm is developed and trail production is initiated.

Fig. 3.17 (a) Assembled Prototype i-SASSS A (b) Digital hydrophone array during ATF tests

- Initiated adapting the Drone Technology for marine applications and field demonstrated the functional capability of Drone based ocean data and sea water sample collections.

3.4.6. OCEAN ACOUSTICS

The Deep-Water Ambient Noise Measurement System (DANMS) was developed indigenously for long term noise data acquisition and was incorporated with the moored buoy and deployed in the Arabian Sea (AS) in March 2022 (Fig. 3.18 a) and in the Bay of Bengal (BoB) in September 2022 and they are operational. The acoustic data from Ambient Noise Measurement System (ANMS) deployed as part of CAATEX (Coordinated Arctic Acoustic Thermometry Experiment), in Central Arctic Ocean during August 2019 – August 2020has been retrieved. ANMS incorporated in the IndARC mooring has also been retrieved. A bottom mounted vector sensor system has been developed and deployed for underwater source localization in shallow waters. Field trial was successfully conducted in the harbour region in Chennai for ship noise localization towards coastal surveillance applications (Fig. 3.18 b).

3.4.7. SEAFRONT FACILITY

MoU has been signed with CPWD for the proposed Seafront Facility development works. The planning, structural design and configuration for Ballast Water Treatment Technologies – Test Facility (BWTT-TF) are completed. The planning, preliminary structural design and configuration for pipeline trestle with seawater intake system for BWTT-TF has been completed.

3.4.8 Shallow water bathymetry:

NIOT is collecting shallow water bathymetry data (0 – 30 m water depths) for the east coast of India. Currently, 100% of the survey along West Bengal has been completed successfully, 70% of survey work has been completed in Tamil Nadu and Andhra Pradesh, and 10% of work has been completed on the Odisha coast.

3.4.9 Ocean Observation system network

As part of the maintenance of the moored buoy network 23 operations (13 deployments, 7 retrivals and 3 mooring retrivals) have been carried out in 40 ship days during this year.) The moored buoys (BD10 & BD11) in the BoB provided real-time observations during the cyclone ASANI, May 7-12, 2022 and

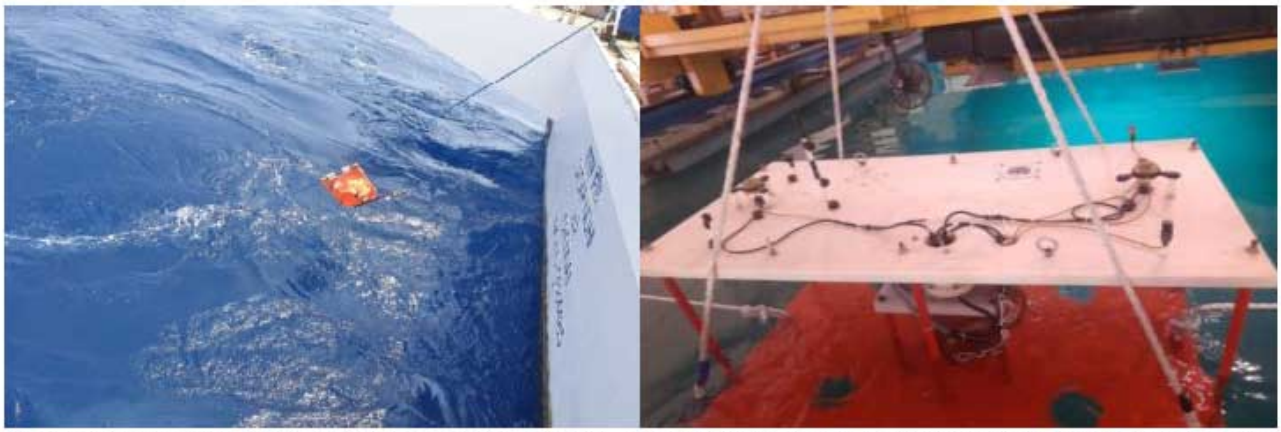


Fig. 3.18 (a) Deep Water Ambient Noise System Deployment in Arabian Sea (b) Field trial of Bottom mounted vector sensor system

Tropical Cyclone Heat Potential (TCHP) data was provided to IMD (Indian Meteorological Department) (Fig. 3.19 a)

Developed an Indigenous Automatic Rain Gauge and the system is installed at NIOT, Chennai campus and data is being shared with IMD National ARG network. Established an indigenous Calibration facility for Digital compass used in buoy systems at NIOT. A Prototype unit of Indigenously developed Tsunami Bottom Pressure Recorder (BPR) Sagar-Bhoomi was successfully deployed off Chennai on 17th September 2022. The interfacing satellite telemetry systems with existing AWS of NCPOR for Real time data transmission was carried out at Indian Himalayan Research Station-Himansh (Fig. 3.19 b). Indigenous technology developed like Robo Coastal Observer, Met Ocean Buoy System, Indian Tsunami Buoy System (and were successfully transferred to M/s. Larsen & Toubro and M/s. Norinco Private Ltd., Chennai . Indian Coastal Ocean Radar Network operates and maintains 10 systems along the coast of India including two systems in the Andaman Islands. Velocity data from the HF radar Network are combined on standard grids, and this data is disseminated through Central servers at NIOT and INCOIS for operational and academic use.

3.4 Ocean Survey and Mineral resources:

The activities of this component are carried out by National Centre for Polar and Ocean Research (NCPOR), Goa

3.5.1 Geoscientific Studies of the Exclusive Economic Zone (EEZ)

This program generated high-resolution bathymetric data of the Indian EEZ with an area coverage of about 1.7 million km^2. The coverage of surveys undertaken so far is shown in Fig.3.20. The bathymetric chart creation for the Indian EEZ in 2°x2° format is in progress, as per the Marine map compilation Index. Geomorphological analysis of the high-resolution multibeam bathymetric data from the western coast of India show regional-scale submarine landslides, approx. 50 km offshore Quilon, Kerala Water depths range between 150 m at the continental shelf edge and 2,000 m towards the opening of the abyssal plain and the seafloor is characterized by slide scars, channel incisions and a crack system collectively named as the Quilon Slide Complex (QSC). Multiple slope failures have been identified along the crack system, and the region can be categorized as a 'landslide susceptible zone'.

3.5.2 Hydrothermal Sulphide Exploration Program

A mission-mode multi-disciplinary program on hydrothermal sulphide mineralization exploration studies at mid-ocean ridges, with emphasis on the South West and Central Indian Ridges is in progress as per the ongoing contract with the International Seabed Authority (ISA) in the allotted area of 10,000 sq km in the Indian Ocean. .

The major objective of the program is to identify the

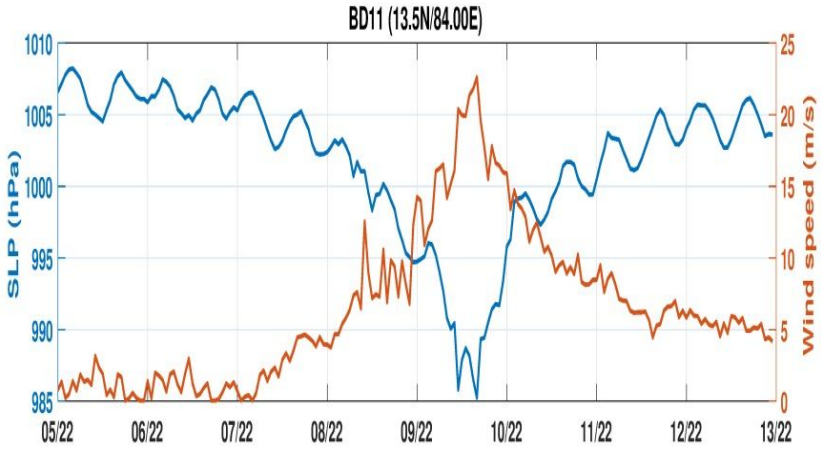


Fig. 3.19 (a) Time Series of SLP and Wind Speed recoded by BD11 buoy in the Bay of Bengal during the ASANI cyclone, 7-12 May 2022 (b) Interfacing satellite telemetry at HIMANSH Station

most probable locations of polymetallic sulphide deposits in the proposed exploration area in the Indian Ocean together with scientific research in the frontier areas of hydrothermal mineralization including the tectonic environment, host-rock composition, and development of geological models for seafloor hydrothermal system. The integrated multidisciplinary studies carried out so far leads to the identification of few promising locations of hydrothermal activity in the contract area. Some of the significant outcomes of the program are highlighted below:

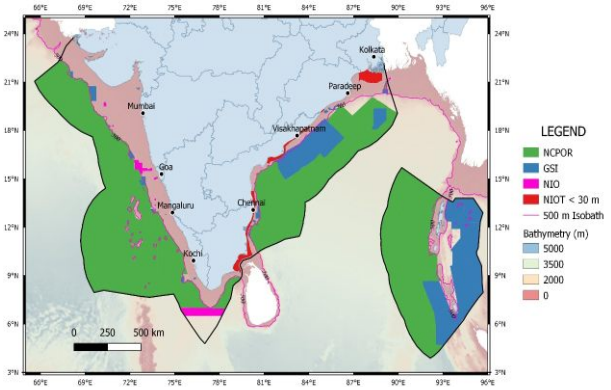


Fig. 3.20 Total surveyed area so far in the Indian EEZ

- **Discovery of new hydrothermal plumes in eastern SWIR:** Systematic water column studies for helium (^{3}He), methane concentrations and its carbon isotope studies in deep waters(2000-5500m), along the ~480 km long stretch of eastern Southwest Indian Ridge (63.5°-68°E) show presence of eleven plumes of which eight are reported for the first time. In addition, the presence of three plumes and their dispersion over 160 km along the east-west direction along the ridge has been identified. Moreover, high δ^3He values (up to 180%) in the 67.67°E region of the Indian Ocean were recorded indicating magmatic degassing in the ultraslow-spreading Southwest Indian Ridge.

- **Geochemical characteristics of sulphides recovered from Cluster A, CIR** Geochemical characterization of polymetallic sulphide recovered from Cluster 'A' represented three varieties like massive to crystalline variety of sulphide [with Fe (35.55%), S (57.01%) and Cu (1.03%)], altered and secondary mineralized variety [with Fe (27.32% to 54%) , Cu (22% to 40%)and very low S (0.14% to 0.64%) and predominantly of Fe contained type [Cu and S are negligible].

- **Geochemical characteristic of sediments from SWIR and CIR** Geochemical studies of surface sediments from CIR shows low metalliferous index (<40), negative Ce and positive Y anomaly

suggest the influence of hydrothermal activity in these sediments. Cluster analysis (Fig. 3.21) broadly classified the sediments into two groups a) hydrothermal sediments with low input of detrital elements like Al, K, and Ti and b) pelagic sediments with high input of Si, Al, and Mg and low input of biogenic carbonate. The studies on the sediment core from the deepest part of the NTD, SWIR indicate that the sediments are a mixture of biogenic, local mafic, ultramafic and hydrothermal components. The presence of volcanogenic glass shards and phillipsite throughout the sediment core confirms the local volcanic activities in the proximity to this area. The major and trace element data of the samples reveal that the sediments of this area were altered by the low-temperature hydrothermal activities.

- **Geophysical studies in CIR and SWIR:** Geophysical studies were carried out between Melville FZ and RTJ (~1160 km) using updated multibeam bathymetry data, satellite-derived free-air gravity anomalies, published marine magnetic anomalies, shipborne magnetic cruise tracks, and earthquake event data. Studies identified volcanic cones and their distribution analysis shows higher density (~ 3 times) in the magmatic corridors. Three new Oceanic Core Complex features are identified in SWIR near the 64°40'E axis. The active magmatic upwelling on the 64°40'E axis has been suggested. Moreover, studies in CIR region between Gemino Fracture Zone and Rodriguez Triple junction mapped the morphological features like Ridge Segments, Neovolcanic zone, volcanic cones, traces of NTDs, Axial Highs). This study identified six new OCC and mapped extend of amagmatic corridors in the CIR study area.

- **Nature of hydrothermal plume over the axial volcanic ridge at 63° 55'** In order to identify new hydrothermal plumes and to narrow down the source of plumes in the exploration area, a tow-yo cast was conducted over the axial volcanic ridge at 63° 55' close to Mt. Jourdanne inactive site. A prominent plume was observed in this cast (Figure 3.22). The plume was located at depths of 2500 – 2700 m with turbidity

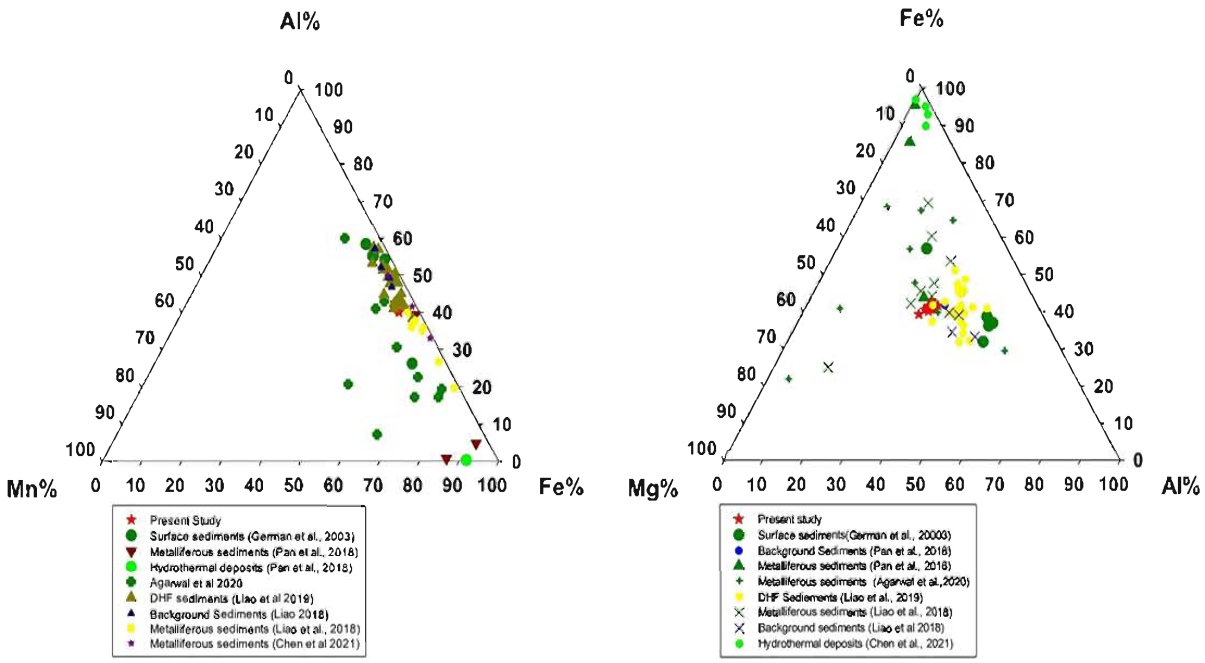


Fig. 3.21 Al-Mn-Fe and Fe-Mg-Al ternary diagram for BC-10 core and comparison with other studies from the SWIR.

anomalies 0.035 dNTU. The plumes might have originated from Tiancheng active field, or from the axial volcanic ridges in the vicinity.

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 CSIR- National Institute of Oceanography (NIO), Goa. High resolution bathymetry survey using Autonomous Underwater Vehicle (AUV) to collect micro-bathymetric data for near seabed mapping is undergoing in the relevant zone of the Indian contract area for Polymetallic nodules program with International Seabed Authority (ISA). A cruise was undertaken at the Indian Contract Region in the Central Indian Basin being onboard ORV Sindhu Sadhana for collection of sediment and water samples as well as deployment of the deep-sea morning and surface mooring for the measurement of currents, hydrographic parameters and sediment flux in the proposed mining trail site. The technology for extractive metallurgy of polymetallic nodules is being developed at CSIR-Institute of Minerals and Materials Technology (CSIR-IMMT), Bhubaneswar. primarily for recovering Cu, Ni, Co, and Mn from polymetallic nodules. The hydrometallurgical processing route based on the integration of ammoniacal-SO_2 process and reductive sulphuric acid process has been attempted taking into consideration efficient removal of iron from the acid sulphate solution and possible utilization of the ammoniacal leach residue for silicomanganese production as well as recycling of ammonium sulphate. The gaseous reduction roasting of polymetallic nodules followed by melting of the reduced material and separation of Cu, Ni, Co in the form of an alloy from the Mn-bearing slag as well as recovering Mn as the silicomanganese alloy from Mn-bearing slag has been also established.

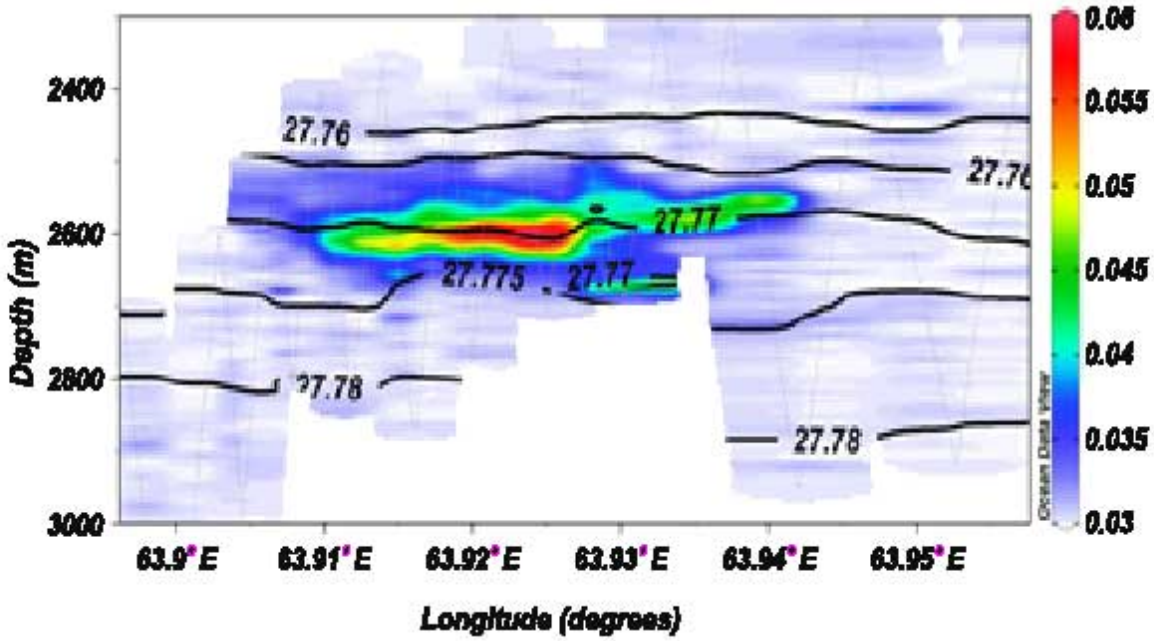


Fig. 3.22 2D-distribution of turbid layer over tow-yo track close to Mt. Jourdanne inactive vent site.

3.6 RESEARCH VESSELS

A total number of 50 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 600 days in the

Sea. Sagar Nidhi, Sagar Manjusha, Sagar Tara has completed dry dock and afloat repair work. Dr. Jitendra Singh, Hon'ble Minister of State (Independent Charge) of the Ministry of Earth Sciences and Ministry of Science & Technology, visited Sagar Anveshika at Chennai Port on 12th August 2022 and hoisted Tricolour onboard Ship as part of 'Har Ghar Tiranga, Har Jahaj Tiranga' (Fig. 3.23)

Fig. 3.23 Honourable Minister visiting Sagar Anveshika at Chennai Port and hoisting Indian flag as part of 'Har Ghar Tiranga, Har Jahaj Tiranga' event.

Chapter 4

POLAR AND CRYOSPHERE RESEARCH (PACER)

4.1. Scientific Studies in Antarctica

4.1.1. Application of visual stratigraphy from line scan images to constrain chronology and melt features of a firn core from coastal Antarctica

Establishing an accurate chronology is crucial for interpreting ice-core-based climatic records. Visual stratigraphy (VS) obtained from line scan images was studied as a proxy for annual layer counting in the firn section of an ice core (1919–2016 C.E.) from the central Dronning Maud Land, East Antarctica (Figure 4.1). These images were used to obtain melt history for the site, and it was found that traditional thickness-based quantification of melt proportion may result in significant overestimations. The study revealed that melt layers do not significantly alter the VS records if masked during pre-processing. The age-depth model based on the reconstructed VS profile showed an excellent match with identified timemarkers within an uncertainty of ±2 years.

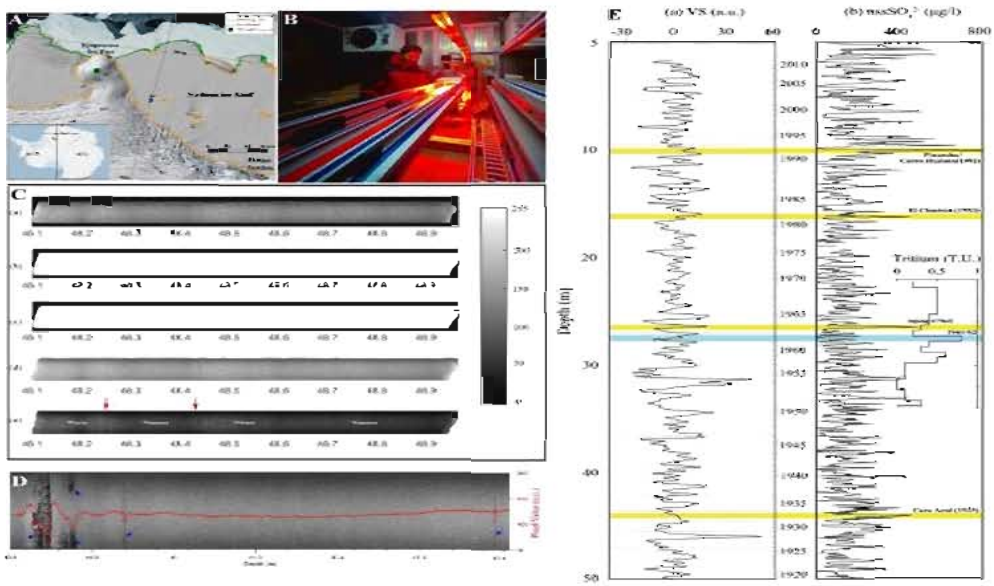


Fig. 4.1 (a) The ice core site (green circle) at the summit of the Djupranen Ice Rise in coastal Dronning Maud Land, (b) The Intermediate Layer Core Scanner (ILCS) set up at the Ice Core Lab of the National Centre for Polar and Ocean Research, (c) line scan image processing steps from 48.1 to 48.97 m depth,(d) line scan image profile of a core section melt layer, (e) Comparison of age models using Visual Stratigraphy (VS) record and volcanic events.

4.1.2. Spatio-Temporal Investigations of Polar Lacustrine Systems (STAPLES)

The STAPLES is an ongoing NCPOR's long-term project focusing on multi-proxy high-resolution records of paleoclimate variations in the East Antarctic lacustrine systems to understand their evolution, modern biogeochemistry, temperature, RSL, ice-sheet dynamics and paleoenvironmental reconstructions. During the 41-ISEA, a team of four researchers carried out a field campaign in the Larsemann Hills to collect sediment cores (aided by sub-bottom profiling of lake sediments), surface sediments and water samples from 11 lakes along with coastal surface sediments off Bharati. The team also carried out Conductivity, Temperature, and Depth (CTD) measurements in lakes, to estimate sediment thickness and identify depocenter. Further, surface sediments were collected from 21 locations from Quilty Bay to understand the surface productivity changes. The team also collected samples from Vestfold Hills, Rauer Group of Islands,

Fig. 4.2 Retrieval of two sediment cores from Discussion Lake, Broknes Peninsula (East Antarctica) using a VibeCoreD4 corer on a UWITEC platform during the 41st Indian Scientific Expedition to Antarctica.

Bolingen and Sostrene Islands to initiate preliminary data collection for future proposed expeditions.

4.2. Operations and Management of Indian Antarctic Stations

After a downsized programme in the earlier year, the 41st Indian Scientific Expedition to Antarctica (41-ISEA) was launched at full scale. A total of 96 persons, including scientists, doctors, engineers, operational staff and helicopter crew, were deployed during the austral summer of 2021-22. Covid mitigation protocols, as per the guidelines of Council of Managers of National Antarctic Programs (COMNAP) and The Dronning Maud Land Air Network (DROMLAN), were implemented for the induction of expedition members. The expedition vessel, M/V VasiliyGolovnin, having re-supplied Maitri and Bharati stations of fuel, food and provisions, spares, etc., returned to Cape Town on 4 April 2022.

The 41-ISEA accomplished the scientific and logistics objectives. Four major scientific projects, including Geological Exploration of Amery Ice Shelf (GeoEAIS), Spatio-temporal investigations of polar lacustrine systems (STAPLES), Prydz Bay air–ice–sea exchange (PRAISE), and Sea ice and Westerly winds during the Holocene in coastal Antarctica (SIWHA) were undertaken. In addition, work related to 15 other projects from different institutes and organization sunder different scientific themes were undertaken during the summer of 41-ISEA.

The first systematic fieldwork in the Amery Ice-shelf region of Antarctica was conducted under the Geological Exploration of Amery Ice-Shelf (GeEAIS) initiative. Infrastructure at "Sandhi" basecamp at the Reinbolt Hills was strengthened with the augmentation of an additional living module, increased fuel depot and storage of survival ration and medicines. For inland penetration in Antarctica and enhanced scope of scientific research around Bharati, a fuel dump was set up on Gillock Island (about 227 Km from Bharati) to support the flying activities in and around Amery Ice Shelf for a future approach (Fig. 4.3).

For the 42-Indian Scientific Expedition to Antarctica, 40 scientific projects were received in different scientific disciplinesand evaluated in the workshop held during 7-9 June 2022. National Coordination Committee for Polar Programme (NCPP) has recommended 28 projects

Fig. 4.3 Collection of snow accumulation/ablation data and DGPS Survey on Polar Ice Sheet, Prydz Bay Region Antarctica.

4.3 Himalayan Studies

4.3.1. Field activities and observations

Glaciological field campaigns have been carried out for six benchmark glaciers (Sutri Dhaka, Batal, Bara Shigri, SamudraTapu, Gepang and Kunzam) in Chandra basin and Lato glacier, Leh during May - September 2022, covering a total glacierized area of ~300 km^2 (Fig. 4.4). Various observations such as stake networking, snow pits measurements for snow/ice accumulation-ablation and data collection from Water Level Recorder (WRLs), Automatic Weather Station (AWS), Aethalometer, Nephelometer, Aerodynamic Particle Sizer (APS) etc were carried out. Field surveys like Global Navigation Satellite System (GNSS) and Terrestrial Laser Scanner (TLS) have been carried out for glacier mass balance, terminal monitoring and ice velocity. An Inmarsat terminal has been installed at the

Fig. 4.4 (a) Overview of studied glaciers in the Chandra, western Himalaya and the field measurements (May to September 2022) field campaign, (b &c) Snow stratigraphy and density measurements using snow corer and snow fork over the Sutri Dhaka Glacier,(d) Trekking towards accumulation zone (e) TLS Survey and, f) Installing Inmarsat terminal for real time data transmission from AWS, g) GNSS Survey, h)AWS data collection, I) Debris thickness measurement and J) Discharge measurements

Himansh field station, Chandra basin and tested for real time AWS data transmission from Himansh to NCPOR.

4.3.2. Energy fluxes, mass balance, and climate sensitivity of the Sutri Dhaka Glacier in the western Himalaya

Studies showed that net shortwave radiation (S_{net}) contributed 56% to the total surface energy fluxes, followed by net longwave radiation(L_{net}) (27%), sensible heat (H_s) (8%), latent heat (H_L) (5%), and ground heat flux (Q_g) (4%) over Sutri Dhaka glacier. However, over the ablation zone, inward fluxes account for most of the total heat flux, resulting in strong summertime melting (Fig. 4.5). A sensitivity analysis demonstrates that the mass balance of the glacier is affected by both air temperature (–0.21 m w.e. a^{-1} $°C^{-1}$) and precipitation (0.19 m w.e. a^{-1} $(10\%)^{-1}$) changes. This study suggests that the mass balance of the Sutri Dhaka Glacier is less sensitive to changes in the partitioning of precipitation into snow and rain because the majority of precipitation falls as snow during the winter when the temperature is well below 0°C.

4.4. Scientific Studies in Arctic

4.4.1. Aerosol optical depth over the Arctic

Aerosols absorb and scatter incoming solar and outgoing terrestrial radiations and affect regional and global climate systems by influencing the earth–atmosphere radiation balance. Monthly mean mid-visible (at 0.55 mm) aerosol optical depth (AOD) derived from the MODerate resolution Imaging Spectroradiometer (MODIS) sensor onboard the Terra satellite are utilized from 2002 to 2018 over the Arctic region to investigate the spatio-temporal variations of aerosols. The seasonal mean AOD during boreal winter (December-January-February), spring (March-April-May), summer (June-July-August), and autumn (September-October-November) are shown in Figure 4.6. AOD values cannot be retrieved over most of the locations of the Arctic region during boreal winter due to the absence of reflected short-wave

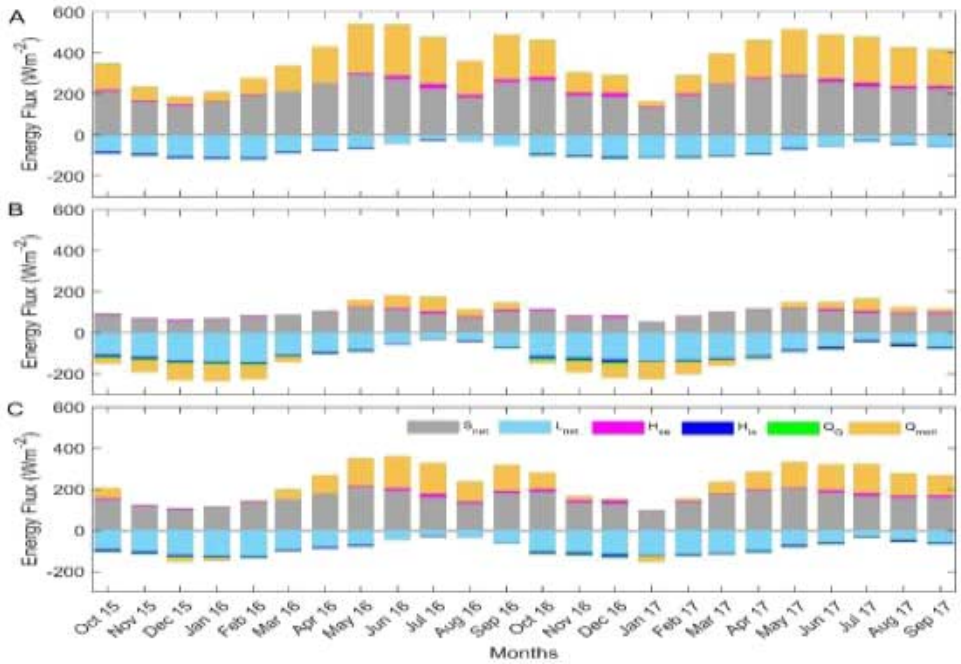


Fig. 4.5 The monthly mean surface energy fluxes for the (A) ablation zone (below 5,300 m a.s.l.), (B) accumulation zone (above 5,300 m a.s.l.), and (C)glacier-wide region of the Sutri Dhaka Glacier. S_{net} is net shortwave radiation, L_{net} is net longwave radiation, H_s is turbulent sensible heat flux, H_L is turbulen latent heat flux, Q_g is ground heat flux andQ_{melt} is available melt energy.

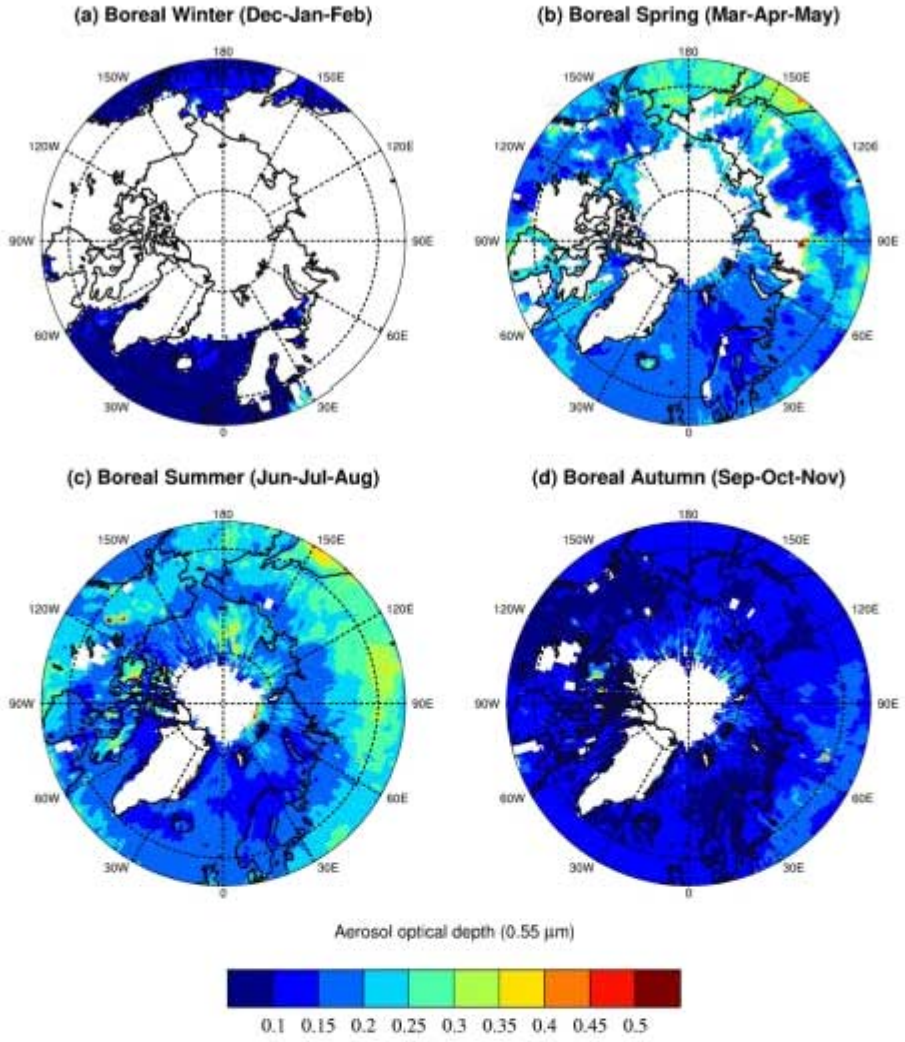


Fig. 4.6 Spatial variations of mid-visible (at 0.55 μm) aerosol optical depth over the Arctic during boreal (a) winter (Dec-Jan-Feb), (b) spring (Mar-Apr-May), © summer (Jun-Jul-Aug) and (d) Autumn (Sep-Oct-Nov) seasons of years 2002 – 2018. AOD data could not be retrieved over the white color regions.

radiation in the season. AOD over the central Arctic and other ice-covered regions can also not be retrieved by MODIS due to high surface reflectance values. During the boreal spring and summer, AOD values are observed to be higher. The higher values can be owing to anthropogenic activities and fire events over the region.

4.4.2. Near-inertial waves induce mixing and redistribution of heat in a rapidly warming Arctic

The Atlantic Water (AW) advection through the West Spitsbergen Current is one of the primary reasons for the physical and biogeochemical changes in Kongsfjorden. These changes are positively fed by vertical mixing between the cold surface Arctic water (AW) and the subsurface AW. Our recent observations demonstrate that the near-inertial waves (NIW) are a primary contributor to the prominent vertical mixing found in Kongsfjorden. In summer, during storm events, the near-inertial currents induce large shear at the base of the mixed layer, and downward propagating NIW induces shear in the fjord interior leading to an enhanced vertical mixing (Figure 4.7). These two processes

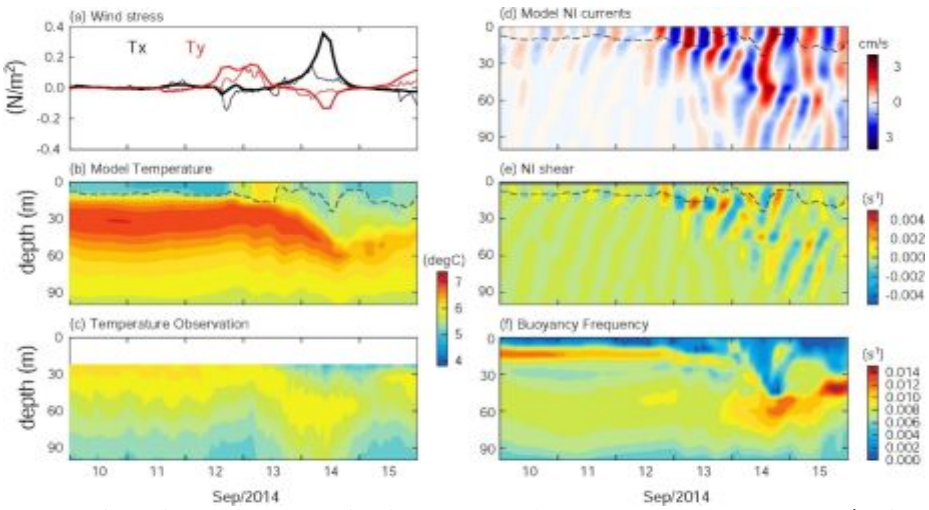


Fig. 4.7 (a) The eastward (black) and northward (red) wind stress (newton per square metre, N/m2) componentsduring 10-15 September 2014. The thick lines represent wind stress extracted from themodel forcing at the IndARC mooring location. The thin lines represent the computed wind stress using Ny-Ålesund weather station wind near Kongsfjorden. (b) Time-series of the ROMS model simulated fjord water column temperature (°C) at the mooring location during 10-15 September 2014. The dashed black line represents mixed layer depth. (c) Time-series of the fjord water column temperature obtained from the mooring. The blank space shows the non-availability of the mooring data. (d) The eastward component of the near-inertial currents extracted from the model output, (e) vertical shear of the near-inertial currents, and (f) buoyancy frequency estimated from the model temperature and salinity at the mooring location.

during storms lead to redistribution of the subsurface AW thereby warming the mixed layer by ~1°C.

4.5. The North Pole Expedition

The Central Arctic Ocean (CAO) is undergoing remarkable changes in terms of a large decrease in the sea-ice extent and thickness. These changes are impacting marine microbiota with a possible consequence on carbon export and sequestration. In the CAO, ice-algal aggregates export a large quantity of algal carbon to the seafloor and promote vertical microbial connectivity. However, the impact of increased primary productivity, fueled by a sea-ice decline, on carbon export to the seafloor is not that clear. Nevertheless, recent studies indicate that sea-ice retreats may reduce carbon export and vertical microbial connectivity in the Fram strait region. In view of these two scientists from the Arctic Division participated in the North Pole Expedition conducted by the Norwegian Polar Institute using a Research vessel "KronPrinsHakoon". NCPOR team members studied the physical (Figure 4.8) and biological aspects

Fig. 4.8 Photo showing an NCPOR team member deploying a turbulence profiler for studying the ocean turbulence in the Central Arctic Ocean and R.V KronPrinsHakoon is seen in the background.

related to sea-ice variabilities, especially, the impact of sea-ice variabilities on the vertical connectivity and assembly mechanism of microbial communities.

4.5.1 Salinity variations among Arctic sea ice melt-ponds drive bacterial community composition

Melt-ponds are pools of melted snow and surface ice that form on sea ice in the warmer months of

spring and summer, and it is a seasonal pan-Arctic process. Melt-ponds are habitats for diverse assemblages of auto- and heterotrophic organisms, including bacteria. To expand current understanding of bacterial commonalities in the melt ponds, the diversity and distribution pattern of bacterial communities were studied, especially, in response to the salinity variations associated with the progression of melting and deepening of melt ponds. A significant difference in the bacterial community composition was observed among melt ponds having differences in the salinity range. Higher bacterial diversity was recorded in melt ponds with higher salinity. This higher heterogeneity of the melt-pond microbial community could be attributed to the environmental gradient created by the salinity variation ranging from 0.3 to 27.8 psu.

4.5.2 Lower Arctic sea ice extent contributed to a stronger Indian monsoon during a past period of global warming

Due to the increasing CO_2 level and resulting global warming, the sea ice extent in the Arctic has declined drastically. It is crucial to explore whether this decline in the sea ice impacts India, precisely its monsoon strength. One way is to study a past warm interval with similar CO_2 concentration, which may provide insights into what might be expected with continued climate warming. Mid Placenzian Warm Period (MPWP) during the late Pliocene was an interval that occurred around 3 million years ago with similar to higher CO_2 concentrations. To go back so far in time, NCPOR researchers collected sediments from the Arabian Sea, which record the signatures of the monsoon strengths in their layers. This study was carried out under the Indo-Norwegian PACT (Pliocene Arctic Climate Teleconnection) project using geochemical and model data in sediment collected during the IODP Expedition 355 from the Arabian Sea.It isobserved that various factors influenced the monsoon during the MPWP, including CO_2 concentration, insolation, and oceanic circulation changes along with Arctic sea ice extent. Lesser sea ice strengthens the monsoon, possibly by changing energy transport and atmospheric circulation. Further, it is found that the monsoon was overall more vigorous during the warmer MPWP (Figure 4.9). But it was regionally varying with lower rainfall over the Gangetic Plains, eastern, northeastern, and southernmost India - a

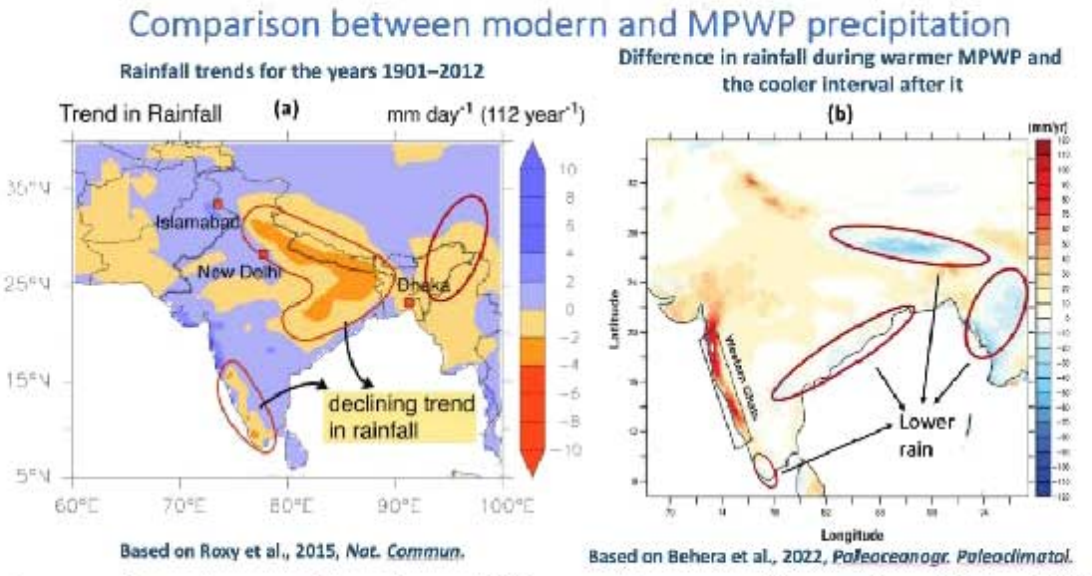


Fig. 4.9 The resemblance between (a) modern rainfall pattern (data span 112 years from 1901 to 2012) and (b) monsoon rain intensity difference between the warmer Mid-Placenzian Warm Period (MPWP) and the colder interval after it (this study).

pattern similar to the present, as shown in the figure. Their results imply that in a future with continued warming and declining sea ice, one may expect more intense and spatially heterogeneous precipitation.

conditions favoured the formation of a deep ASL. A deeper ASL led to enhanced ice transport away from the Ross Ice Shelf and coastal areas to the east and the generation of new, thin ice over the southern Ross Sea. In late 2021 the strong offshore flow

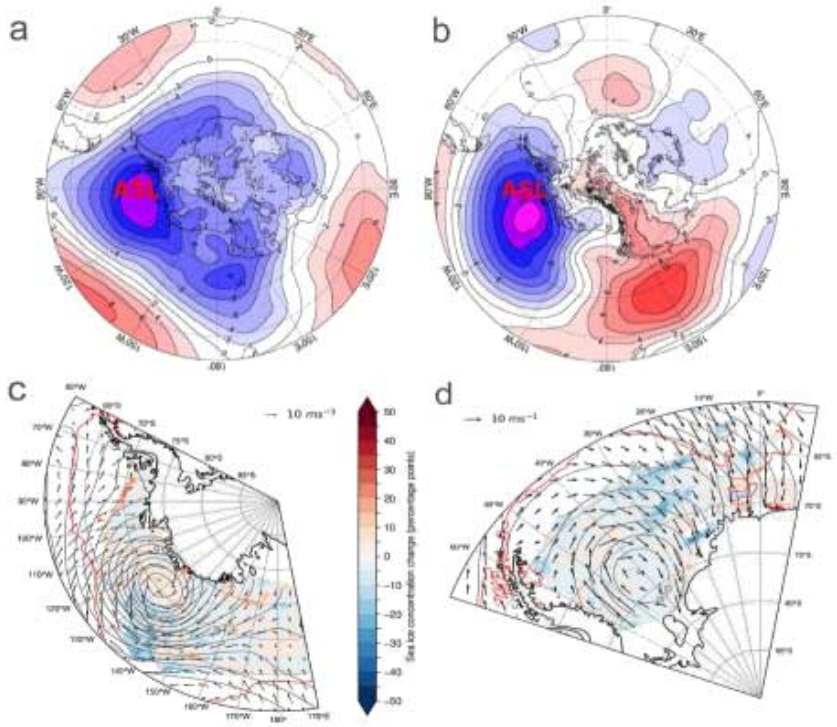


Fig. 4.10 The monthly mean sea level pressure (MSLP) for (a) September 2021 and (b) October 2021. The change in sea ice concentration relative to the previous day (shaded background) for (c) the Ross Sea on the 14November 2021 and (d) the Weddell Sea on the 21December 2021. Day-mean MSLP is overlaid in gray contours at 5 hPa intervals (950 and 975 hPa levels labelled) as well as the day-mean 0°C 2m temperature isotherm (red line) and 10 m wind vectors. MSLP, temperature and winds data are from ERA5.

4.6. Southern Ocean Studies

4.6.1. Antarctic sea ice changes in the warming world

The Antarctic sea ice extent (SIE) dropped to an all-time low of 1.92×10^6 km^2 in February 2022. The drop is because of negative ice anomalies in all sectors of the continent, especially in the Ross and Weddell Seas. In October/November 2021, the Amundsen Sea Low (ASL) had a record low depth, which led to southerly winds of record strength off the continent (Figure 4.10).

During this period, a combination of a positive southern annular mode (SAM) and La Niña resulted in an anomalously northern sea ice edge which was then rapidly eroded by the passage of a series of intense polar cyclones, and also favoured the establishment of a large coastal polynya by early December, which was associated with an unusual upper ocean warming of up to ~0.6°C. Open water then allowed the absorption of solar radiation at its maximum intensity in December, which aided the further loss of sea ice through the ice-albedo feedback. In parallel, westerly winds of record strength induced by positive SAM conditions led to ice export from the northern Weddell Sea, resulting in negative ice anomalies in this region. Therefore, the simultaneous low ice extent in the Ross and

Weddell Seas (contributing 72%) was influential in establishing the all-time low ice condition for the entire Southern Ocean.

4.6.2. Anomalously high sub-surface dissolved oxygen in the Indian sector of the Southern Ocean

An analysis of data from Bio-Argo floats deployed in the Southern Ocean reveals seasonality in dissolved oxygen variability. The effect of the cyclonic eddy on the vertical distribution of dissolved oxygen was studied in the Indian sector of the Southern Ocean

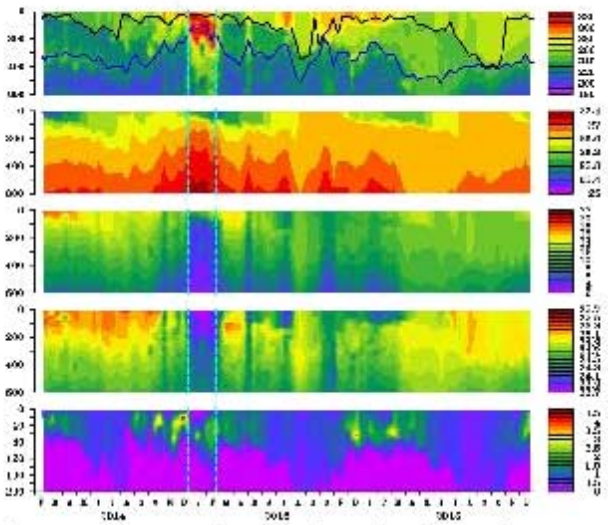


Fig. 4.11 Seasonal evolution of Dissolved Oxygen (µmol/kg), density (kg/m^3), temperature (° C),salinity (psu) (in upper 600m depth) and chlorophyll (mg/m^3; upper 200m depth) from top to bottom panels, respectively. The black line represents MLD. The vertical lines represent the observation dates 24 December, 2014 and 12 February 2015, respectively.

(ISSO). The impact of the cyclonic eddy was investigated, and unusually high dissolved oxygen levels were discovered below the mixed layer depth (Figure 4.11). The results show that cyclonic eddies play an important role in sustaining oversaturated dissolved oxygen and the high summer bloom in the Southern Ocean.

4.6.3. Diversity of actinobacteria in the sediment and water column in the Indian sector of the Southern Ocean as revealed by 16S rRNA-based metagenomics analysis

Actinobacteria are one of the largest bacterial phyla with high ecological and industrial significance. Marine derived actinobacteria are recognized as an important source for diverse bioactive compounds. Here we present the first set of amplicons based actinobacterial diversity data from the water (2 stations) and sediment samples (1 station) in ISSO (Figure 4.12). The taxonomic analysis identified a total number of 27 phyla of which Proteobacteria

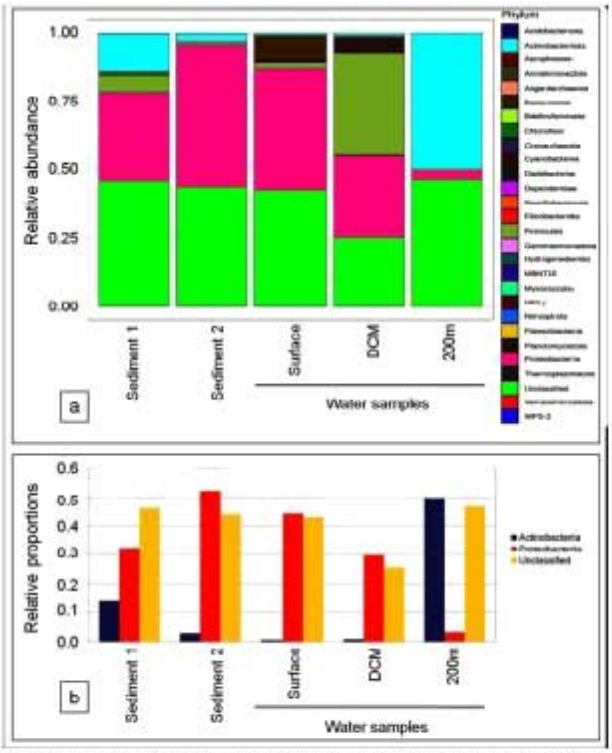


Fig. 4.12 (a) Relative abundance of bacterial diversity at Phylum level, and (b) Relative distribution of Actinobacteria compared to Proteobacteria and unclassified bacteria.

(40.2%), Actinobacteria (13.6%) and Firmicutes (8.7%) were found to be dominant. The comparative study of water and sediment samples revealed dominance of different actinobacteria in water and sediments. Streptomycetales was dominant in the water samples while Micrococcales was dominant in the sediment samples. Five groups were common in both in sediment and water samples.

4.7 NCPOR hosted Scientific Committee on Antarctic Research (SCAR) 2022 Open Science Conference and Meetings

The National Centre for Polar and Ocean Research (NCPOR), under the aegis of the Ministry of Earth Sciences (MoES) , organized the SCAR 2022. It was the first time that India hosted SCAR Open Science Conference along with the SCAR Business and Delegates Meetings. In view of the pandemic, the 10th Open Science Conference (1st-10th August 2022) and SCAR Business Meeting (27th -29th July 2022) were organized online. Hosting of the conference coincided with the celebration of 75 years of India's Independence—Azadi Ka Amrit Mahotsav.

MoES-NCPOR, Goa also hosted the XXXVII SCAR Delegates Meeting from 5th -7th September 2022 in Goa, India. The meeting was organized in a hybrid format and delegates from more than 50 countries attended it in person or online. The meeting was attended in-person by more than 36 delegates from 19 countries.

Chapter-5

SEISMOLOGY AND GEOSCIENCE RESEARCH (SAGE)

5.1 Observational Seismology, Earthquake Monitoring and Services

The National Seismological Network consisting of 152 seismological observatories are connected through VSAT with the operational capability to detect any earthquake of magnitude 3.0 or above in most parts of the country. The Operational Centre is equipped with state-of-the-art facilities for data collection, processing and dissemination of earthquake information to user agencies through various modes of communications, such as mobile app (Bhookamp), SMS, Fax, Email, social media platforms like Twitter, FaceBook, WhatsApp and published with value-added products on official website of NCS (https://seismo.gov.in).

The National Seismological Network was successful in operation and the 24x7 operational centre at NCS HQ, New Delhi continued to maintain round-the-clock monitoring of seismic activity in and around the country and quickly disseminated the earthquake information immediately after its occurrence to all concerned agencies. A total of 1304 earthquakes were located in and around neighboring region of the country (0°-40° N and 60°-100°E) during the period January 2022 to 31st December 2022 as shown in Fig. 5.1. Out of these, 32 events of magnitude M:6.0 and above, 31 events are of magnitude M:5.0 and above, 554 events of magnitude M:4.0-4.9, 468 events of magnitude M:3.0-3.9 and remaining events fall within the category of small earthquakes. The distribution of magnitude of earthquakes is shown in Fig. 5.2.

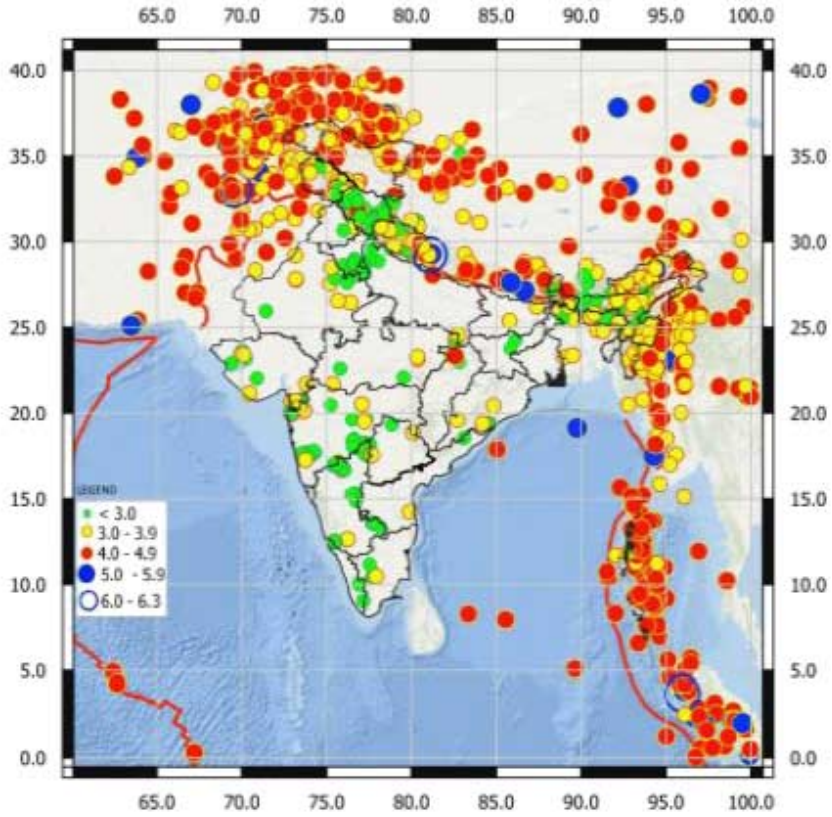


Fig. 5.1 Location of earthquakes disseminated by National Seismological Network of NCS during 01st Jan- 31st Dec 2022

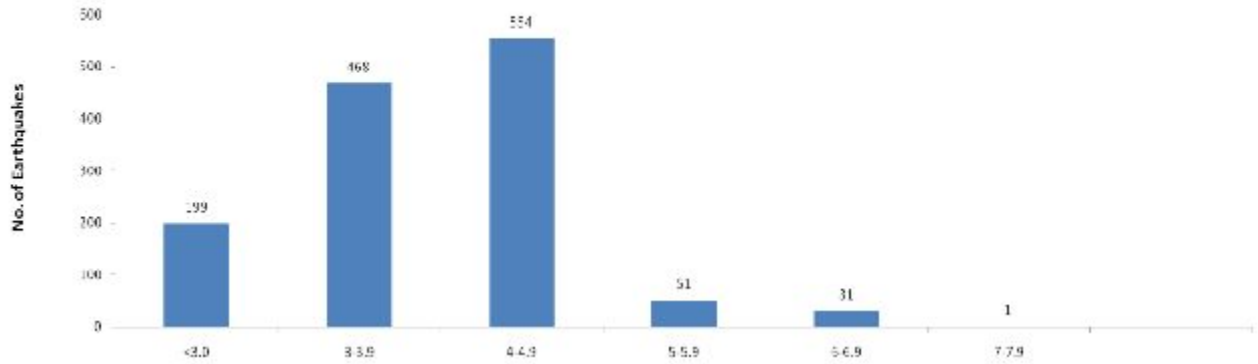


Fig. 5.2 Distribution of earthquakes occurred during 01st Jan -31st Dec 2022 in different magnitudes ranges in India and in its neighbourhood.

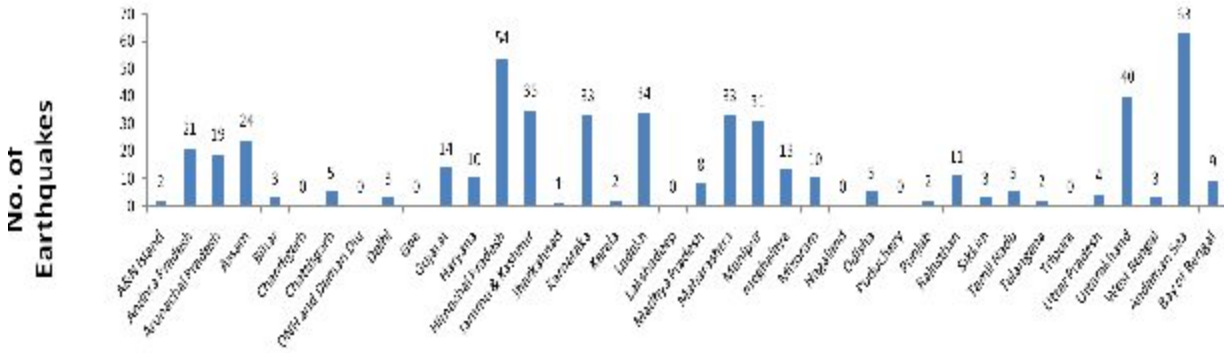


Fig. 5.3a State/UT wise distribution of earthquakes occurred during 01st Jan -31st Dec 2022

1. Out of 1304; 481 earthquakes occurred within Indian territory during the period January 2022 to 31st December 2022. During the period 63 earthquakes occurred in Andaman sea, 54 in Himachal Pradesh, 34 in Ladakh and 35 in Jammu and Kashmir. State/UT wise distribution of earthquakes is shown in Figure 5.3a. Most of these earthquakes were of small to moderate magnitude range of M <3.0; M: 3.0 -3.9 and M: 4.0 -4.9; except few earthquakes of M >5.0 in Ladakh and Andaman sea. One earth quake of M:7.9 has occured in South Pacific Ocean in Tonga island region.
2. Ladakh Earthquake of M:5.2 occurred at 19:05:23 IST of 16th March 2022 in Northern Ladakh at 36.01^{0}N and 75.18^{0}E with focal depth of 110 km. The epicentre is 75 km W of Gilgit, 90 km NNW of Skardu, 220 km NNE of Srinagar and 300 km NW of Leh. This earthquake occurred in trans-Himalaya zone. The region within 100 km from this earthquake has experienced four earthquakes of magnitude M≥5.0; (M: 5.0, 5.1, 5.6 and 5.7) during 01st Jan 2010 to 16th Mar 2022 (Figure 5.3b). Andaman Sea Earthquake of

M:5.2 occurred at 10:15:45 IST of 06th April 2022 in Andaman Sea at 07.45°N and 94.27°E with focal depth of 10 km. Th epicentre is 45 km NE of Campbell Bay, 500 km SSE of Port Blair and about 450 km WSW of Phuket, Thailand. This earthquake occurred in subduction zone. The region within 100 km from this earthquake has experienced one earthquake of magnitude M:6.1 occurred on 26th Dec 2004 2022; but more than 20 earthquakes of M≥5.5 occurred during last twenty years of period. Location and intensity map of earthquake is shown in Figure 5.3c. Besides this event; 34 earthquakes region in the magnitude range of 3.6 - 5.0 occurred in the Andaman Sea during 4th to 9th July 2022.

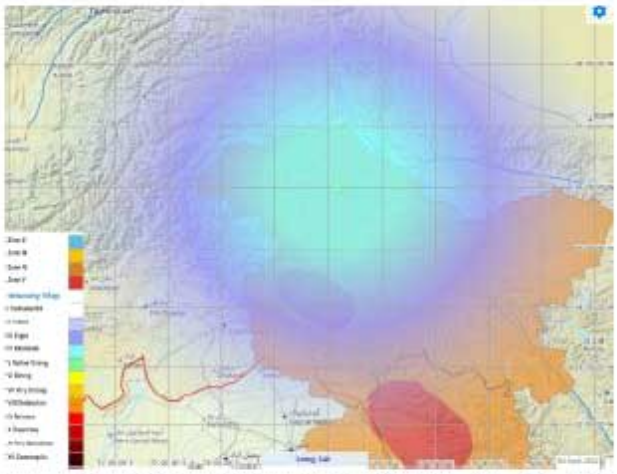


Fig. 5.3b Map showing the epicentre (circle) and expected intensity map for Ladakh Earthquake of M:5.2 occurred on 16th March 2022

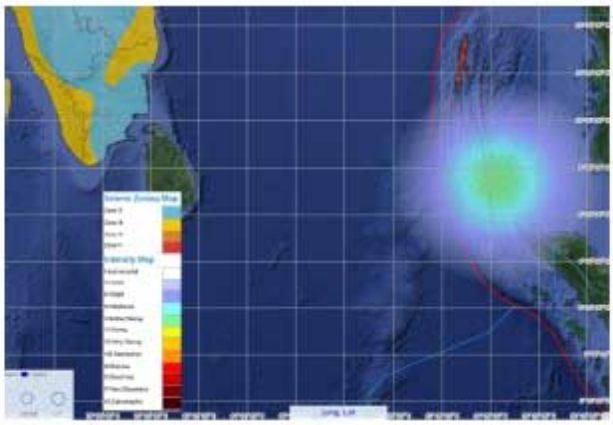


Fig. 5.3c Map showing the epicentre (circle) and expected intensity map for Andaman Sea Earthquake of M:5.2 occurred on 06th April 2022.

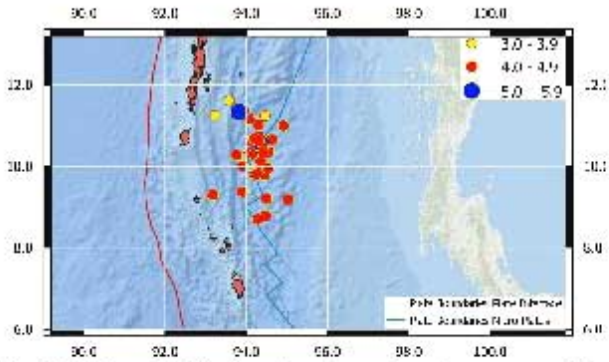


Fig. 5.3d Spatial distribution of earthquakes occurred in Andaman sea region during the period 01st – 31st July 2022

Figure 5.3d shows the spatial distribution of earthquakes occurred in Andaman sea.

Monthly Seismological Bulletins containing the phase data and the processed information on source parameters of all earthquakes located by the seismological network are prepared and published. In addition, the monthly reports of Earthquakes are also available on NCS website at the URL https://seismo.gov.in/monthly-reports.

Autolocation software with new modules was upgraded in Feb 2022 and the development of customised software for Unified Dissemination System (UDS) for dissemination of earthquake parameters through different mediums is under testing for operational use.

5.1.1 Seismic Hazard and Risk Assessment study

Seismic Microzonation is a site-specific study, which provides a realistic and reliable representation of ground motion characteristics. Comprehensive report on Seismic Hazard and Risk Microzonation of four cities such as Bhubaneswar, Chennai, Coimbatore and Mangalore are in progress and expected to be released soon. Field and soil Laboratory Geotechnical and Geophysical investigations on of other 08-cities (Agra, Amritsar, Dhanbad, Kanpur, Lucknow, Meerut, Patna and Varanasi) are in progress since March 2021. Seismic microzonation involves various components in it, viz., Geophysical, Geotechnical (In-situ and

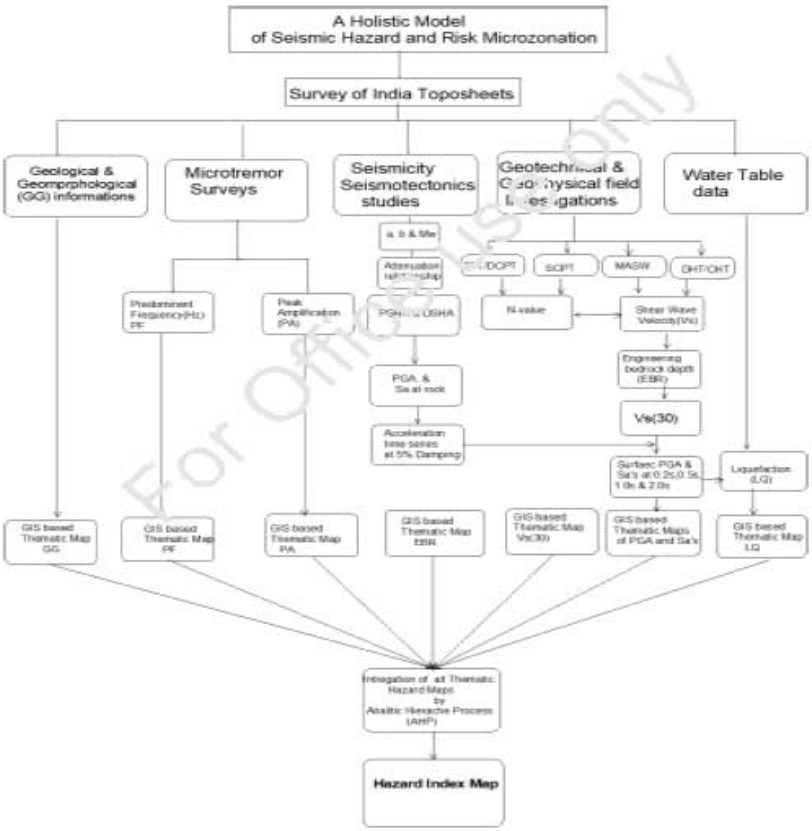


Fig. 5.4 Flow chart below is a holistic model for assessment of seismic hazard and risk Microzonation

Laboratory), Seismological etc. which are explained step by step in a Flow Chart shown in Figure 5.4

Comprehensive Seismic Microzonation of targeted/populated cities may be helpful for construction engineers in refining the building codes across the country to attain sustainable usage and long life of buildings in order to save life and property in case of disastrous earthquakes. An important intervention in the times ahead could witness as improvement in the scale of Microzonation studies. This would facilitate the generation of various thematic and integrated seismic hazard maps on a higher resolution.

5.1.2 Three-dimensional seismic velocity structure and seismotectonic beneath the Sikkim - Darjeeling Himalaya

Efforts have been made to establish the plausible depth of disposition of the basal décollement through 3-D seismic imaging using local earthquake tomography and to understand the linkage between seismogenesis and collisional tectonics of the Sikkim-Darjeeling Himalayan region. A total of 2105 events recorded by 42 broadband seismograph stations during 2005–2011 have been analyzed. Detailed 3-D seismic imaging unraveled heterogeneous velocity structures (Vp and Vs) with low and high velocities with distinct variations in Poisson's ratio (б) at different depth ranges. A well-resolved low-velocity zone is found to persist consistently at a depth of about 20 km corresponding to the gentle, north dipping décollement plane, exhibiting significant velocity perturbations across this interface. The geometry and depth of the décollement surface are found to vary laterally, and its deepest disposition is observed at a depth of ~ 30 km. The shallower low-velocity zone up to 10 km with higher-б suggests the presence of the Quaternary piedmont sediments with high fluid saturations. In contrast, the higher velocity perturbation with low б at the mid-crustal layer is indicative of the competent parts of the

crust, where seismogenesis is related to the occurrence of earthquakes of varying strengths beneath the Sikkim - Darjeeling Himalayan region. Our seismic imaging corroborates with the past moderate earthquakes that were confined to the vicinity of high and low velocity (Vp Vs) and ß zones

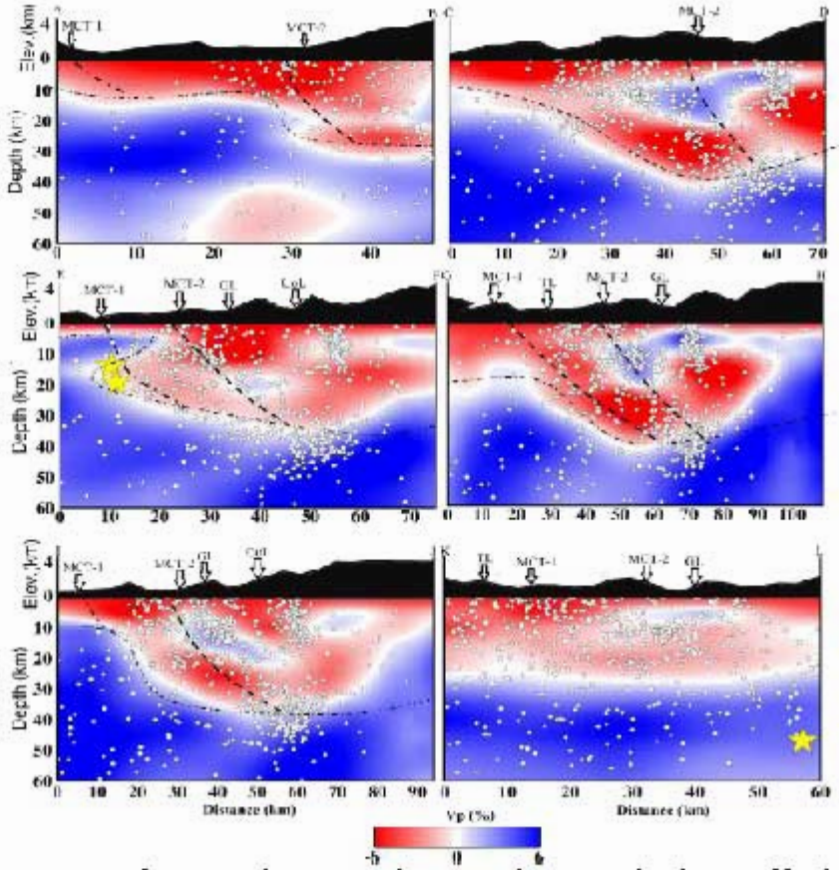


Fig. 5.5 Vertical cross-sections of P-wave velocity perturbations with topography along profiles (AB-U) are shown. The dots indicate seismicity. At the same time, black dotted lines show the locations of possible décollement and faults in cross-sections, which are marked based on an earlier study. Stars show earthquakes $M_w \geq 5.0$ in the study area. The scale is shown bottom of the figure.

whilst the strong size earthquakes (M > 6.0) occurred mostly below the décollement plane where high-velocity basement thrust exists along with Indian subducting plate (Figure 5.5). This study clearly expresses the well-defined disposition of the décollement zone that controls the nature and extent of seismogenesis.

5.1.3 Construction of NCS building Complex

Work for construction NCS building Complex at Plot No. A-33, sector-62, Noida has been assigned to CPWD. As per the plan, the NCS Complex will be comprised of NCS Building, Earth Science Museum, IMD's Regional MET Office, Training Centre and accommodation for HPC Centre of NCMRWF and Geochronology facility of IUAC. The architectural drawings/ design of the NCS Complex has been approved by the project monitoring committee formulated by MoES.

5.2 Establishment of five-station broadband seismic network in the vicinity of the Koyna Pilot Borehole

Geological and geophysical datasets acquired down to depth of 3 km in the Koyna Pilot Borehole KFD1 provide strong evidences for the presence of

multiple fault-fracture zones in the upper few kilometers of the Koyna Seismogenic Zone and that the borehole penetrated one or more faults potentially associated with the NNE striking Donichawadi fault at depth. The fault, which was associated with the 1967 M6.3 Koyna earthquake, extends to depth of up to 10 km and continues to be active, as observed from the distribution of hypocenters in the region. Therefore, the KFD1 site is considered suitable for setting up of a Fault Zone Observatory at depth of 5-7 km.

To constrain the subsurface disposition of the fault zone(s) and optimize the borehole configuration and trajectory, a local network of five surface broadband seismic stations has been established recently in the vicinity of the Koyna Pilot Borehole (Fig. 5.6). The stations are located within a radius of ~5 km from the borehole KFD1. It is also proposed to instrument the borehole KFD1 with an array of seismometers in the near future. The purpose of the seismic network is to test existing velocity models in the Koyna seismogenic zone and to provide improved earthquake locations. The network is operational since January 2022. until Nov. 2022 1353 earthquakes with magnitudes ranging from -0.5 to 3.7 have been recorded. The distribution of seismic events is also shown in Fig. 5.6. Preliminary data analysis reveals that the seismicity extends down to a depth of ~10 km and the locations of earthquakes follow the trend of the Donichwadi fault zone. This implies that Donichawadi fault is still active and majority of the earthquakes are occurring along this fault. Studies carried out in the Koyna pilot borehole KFD1 at Gothane, ~5 km to the south of Kadoli, reveal that the majority of the subsurface fractures strike along NW-SE to NNE-SSW direction and are steeply dipping (40°-75°), consistent with the strike azimuth of major and minor fissures associated with the Donichawadi fissure zone. Improved locations of seismic events obtained using the enhanced broadband network will help in delineating the trend of the fault zone and provide critical constraints to guide deep drilling in the future.

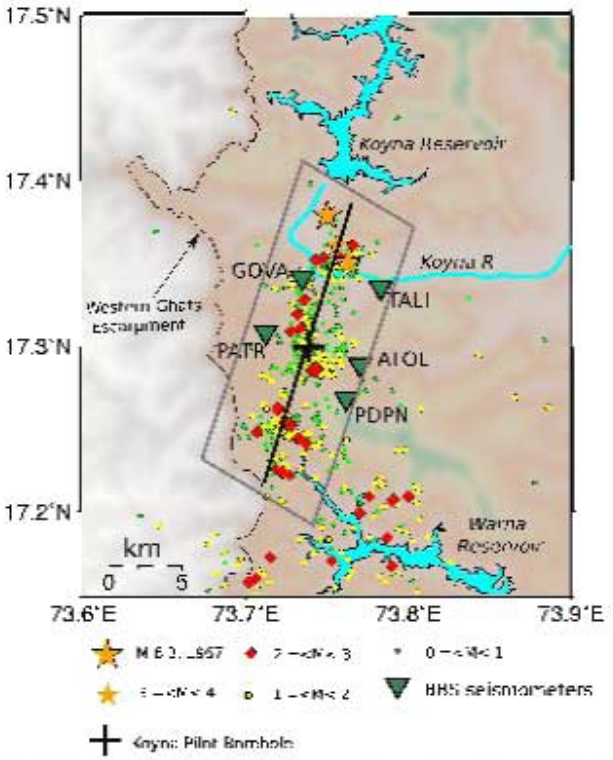


Fig. 5.6 Seismicity map of Koyna region using data acquired by the five-station broadband seismic network surrounding the Koyna Pilot Borehole KFD1. The five stations are located at Govare (GOVA), Talye (TALI), Atoli (ATOL), Panderpani (PDPN) and Patharpunj (PATR).

5.2.1 Geochemical characterization of basement granitoids

The geochemical characteristics of the basement of the Koyna-Warna region of western India have been studied through core samples and cuttings made available from the scientific drilling to the depth of 3014 m. For the bulk rock geochemical analyses, 41 representative samples of basement rock recovered from three boreholes, KFD1, KBH4A and KBH7, were studied. The major elements were analyzed through X-Ray Fluorescence facility at Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow using pressed powder pellets. Two reference standards, i.e., QLO and DGH were used during the analysis. The analytical precision (% RSD) and accuracy (% error) are within ±2% for major elements. Trace elements were measured using Inductively Coupled Plasma Mass Spectrometry at BSIP. For trace element study, 30 mg of powdered sample was digested using a

mixture of HF, HNO3 and HClO4, following the method described by Xiong et al. (2012). During the ICPMS analysis, three reference standards, i.e., GSP-2, DGH and MBH were used. The precision and accuracy for trace elements are better than ±5% (<20 ppm). The basement rock comprises dominantly of granite, granitic gneiss and tonalite (Fig. 5.7). The major minerals are quartz, plagioclase and orthoclase, whereas the minor minerals include epidote, chlorite and hornblende, etc. The bulk rock geochemistry of the basement granitoids shows a range from tholeiitic to calc-alkaline series of magma types which mainly belong to adamellite-granodiorite-tonalite suites (Fig.5.8). The basement rocks are predominantly peraluminous in nature and have an overall predominance of sodium over potassium. Fractionated REE patterns with enriched light REE (LREE) and depleted heavy REE (HREE) along with a small negative Eu-anomaly are observed in the samples. Overall, the Precambrian basement rocks are lithologically heterogeneous and apparently genetically related by fractional crystallization and partially derived from magmas.

5.3 Setting up of facility for Geochronology

In the past few decades, the field of geosciences has witnessed a paradigm shift from being an observational science to a more rigorous multidisciplinary subject with a robust quantitative database. The field has seen new developments in geochronology at the micro phase and single-grain levels.

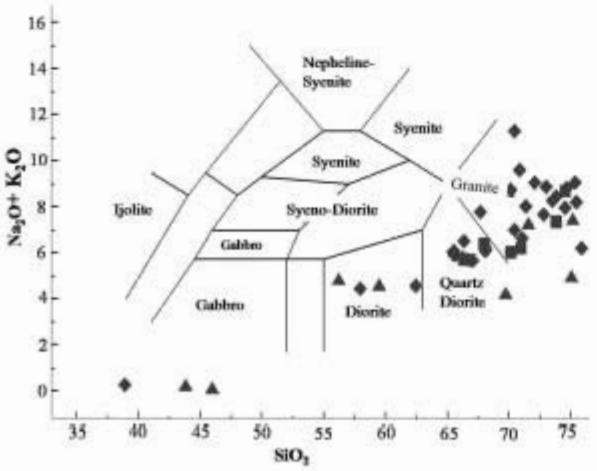


Fig. 5.7 TAS Diagram (after Cox et al. 1979) showing the distribution for drillcore samples from Koyna region (Rectangle-KBH7; Triangle-KBH4A; Diamond- KFD1).

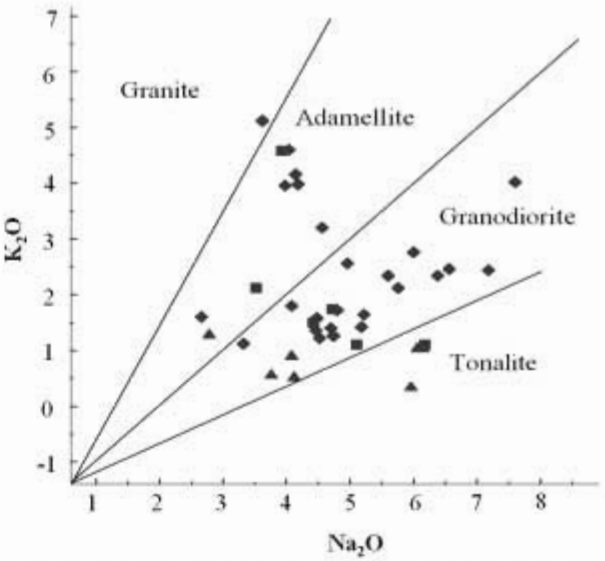


Fig. 5.8 K_2O versus Na_2O diagram (after Harpum, 1963) showing the distribution for drillcore samples from the Koyna region (Rectangle-KBH7; Triangle-KBH4A; Diamond- KFD1).

Geochronology is the study of the age of rocks, fossils and sediments. It seeks to answer several perplexing scientific questions. Modern research has established that isotopic composition (stable and radiogenic) of geological material is essential to understand geological processes in time and space, that is, for studying geochronology.

High precision isotopic measurements require equally sophisticated instrumentation and laboratory infrastructure. India is in the process of developing such facilities. MoES is setting up a geochronology facility at Inter University Accelerator Centre (IUAC), New Delhi to cater to the need of geoscientists of the country. The geochronology facility has the mandate of developing an internationally-competitive centre for geochronology and isotope geochemistry that will facilitate generation of quality isotopic data for geochronological and isotopic fingerprinting.

IUAC would enable geoscientists to undertake cutting-edge research with high-quality data and its characterization at the highest international level. It will provide high-end experimental capabilities which are currently non-existent in the country. More facilities to complement the existing infrastructure will be added going forward. IUAC will have two major machines, namely, an Accelerator Mass Spectrometry (AMS) and High-Resolution Secondary Ionization Mass Spectrometry (HR-SIMS). A variety of ancillary equipment capable of dating geologically youngest and the old formations/rocks/sediments in the Earth's history will also be present. IUAC would facilitate an improved and quantitative understanding of the evolution of the Indian lithosphere.

Accelerator Mass Spectrometry (AMS) will attempt to address questions around erosion rates, dating of seismic events, sediment provenance, quantitative Earth surface processing studies, etc. Establishment of AMS dating facility will also provide a means to explore new isotopes like 32Silicon, 36Chlorine, 41Calcium. AMS dating data has potential applications in hydrology, glaciology and ocean circulation studies.

The High-Resolution Secondary Ionization Mass Spectrometry (HR-SIMS) will provide data for dating of elements such as zircon, and accessory minerals such as monazite, titanite, sphene and apatite at a high spatial resolution. HR-SIMS has been recently established and operational at IUAC, New Delhi and will aid scientists to decipher complex growth histories in processes that led to Earth's crust formation and continental dynamics. It will also help in conducting elaborate isotopic analyses in deep earth processes and those related to cosmochemistry.

5.4 Geological and Geophysical studies:

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

The International Ocean Discovery Program (IODP) is an international collaborative research endeavor that explores Earth's history and dynamics using rock coring through scientific ocean drilling. The Ministry of Earth Sciences (MoES), is an Associate Member of the IODP consortium and National Centre for Polar and Ocean Research (NCPOR), is the nodal implementing agency for this program. Ever since our association with IODP in 2009, more than 50 young Indian scientists have been benefited by their exclusive participation in global IODP expeditions. During this year particularly, India researchers from various national organizations participated in the five expeditions: IODP-391 (Walvis Ridge Hotspot), IODP-386 (Japan Trench Paleoseismology), IODP-392 (Agulhas Plateau Cretaceous Climate), IODP-390&393 (South Atlantic Transect 1 and 2) and IODP-397 (Iberian Margin Paleoclimate).

5.4.1.1 Deciphering late stage plume magmatism along Ninety East Ridge (IODP-362)

The scientific drilling in the Sumatra Seismogenic region (IODP-362) in 2015 recovered igneous lava from sites near Ninetyeast Ridge (NER) in the Indian Ocean (Figure 5.9). Scientists from NCPOR carried out geochemical and isotopic investigations on these basaltic samples and found evidences for off-sequence plume magmatism on the eastern flank of the NER. The sediments just above and below the basement basalt constrain minimum and maximum age bounds of ~68 Ma and ~58 Ma for the basement basalts and sills respectively. Interestingly, the age of these sills is quite younger than the adjoining blocks of NER (i.e. 82-78 Ma). Combined geochemical investigations with petrography, bulk-rock geochemistry, and Sr-Nd isotope results confirm that the basement samples comprise ferro-basalts that contain high Fe_2O_3 (>13 wt%) and CaO (>11 wt%). Their rare earth elements (REE) patterns and high field strength elements (Nb, Zr, Th etc.) composition show typical characteristics of N-MORB composition. This potentially implies their seafloor spreading affinity. In contrast, the sills are

low in Fe_2O_3 content (< 9 wt%) and CaO (<9 wt%). They are highly alkaline with enriched REE patterns showing distinct plume signatures. The Sr-Nd isotope compare remarkably well with the Kerguelen plume. Based on the analyses, in Khogenkumar et al.,(2022) it is proposed that the fast-moving Indian plate during Cretaceous-Palaeocene dragged the Kerguelen Plume material underneath the NER in the form of a sub-lithospheric lateral flow. Most likely, reactivation of deep fractures triggered decompression melting of the underlying plume material and emplaced as magmatic sills and lava flow near the NER around ~58 Ma. These findings suggest that the impact of the Kerguelen plume in the formation of the oceanic crust was much larger and unique than previously understood.

5.4.2 Seismic imaging of intra-plate oceanic deformation in the Indian Ocean Geoid Low (IOGL) region:

NCPOR under the aegis of MoES has been leading an extensive marine experiment, aimed at crustal and upper mantle imaging in the IOGL region. Recently, Pandey et al. (2022) presented detailed interpretation of high quality deep penetrating multichannel seismic (MCS) and Ocean Bottom Seismometer (OBS) data. This study reveals that the extensive compressional deformation in the region is likely to have been initiated around the early Miocene - significantly earlier than previously believed. The new crustal and upper mantle images have also enable scientists to explore variably thick oceanic crust in this region for the first time. The snapshot of deformation is shown in Fig 5.10.

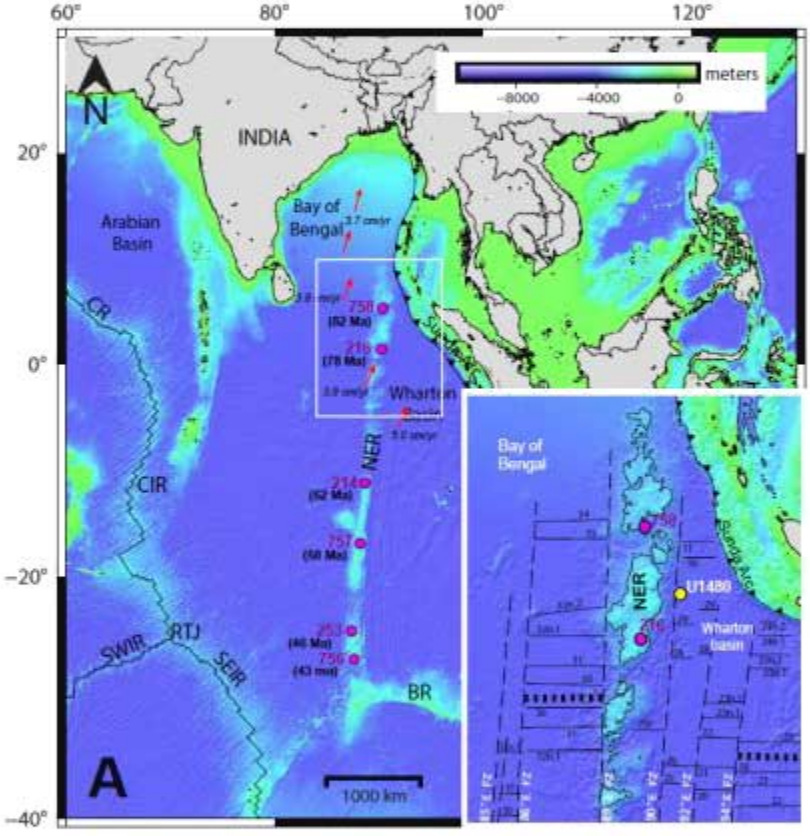


Fig. 5.9 Bathymetry map showing the regional tectonic configuration of the Indian Ocean with sequential younging age pattern of NER (N-S) from ODP/DSDP drill sites (in solid purple circles).

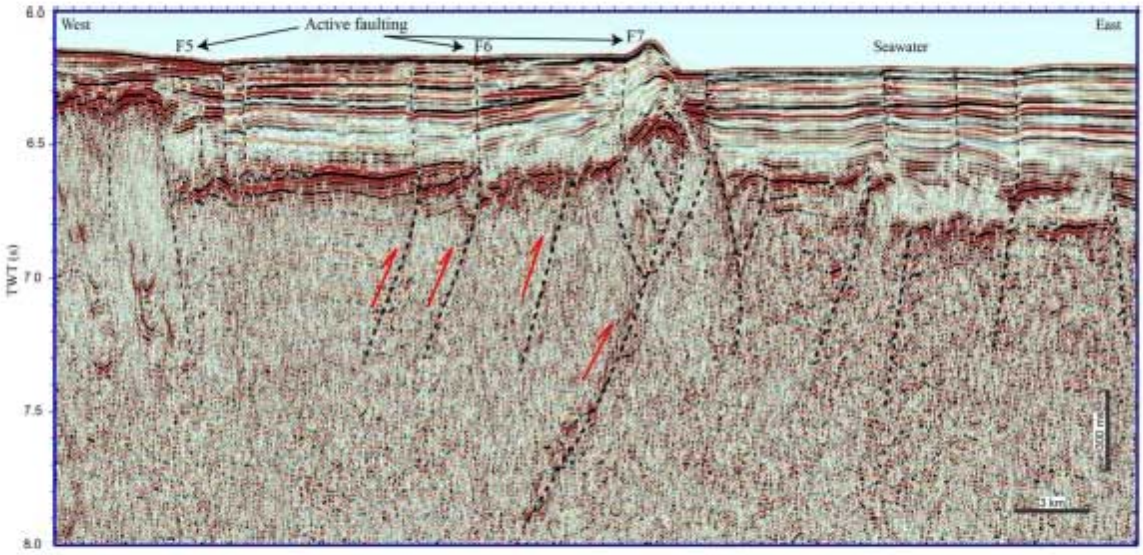


Fig. 5.10 A part of East-West MCS profile showing different deformation structures

5.5.1 Phase equilibrium modelling and zircon-monazite geochronology of HT-UHT granulites from Kambam ultrahigh-temperature belt, South India

The Madurai block, the largest crustal block in the Precambrian Southern Granulite Terrane of South India, preserves rare assemblages of high- to ultrahigh-temperature metamorphic rocks. These rocks bear exclusive evidence for the high thermal regime prevalent during their formation and can be constrained from accessory phases such as zircon, monazite and garnet. The study presents the P-T-t evolutionary history of garnet-cordierite-spinel granulites from different localities in the Madurai block. Combined petrography, mineral reaction, geothermobarometry and pseudosection modelling of the samples record HT to near-UHT metamorphic conditions with clockwise P-T trajectories. LA-(MC)-ICPMS U-Pb/Hf isotopic studies on zircons point to Paleoproterozoic high-grade metamorphism in the area with juvenile magmatic signatures. LA-ICPMS/EPMA monazite dating constrains the timing of HT to near-UHT metamorphism at ~580 and ~550 Ma. The heat source required for the Paleoproterozoic high-T event is correlated with the synchronous igneous emplacements reported in the region, whereas the heat source responsible for the Neoproterozoic HT to near-UHT event can be related to the processes associated with crustal thickening and synchronous mafic emplacement. The clockwise P-T trajectories of these granulites are interpreted as the signature of collisional orogeny prevalent in the region during the final stages of Gondwana assembly.

5.5.2 Detrital zircons in crustal evolution: A perspective from the Indian subcontinent

Detrital zircons are frequently used for crustal evolutionary studies as they sample vast regions of the continental crust. In the present study, NCESS utilise newly compiled U-Pb detrital zircon data from the Indian subcontinent as well as a compilation of previously reported global data along with Hf isotopes of modern and ancient sediments in order to understand crustal evolution in the Indian subcontinent. The detrital zircon U-Pb age data from the Indian subcontinent show peaks (at 2400–2700, 1600–1900, 850–1200, and 450–550 Ma) that correlate with the formation of major known supercontinents. In addition, two other peaks at 3200–3400 Ma and <100 Ma do not correspond to periods of supercontinent formation. The former peak may represent uneven geographic

sample density due to enhanced erosion and exhumation of Archean sources. The distinctly younger (<100 Ma) detrital zircon age peak may represent zircon preservation due to the Himalayan orogeny. The zircon Hf model ages from the Indian subcontinent suggest that the Precambrian crust was the major source of continental crust with younger ages. The conspicuous shift to positive $\varepsilon_{Hf}(t)$ at ca. 3600 Ma from detrital zircons of the Indian subcontinent may underscore a change in geodynamic processes, while the highly negative values post ~3200 Ma may be associated with the crustal reworking. A wavelet analysis of detrital zircons from the Indian and global databases reveals a prominent cyclicity of ~800 Myr and ~ 350 Myr plausibly representing the supercontinent cycle and its half cycle Fig 5.11. An incongruence in power between global and Indian $\varepsilon_{Hf}(t)$ could be due to the local subcontinental geologic processes during the Paleo- to Mesoarchean.

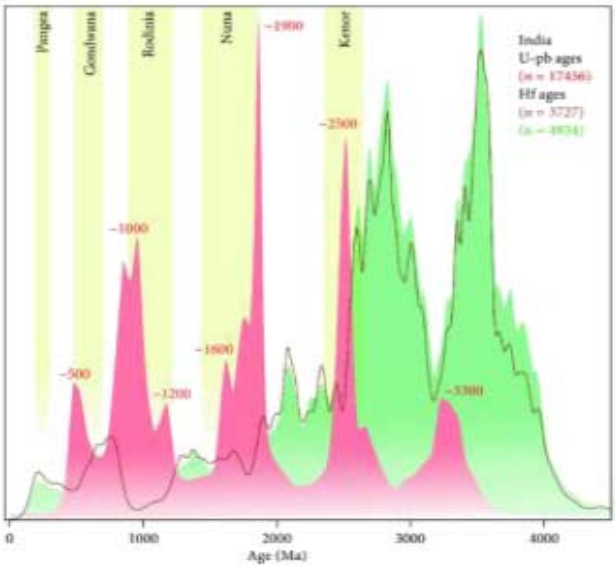


Fig. 5.11 KDE plot for U-Pb ages (red and present study) and Hf DM (brown, green and present study) of detrital zircons from the Indian subcontinent. The yellow bands depict the ages of supercontinent assembly.

5.5.1 Hydrocarbon fluid inclusions and source rock parameters: A comparison from two dry wells in the Western offshore, India

Fluid inclusions represent the direct evidence of paleofluids and can provide valuable information on the evolution of sedimentary basins and oil-bearing strata. Hydrocarbon fluid inclusion(s) (HCFIs) are the vestiges of oil from the geological formations. The study delineates the paleotemperature (T_h) / oil window, the oil quality of HCFIs and Raman peaks corresponding to hydrocarbon species of HCFIs using fluid inclusion techniques, and source rock potential of hydrocarbon generation, thermal maturity, the quantity of organic matter, and the kerogen types obtained through Rock-Eval pyrolysis data from two dry wells, RV-1 well of Mumbai offshore and KKD-1A well of Kerala-Konkan Basin. The present study compares the fluid inclusion parameters as well as the source rock geochemical characteristics of these two dry wells to address the scientific problem of the wells going dry. Further, evaluated whether the results agree with an earlier finding from a case study of two wells named KK4C-A1 (Kerala-Konkan basin) and RV-1 well where only a few parameters such as temperature of homogenization (T_h) & API gravity were utilised, and the chances of getting oil in the nearby areas of these two wells were reported. In the present study, the fluid inclusion parameters such as the palaeotemperature (T_h), API Gravity and Raman spectra were obtained from micron sized fluid inclusions at different depths for a quick assessment of nature of oil inclusions within the two dry wells. Along with fluid inclusion parameters, different source rock parameters obtained from Rock-Eval Pyrolysis analysis (secondary data) such as S1, S2, S3, T_{max}, Hydrogen Index (HI), Oxygen Index (OI), Potential Yield (PY), Production Index (PI) and Total Organic Carbon Content (TOC) were also considered for a detailed source-rock evaluation of two wells (RV-1 and KKD-1A) and the results act as the supporting evidence to address the reason for the wells gone dry.

Temperature of homogenisation (T_h) of hydrocarbon Fluid Inclusion Assemblages (FIAs) from both the wells fall in the oil window (60–150 °C) range indicating that there was a conducive thermal

condition favourable for oil generation in these two basins. API gravity of oils in RV-1 well of Mumbai offshore (48–53) was lighter when compared to those in KKD-1A (18–22) of Kerala-Konkan basin. Raman spectra of HCFI samples could decipher important hydrocarbon species from RV-1 well samples. Raman spectra of KKD-1A well show less prominent peaks (broad) only. Pyrolysis data shows that Palaeocene–Early Eocene source rocks of Panna formation of RV1 well are mature enough to generate hydrocarbons. On the other hand, Palaeocene aged source rocks of Kasaragod formation of KKD-1A well are immature. Source rock maturity therefore could be considered as crucial in hydrocarbon generation in these two wells even if oil-window was achieved. This study reports that, in RV-1 well, even though it is a dry well in a proven basin, the oil window, API gravity of oils and constituents from HCFIs of RV-1 well and the source-rock maturity opens up a demand for detailed exploration in nearby areas of RV-1 in the Mumbai offshore basin hopeful of finding a high-value prospect for oil, whereas the fluid inclusion studies in the HCFIs of KKD-1A well of Kerala-Konkan basin is showing only a minimal chance of oil generation that too of a heavy nature and the source rock immature characteristics suggesting only minimal generation of hydrocarbons. Due to the heaviness of the available oil in the KKD-1A well impedes migration. The study suggests that there is no potential for finding oil in the nearby areas of KKD-1A well of Kerala-Konkan basin.

5.5.2 Joint geomorphological and geophysical (electrical resistivity) investigation for the configuration of soil pipe

Soil piping is a complex mechanism of subsurface soil erosion, which results underground conduits (cave / tunnel) of varying dimensions. Soil piping associates with severe consequences, such as land subsidence and land slide. Therefore, the investigation of soil pipe is crucial. However, the study of soil pipe is challenging unless characteristic surficial evidences of the pipe are available. Based on the surficial evidences, soil pipe can be configured with geophysical techniques which in-turn aid in designing precursory measures. Therefore, the present study carried out a combined geomorphological and geophysical investigation to configure the soil pipe at Kinanoor village, Kasaragod, Kerala, India. Based on the vital geomorphological information, resistivity survey was carried out and configured an underground soil pipe of diameter ~ 6.5 to 7 m that is seated ~ 3 m beneath the surface. This hollow pipe is underlain by the only accessible road of that locality which makes the road vulnerable for transportation. Therefore, a bridge like structure is recommended to construct at the pipe location to stabilize the risk factor. Since the study area is situated on a fringe-slope, the geomorphological investigation points out that the disturbance in natural course of the drainage system and the accumulation of water in the up-slope area due to the man-made activities might act as potential causes for the piping in the area Fig 5.12. Therefore, it is suggested not to disturb the natural course of the drainage which may lead to subsidence of the area in future.

5.5.3 Diverging monthly rainfall trends in south peninsular India and their association with global climate indices

With the frequent recurrence of hydroclimatic hazards, such as rainfall-induced floods and landslides, it is essential to look at the spatio-

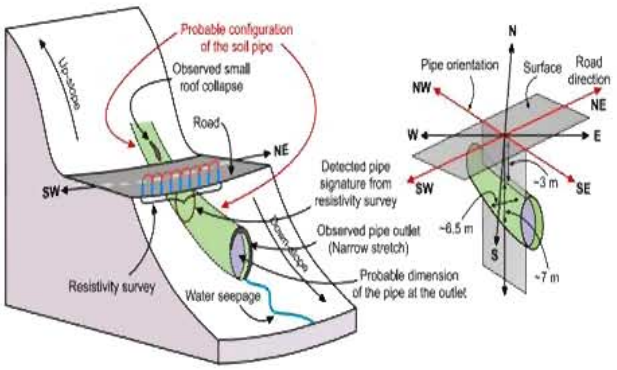


Fig. 5.12 Schematic diagram shows the probable configuration of the soil pipe beneath the study area.

temporal evolution of rainfall trends and teleconnections of regional rainfall with global climatic indices. The present study is carried out in two climatologically contrasting terrains, the humid regions in the western side of South-Peninsular India (SPI-W) and semi-arid to arid regions in the eastern side of South-Peninsular India (SPI-E). Trends in the rainfall were studied over a long-term (1901–2020) gridded rainfall data, and change points were detected using the Pettitt's test. An expanding-sliding window trend analysis based on Kendall's Taub was carried out to decode the time evolution of rainfall trends and to differentiate consistent gradual monotonic trends from step changes. Two distinct change points were observed in the rainfall, the first in the 1960s and second in 1990s. SPI-E manifested a strong positive trend in the monsoon rainfall after 1990's while SPI-W demonstrated a weakening in rainfall after 1960's. The regionally diverse trends during the recent epochs are evaluated along with IOD (Indian Ocean Dipole) and it was observed that there is a significant increase in co-occurrence of positive rainfall anomaly, positive IOD and positive ENSO (El Niño Southern Oscillation) events after 1990. Increase in positive IOD events could be associated with the changes in the regional rainfall during these recent epochs. The trends in monthly and annual rainfall showed high sensitivity to data periods and data lengths, highlighting the need to perform such comprehensive analysis for the planning of reservoir operations, water management and agricultural activities Fig 5.13.

5.5.4 Geochemistry pollution status and contamination assessment of potentially toxic metals from the sediments of a tropical river of Kerala, India

The contamination of heavy metals within the sediments of a tropical river basin of Kerala, India was studied using pollution indices thereby to examine the level of deterioration. Sediment samples were taken from 20 locations and the major investigations carried out in the sediment samples include geochemical analysis for the determination of major ions and minor (trace) elements by using X-Ray Fluorescence spectrometer (XRF) and textural analysis for the classification of sediment samples into different categories. To understand the

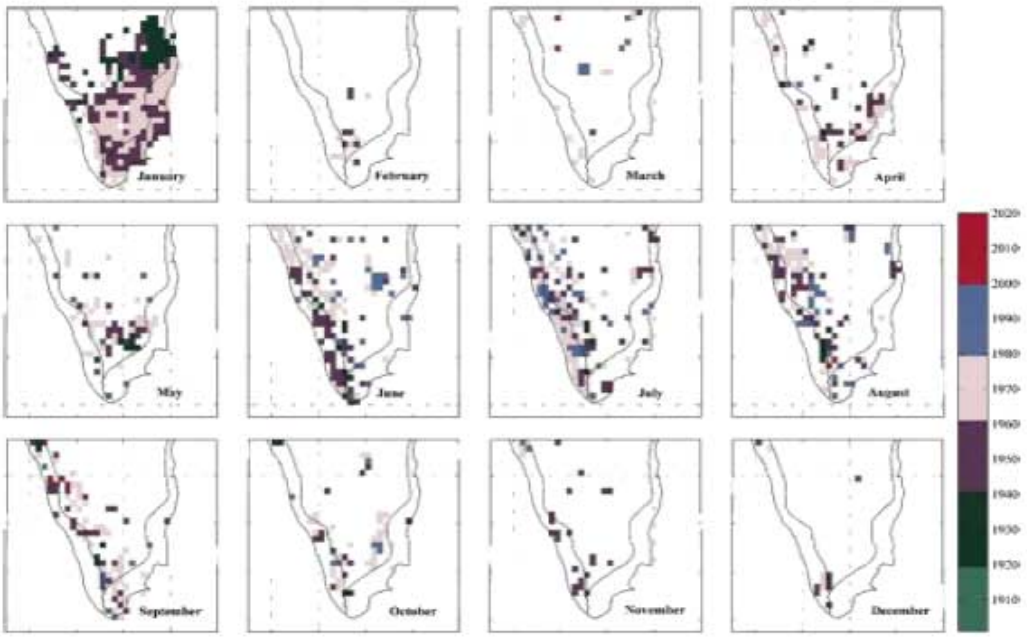


Fig. 5.13 Significant change points of monthly precipitation data using Pettit's test of 120-year data from 1901–2020.

pollution loads in the sediments of the study area, the heavy metal and major element contamination of the samples were assessed based on Crustal Enrichment Factor (EFc), geo accumulation index (Igeo), Contamination Factor (CF), Degree of contamination (Cdeg) and Pollution Load Index (PLI). From the analysis, it is seen that the coastal sediments of KRB were polluted mainly by Zirconium which exhibits high values in the pre monsoon season. Among the major elements, Titanium is the only one which manifests slightly higher values in the pre monsoon period. Based on the textural analysis, it is observed that these sediments predominantly come under sandy loam and loamy silt classifications during the three seasons of study. The unplanned urbanization and industrialization have detrimental effects on the quality of river sediments in the recent years. The current work is preferably applied to a river system and the findings will deliver productive evidence for analysing the plenary catchment areas of Western Ghats.

5.5.5 Modelling a multi-stage batch reactor for the immobilization of Fe(III) ions using humic acid and 2-mercaptobenzoxazole fabricated organo-clay

Iron contamination in water resources has remained an unsolved issue globally for many years. This study introduces a novel organo-clay adsorbent material resulted from the condensation reaction between humic acid, 2-mercaptobenzoxazole and Na-montmorillonite. The specific modification to the clay added the most active functional groups like –COOH, -NH_2 and –SH, which imparts enhanced adsorption capacity for NaMMT-HA-MBO to bind Fe(III) ions. The capturing mechanism and the specific binding sites for the metal ions in the adsorbent was confirmed by XPS analysis. The adsorption performance of the material was evaluated and the theoretical optimization was carried out by response surface modelling. The NaMMT-HA-MBO showed a remarkable adsorption capacity of 77.0 mg/g, which outperformed many of the reported adsorbents in the literature. A multi-stage reactor was designed for calibrating the performance of the material during factorial operations. The adsorption of Fe(III) onto NaMMT-HA-MBO was spontaneous, complexation reaction mechanism with a PSO kinetics. The adsorbent material showcased an excellent regeneration capacity, ensures the reusability and stability of the material. Thus, the study unveils a functional organo-clay, which can be utilized as an effective adsorbent to remove Fe(III) ions from spiked and natural water systems.

5.5.6 Heavy metals in coral reef sediments of Kavaratti Island, India: An integrated quality assessment using GIS and pollution indicators

The present study aims to document the contamination levels and ecological risks of heavy metals in the sediments of Kavaratti lagoon, India. A total of 15 sediment samples were collected for the analysis of Al, Pb, Cd, Cu, Cr, Mn, Ni and Zn. The decreasing trend of heavy metals was observed in the lagoon sediment as Pb > Zn > Al > Mn > Ni > Cr > Cd > Cu. The Geo-accumulation index (Igeo) results indicate that Cu, Cr, Mn, Ni and Zn were uncontaminated, while Cd was strong to extremely contaminated and Al and Pb were moderately contaminated. The enrichment factors (EF) of Cd and Pb range from moderate to extremely high (EF > 1) indicating that they have anthropogenic origin on Kavaratti Island. The Contamination factor (Cf) indicated that Cd, Pb and Al belong to a high risk of contamination (Cf > 6). The pollution load index (PLI) value near one suggested that a moderate level of pollution occurs in the study area. The modified degree of contamination (mCd) shows that Al, Cd and Pb have an ultra- higher degree of contamination (mCd ≤ 32). The potential ecological risk (RI) index confirmed that Pb and Cd have considerable to the serious thread of ecological risk (RI > 600). Additionally, multivariate statistical analysis and pollution indexes showed that the Kavaratti lagoon is moderate to considerably polluted by heavy metals. Diesel-based power

generation, activities related to shipping, untreated sewage, fishing and tourism activities are the main anthropogenic sources of heavy metal pollution on Kavaratti Island.

5.5.7 Isotopic fingerprinting of dual monsoon moisture sources, evapotranspiration process and microclimate manifestation over the tropical rainforest region, western part of the Western Ghats, India

The changes in precipitation pattern provide an understanding on the hydroclimatic response to global warming during the Anthropocene. The present study investigates sources of precipitation moisture for the Indian Monsoon and the local environmental mechanisms controlling its distribution over the southwest coast of India. This is achieved by the characterization of stable isotope ratios of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) in rainwater samples collected from a high humid tropical setting (Swarna-Madisal river basin) of the Western Ghats, South India and another station further south (Bakrabail, southern edge of Nethravati river basin). This study contributes to the detailed investigation on rainwater isotopic composition and microclimate characteristics which is lacking in the humid west coast region. The rainwater isotopic composition of coast was close to that of the Arabian Sea water and reflected the first condensate of vapours which were originally formed under fast evaporation at the nearby ocean. In inland location, the higher d-excess values reflect continental moisture recycling. Evapotranspiration has led to higher kinetic fractionation effect in the inland region. The isotopic storm effect during winter monsoon season suggested the rain distribution from saturated air masses formed under deep convective effect in the Bay of Bengal. The overall local meteoric water line (LMWL) in the Swarna-Madisal basin was found to be $\delta^{2}H = \{(7.2 \times \delta^{18}O) + 7.5\}$, $R^2 = 0.98$. Further south, the LMWL of Bakrabail was, $\delta^{2}H = \{(8.19 \times \delta^{18}O) + 16.1\}$, $R^2 = 0.98$ for annual observation and displayed minimal variability for inter-seasonal slopes (7.73 for summer monsoon, 8.48 for winter monsoon and 8.36 for pre-monsoon) and intercepts (15.6 for summer monsoon, 17.8 for winter monsoon and 15.5 for pre-monsoon) Fig 5.14. In regions of vegetation dominance and humid climate, the prevailing local air mass masked the rain-out effect of marine air mass as well as the amount effect which support microclimatic settings at the local precipitation sites in southwest India. The time and space variability of regional moisture circulation in controlling atmospheric water balance has been deduced in this study. Thus, the high efficacy of stable isotopes in tracing the manifestation of microclimate in the humid tropics has been demonstrated.

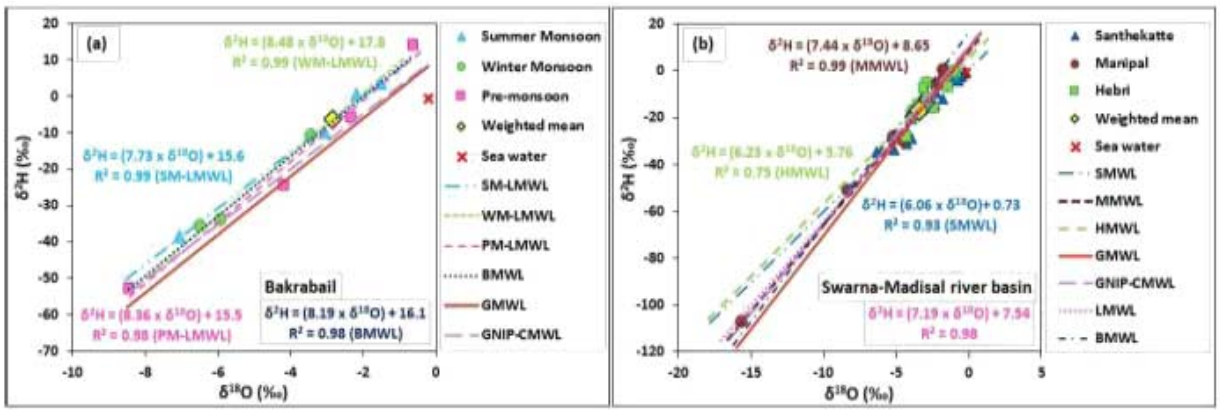


Fig. 5.14 Relationship of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) isotope ratios measured in rainwater samples of (a) Bakrabail station (monthly bulk) as well as (b) three observational stations (daily scale) in the Swarna-Madisal basin.

5.5.8 Influences of summer monsoon variations on the terrigenous influx, bioproductivity and early diagenetic changes in the southwest Bay of Bengal during Late Quaternary

The sediment core (MGS11/02), collected from the lower boundary of the Bay of Bengal (BoB) oxygen minimum zone (890 m) is studied to understand the influences of summer monsoon variations on the terrigenous sediment influx and its relation to bioproductivity and early diagenetic changes in the southwest BoB during the Late Quaternary. The high content of terrigenous controlled metals increased, kaolinite/chlorite increased, and K/Rb decreased after 19 cal kyr BP, indicating a simultaneous increase in the terrigenous influx and intensity of chemical weathering during this period. The variations in summer monsoon and land influx observed in the core sediments are also reflected in the sources of organic matter. High values of $\delta^{13}C$ observed at 40 to 19 cal kyr BP suggests higher influence of marine organic matter and/or presence of C_4 terrestrial plant. The negative shift of $\delta^{13}C$ between 19 and 6 cal kyr BP could be the result of the change in terrestrial plant biomass to C_3 photosynthesis and increased marine organic matter. Rock magnetic properties and redox-sensitive metals distribution suggests the prevalence of reduced environment during 52 to 19 cal kyr BP and oxic condition during 19 cal kyr BP to present. The low sedimentation during glacial period allowed sufficient time for pyritization which resulted in the low magnetic signals during 52 to 20 cal kyr BP and led to reducing conditions in the sediment interval. The $\delta^{15}N$ values in the core sediments are suggesting the absence of denitrification in the water column during last 52 cal kyr BP. Previous studies suggest that the BoB is a geochemical 'tipping point' because the slight changes in water column denitrification by anthropogenic or climatic impact can accelerate BoB nitrogen contribution to the global nitrogen budget. This study indicates the absence of water column denitrification signals during last 52 cal kyr BP even though drastic climatic changes happened in the BoB in the Late Quaternary.

5.5.9 Analysis of pre-monsoon convective systems over a tropical coastal region using c-band polarimetric radar, satellite and numerical simulation

Analysis of pre-monsoon convective systems over the southern peninsular India has been performed using C-band radar and numerical simulation. Statistics on the radar polarimetric measurements show that the distribution of differential reflectivity (Z_{dr}) and specific differential phase (K_{dp}) have much higher spread over convective regions. The distribution of K_{dp} is almost uniform across the vertical over the stratiform regions. The mean profile of Z_{dr} over stratiform regions shows a distinct local maximum near melting level. A comprehensive analysis has been done on an isolated deep convective system on 13 May 2018. Plan position indicator (PPI) diagrams and satellite measured cloud top temperature demonstrate that pre-monsoon deep convective systems can develop very rapidly within a very short span of time over the region. Heavy precipitation near the surface is reflected in the high value of K_{dp} (>5° km^{-1}). High values of Z_{dr} (>3 dB) were measured at lower levels indicating the oblate shape of bigger raindrops. A fuzzy logic-based hydrometeor identification algorithm has been applied with five variables (Z_h, Z_{dr}, ρ_{hv}, K_{dp}, and T) to understand the bulk microphysical properties at different heights within the storm. The presence of bigger graupel particles near the melting layer indicates strong updrafts within the convective core regions. The vertical ice hydrometeor signifies the existence of a strong electric field causing them to align vertically. Numerical simulation with the spectral bin microphysics (SBM) scheme could produce most of the features of the storm reasonably well. In particular, the simulated reflectivity, graupel mixing ratio and rainfall were in good agreement with the observed values fig 5.15.

The extreme rainfall events observed at the High-

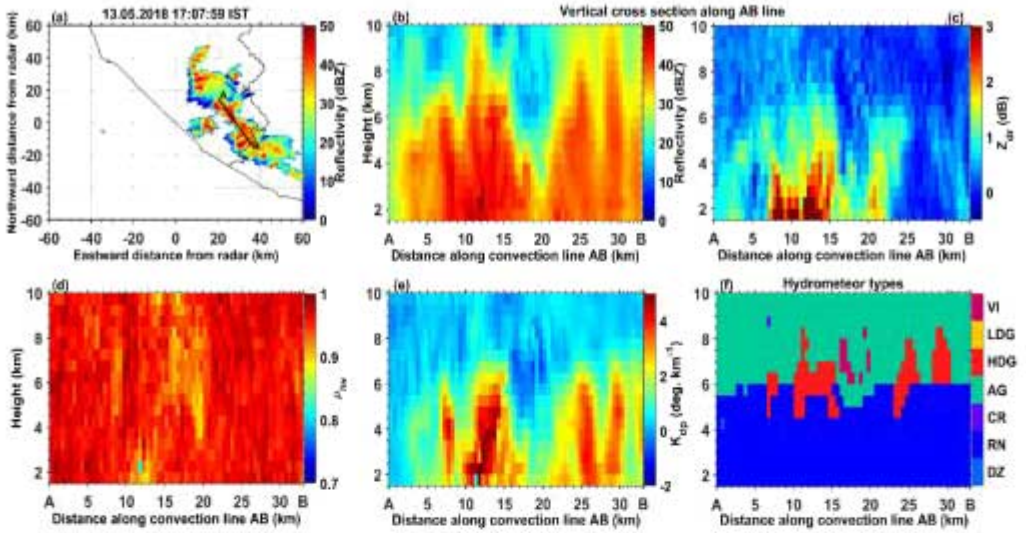


Fig. 5.15 (a) Radar reflectivity averaged between 2.5 and 3.5 km height on 13 May 2018. Vertical cross section of (b) reflectivity, (c) Z_{dr} (d) ρ_{hv} (e) K_{dp} and (f) identified hydrometeor types along AB convection line at 17:07:59 IST.

5.5.13 The extreme precipitation events of August 2018 and 2019 over southern Western Ghats, India: A microphysical analysis using in-situ measurements

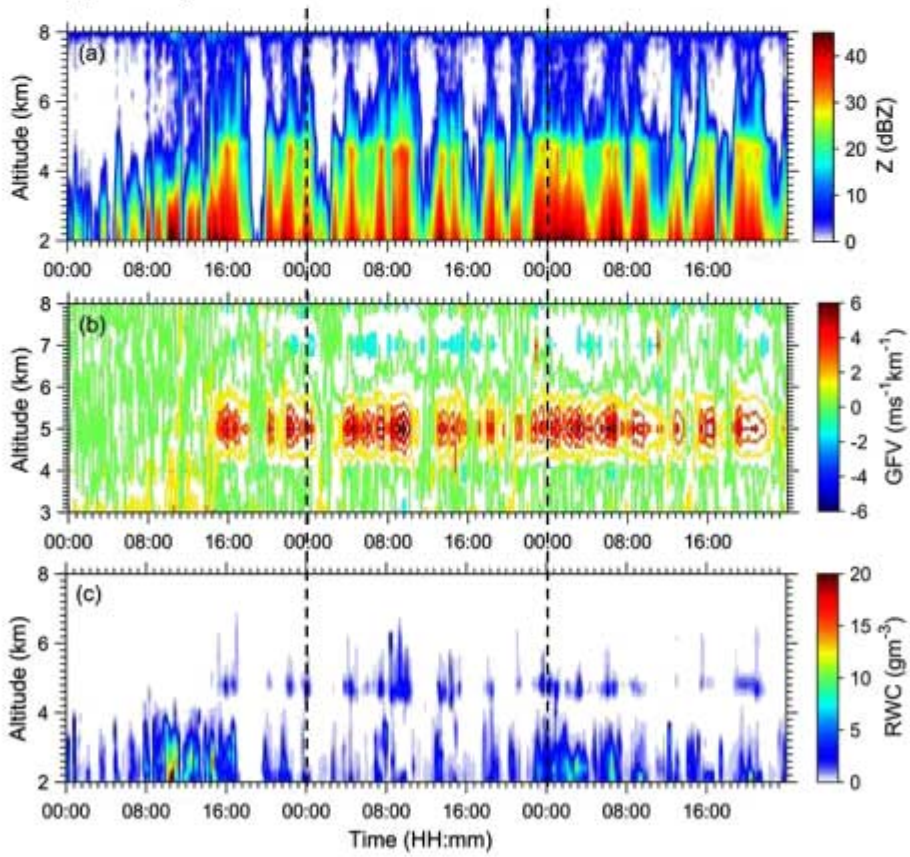


Fig. 5.16 Time series (IST) of (a) reflectivity, (b) gradient fall velocity at melting level, (c) rain water content on 14th, 15th, 16th August of 2018.

Altitude Cloud Physics Observatory (HACPO) in Rajamallay, Munnar (10° 9′ 19.94″ N, 77° 1′ 6.65″ E; 1820 m above MSL) over the southern Western Ghats (India) during the floods in 2018 and 2019 monsoon periods are investigated. The observations from Micro Rain Radar (MRR) and Ceilometer are used to analyse precipitation microphysics and the vertical distribution of clouds during the intense rainfall episodes on 14 – 16 August 2018 and on 8th August 2019. The drop size distribution (DSD) spectra during the 2018 event are characterized by large number of small to medium-sized drops resulting in maximum reflectivity of 48 dBZ with mass-weighted mean diameter (D_m) value of 1.2 mm. At the same time, the 2019 event is characterized by larger drops and resulted in high reflectivity of 53 dBZ and D_m value shifted to 1.4 mm. The consistent increment of D_m and σ_m with slight variation in N_t during the intensive rain hours on 8th August 2019 shows a mixed-phase microphysical process that can invigorate the production of convective rainfall from deep cloud bands (217 K of cloud top temperature) with enhanced rain water content (22 gm^{-3}). The parameters of scaled raindrop size distributions corresponding to higher rain rates (>50 $mmhr^{-1}$) suggest that the microphysical process that control the variations in DSD is strongly number controlled during these extreme rainfall events. The DSDs are evolved from a consistent, widespread rainfall supported by anomalous moisture advection from the Arabian Sea in 2018 monsoon period. The moisture convergence occurred on the elevated terrains leads to an intense spell of rainfall in two consecutive hours and satisfies the occurrence of a mini-cloud burst (MCB) event on 8th August 2019 causing flash flood in the region Fig 5.16.

Chapter-6

RESEARCH, EDUCATION, TRAINING AND OUTREACH (REACHOUT)

To fulfil the primary mandate of the Ministry of providing the nation with best possible services in providing 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. This requires a large number of trained manpower, knowledgeable in atmospheric, oceanic and geosciences that can be inducted into the country's R&D and operational organizations. The Research, Education and Training Outreach (REACHOUT) program which takes care of the above activities consists of the following five sub-programs:

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

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

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

Proposals from various academic/research organizations and universities in the different fields of Earth system Science are supported with an intention that it would help in improving our understanding of the earth system. Activities which are supported include focused research in areas of national importance; Building indigenous development, Human resource development through opening of Centers of excellence, initiation of academic programmes, establishment of MoES Chairs; Setting up of specialized labs as national facilities; National and international collaboration, National coordinated projects and setting-up of Earth Science & Technology Cells (ESTCs). During the current financial year, a total number of 32 proposals have been sanctioned as shown in the table below:

Number of proposals funded during 2022-23	Atmospheric Science	Ocean Sciences	Geosciences	Seismology	Hydrology and Cryosphere
	10	7	8	4	3

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

6.1.1 Atmospheric Research including Climate Change

Three projects have been completed under PAMC-AS. The achievements under each of them are described below:

Innovative and efficient algae based system to reduce carbon dioxide emissions: A possible remedy to climate change, by IIT, Indore-Completed

The study concluded that the indigenous microalgae Scenedesmus sp. proves capable enough to tolerate high concentration of CO2 (15 %) not only in the optimized and standard environmental conditions tailored in the indoor environment but also in the semi-outdoor environment, where the environmental factors vary as per weather conditions. The scaling up the cultivation of microalgae from 500 mL to 600 L also procured higher CO2 fixation rate, higher biomass productivity as well as enriched biochemical profile. The work can be utilized for further studies on CO2 fixation in high-rate algal ponds or raceway ponds in

order to develop a strategy that is economically viable and environmentally sustainable and can be adopted by industries for direct treatment of exhaust gases such as CO2 in conjunction with the production of valuable products. Six papers have been published and one Ph.D is awarded during the project.

Characterization of flow structures in rotating convection with superimposition of vertical and horizontal heat fluxes, by IIT, Bombay- Completed

A new configuration for rotating convection is considered that mimics the localized heating of the earth's equator for better modeling of the baroclinic waves and secondary structures in the atmosphere. Such a configuration is shown to overcome the limitation of the classical differentially heated rotating annulus by providing heating in both horizontal (meridional) and vertical directions using a localized heating strip near the outer bottom periphery and uniform cooling on the inner wall of the annulus. A finite volume method-based CFD toolkit OpenFOAM is used to unravel the flow dynamics. Numerical simulations are performed for a Rayleigh number, and Taylor numbers, The results show the co-existence of the baroclinic wave, meandering in the annulus, and convective columnar plume (CCP), present over the heating strip. The study would be useful in modelling atmospheric flows. Two papers have been published and two have been submitted for publication and two Ph.Ds have been awarded during the project.

Response of land surface processes on simulation of Indian Summer Monsoon (ISM), by Amity University, Rajasthan- Completed

Flawless representation of ISM by a regional climate model (RegCM) is more important for monsoon and climate change research communities. Different land surface processes involving hydrology-heat budgets and their impacts on ISM prediction have to be studied so as to fine tune the climate model over the region. Thus, in present study different hydro-meteorological parameters are analyzed and validated with respective reanalysis or observation data of India Meteorological Department (IMD), ECMWF Reanalysis Interim (ERA-I), Climatic Research Unit (CRU), and ECMWF Reanalysis version 5 (ERA5). Investigation of lateral and boundary conditions have been done with Geophysical Fluid Dynamics Laboratory (GFDL) and ERA Interim from which the latter showcased an added value advantage over the former. Two different land surface parameterizations namely Biosphere-Atmosphere Transfer scheme (BAT) and Community Land Model scheme (CLM) have been tested with horizontal grid spacing. The results suggest that RegCM coupled with CLM land surface scheme forced with ERA interim data provide better simulation over Indian region. Two papers are published and two are submitted for publication in journals. One JRF is trained and registered for Ph.D during the project.

6.1.2 Geosciences

Quantitative reconstruction of the Paleogene climate of paleo-equatorial region based on Indian palynological records- Birbal Sahni Institute of Palaeosciences- Completed

The study explored Indian Tertiary lignites to reconstruct the evolutionary history of tropical angiosperms in the context of Plate tectonics and paleoclimate. The morphological analyses of pollen fossil records combined with the pollen morphology and DNA sequences of their living representative species, under a phylogenetic framework, unravelled that the tropical rainforests were established in Africa by mid-Cretaceous. As the Indian Plate entered the tropical zone, the megathermal angiosperms dispersed from northeastern Africa to India via Kohistan-Ladakh Island Arc during the Maastrichtian-Paleocene. The isolation of the Indian Plate at the equatorial zone during early Paleogene led to an independent evolution of distinct and autochthonous aseasonal flora in India. The early Eocene climate may have offered the ideal ecological conditions for the evolution of perhumid/aseasonal lineages on the

Indian Plate. The tropical lineages were dispersed to Southeast Asia after India-Asia collision, where they diversified giving rise to the rich tropical lowland rainforests. However, the Neogene aridity across the Indian subcontinent restricted the aseasonal flora into the perhumid pockets of Western Ghats and Sri Lanka. Six papers including one in Science were published in this project and two students have completed their thesis under this project.

Age constraints on metamorphic evolution of the Trans-Himalayas- University of Delhi- Completed

Under this project, metamorphic rocks of the Pangong Metamorphic Complex (a zone of Karakoram Metamorphic Complex, TransHimalayas in SE Ladakh, India), were studied to fix the age of metamorphism as well as the metamorphic setting of the region and to provide regional correlation in a broader geodynamic context specifically by studying and evaluating the time constrained petrological studies. Five publications have emanated from this project.

Deciphering the past environment conditions of freshwater myristica swamps of western Ghats using diatom assemblages by Agharkar Research Institute, Pune-Completed

Under this project, diatom-based dataset has been generated from one of the highly threatened and lesser-known modern ecosystems of the Western Ghats and was then correlated it with paleo records. Out of 127 taxa of diatoms documented, 63 diatom species are putative novel species and potentially endemic to the unique environment of Myristica swamps. A monograph documenting all these taxa is under preparation which will serve as baseline data for taxonomic identification in Southeast Asian countries, particularly in the Indian subcontinent, where very few regional datasets are available for taxonomic guidance. Further, this study also documented the environmental change over Holocene (last 4000 yrs) in the Myristica swamps using diatoms as a proxy to establish the past environmental conditions of the swamps during the Holocene. Two research publications have emanated from this project, three under review. One Ph.D student is going to submit her thesis soon.

6.1.3 Hydrology & Cryosphere:

Study of solute transport parameters through porous medium

This study was aimed to investigate and predict the mean arrival time and level of contamination in highly heterogeneous porous medium. A conceptual triple porosity nonequilibrium model (TPNE) was developed which accounts for both physical and chemical non equilibria suitable for process-based investigation. A graphical user interface (GUI) was developed which supports various solute transport models such as advection dispersion model (ADE), mobile immobile model (MIM), multi-process non-equilibrium model (MPNE) and TPNE. Impact of the model parameters on the breakthrough curves was studied using global sensitivity analysis (GSA). Various experiments for stratified medium and highly heterogeneous medium were planned and conducted to validate the TPNE model. Soil moisture and electrical conductivity (SMEC300) sensors were used in the experiments to monitor the solute and moisture transport behaviour. These sensors were calibrated for different texture classes of soil used. A detailed analysis of the sensitivity of the sensors towards wide salinity, moisture and temperature range was conducted. The study was further used to suggest optimum number of sensors to be deployed in field to minimise the error in predicting the contaminant and soil saturation levels.

Groundwater security of Indus basin (Ladakh) in present and future climate and land use scenarios.

The study analyzed the spatio-temporal variations in $\delta^{18}O$, $\delta^{2}H$ and Cl– values in the Upper Indus River Basin at Ladakh. Their main findings comprise of: (1) stable water isotopes of source waters are controlled by topography and meteorology of the region; (2) microclimate in sub-basins governs the stable water isotopic composition and (3) snow and glacier meltwaters dominate groundwater

recharge, with the meltwaters likely originated at higher elevations than the basins in which the groundwaters were collected. Specifically, tracer based two- and three-component mixing models suggest that the glacier melt dominantly contributes to ~44% of average annual groundwater recharge and snowmelt contributes to a further ~39% of recharge. By contrast, the average annual contribution of rain to groundwater recharge is less (~17%). The dependence of groundwater recharge on meltwaters derived from snowpacks and glaciers in the Upper Indus River at Ladakh emphasizes that changes to the pattern, form, timing and amount of precipitation and further shifts to regional glacier mass balances may substantially alter the regional groundwater resources. In summary, the stable water isotopes is an effective tool to better understand, estimate and quantify the groundwater recharge processes, especially in cold-arid environments. This approach to the measurement of groundwater recharge in cold arid desert environments has great potential for hydrological and water resource management studies in the Himalayas.

6.1.4: Seismology

Strong motion seismometry in Darjeeling-Sikkim Himalaya: Comprehensive maintenance for round the-clock seismic monitoring by the 10 stations DSSMA and enriching ground motion database for relooking into seismic source, site and path characteristics from hazard perspectives for a conservative damage and loss estimate in SELENA and HAZUS environment by IIT, Kharagpur. The Darjeeling-Sikkim Strong Motion Network (DSSMN) has been operative since 1998. In the present study, probabilistic seismic hazard analysis (PSHA) has been carried out to deliver seismic hazard distribution of the Darjeeling-Sikkim Himalaya in terms of Peak Ground Acceleration (PGA) and Pseudo-Spectral Acceleration (PSA) at different time periods. Site amplification and predominant frequency at each of the Darjeeling-Sikkim Strong motion Stations have been computed through Horizontal-to-Vertical Spectral Ratio (HVSR) analysis from 350-recorded events with good signal-to-noise ratio greater than 3.0. The generic site response curves for site classes A, B, C, and D as well as 42 next generation attenuation models of Darjeeling-Sikkim Himalaya at surface were developed. Data accrued under different projects related to Darjeeling-Sikkim Himalaya has helped in publishing more than 15 papers in high impact SCI journals.

Deformation across the Karakoram fault and Kaurik Chango rift and its implications on the NW Himalayan tectonic by NGRI, Hyderabad and Snow Avalanche Studies Establishment (SASE), Chandigarh. A total of 10 permanent GPS stations (5 in Nubra valley and 5 in Tangste-Pangong region) were installed to quantify the slip rate across the Karakoram fault and Kaurik Chango rift and analyse their role in the deformation of the Himalayan arc. Additionally, 4 GPS sites were installed in the Spiti valley. GPS data from Nubra valley and Tangste-Pangong region were analysed and site velocities were estimated in the Eurasian reference frame. To further quantify the deformation, the vectors were resolved into fault parallel and fault normal components. Fault normal motion across Karakoram fault does not show any change while fault parallel motion show a slip rate of 0 mm/yr, 2.6 mm/yr, 5.6 mm/yr in the Nubra valley, Pangong, South east of Pangong respectively. The results obtained so far suggest that the slip on the Karakoram fault is very low and slip on the northern Karakoram fault is zero and may increase to the south, which is supported by new field observations and new geochronological results from the Karakoram fault system (KFS). KFS accommodates part of the India-Tibet motion by right lateral motion. The shallow locking depth suggests that it is largely an aseismic fault. In order to further understand the tectonics of the region around Karakoram fault and Kaurik Chango rift, lineaments were mapped using satellite optical and topographical data. The orientation trend of lineaments around Karakoram fault is found towards NE-SW and near Kaurik Chango rift it is NW-

SE. The overall trend has been seen as NE-SW.

6.1.5: Ocean sciences

A Centralized Repository - Semantic Homogeneity in Ocean Data Interoperability through Ontology-Driven Knowledge Representation: by Adhiyamaan College of Engineering, Tamil Nadu.

In this project, Interoperability is being addressed through ontologies, which are widely used as a means for solving the information heterogeneity problems. The heterogeneities between various sensor networks are reduced through ontology mapping with sensor vocabulary. Sensor Observation Service (SOS) provides a broad range of interoperable capability for individual sensors, sensor platforms, and networked constellations of sensors in real-time, archived or simulated environments, through Semantic Sensor Ontology (SSN). This project provides an effective and efficient technical solution to address voluminous data, in terms of semantic heterogeneity. This results in achieving interoperability, semantic information retrieval and effective visualization through domain ontologies. Total four publications have been published and one PhD has been produced from this project.

Studies on impact and response of ecologically important bacteria towards environmental stressors of Bhitarkanika mangrove ecosystem, Odhisa: by NIT, Rourkela.

Mangrove ecosystem of Bhitarkanika is highly rich in biological diversity and is a globally significant habitat for wildlife. The rising pollution associated with industrialization severely threatens mangrove ecosystems affecting the productivity, physiological activities, and the biogeochemical cycle. Studies were carried to understand the interactive effect of stressors in a natural ecosystem, a microcosm study was performed mimicking the stress condition of the present day (control) and the stress condition of the year 2100. The result revealed B. stercoris GST-03 was more tolerable to stress conditions of the year 2100 than P. balerica DST-02. However, P. balerica DST-02 forms a dense biofilm in the control condition. Three publications and one PhD student has been produced from this project.

Benthic-pelagic linking: An approach to delineate economically important macrobenthic population of Sundarbans Estuarine System: by Presidency University, Kolkata

Biological entities are a pivotal component of the estuarine ecosystem and contribute significantly to fisheries and other ecosystem services. In this project, Benthic-pelagic linking approach has improved our understanding about the benthic biodiversity (both macro and meio) as well as the zooplankton community structure. Two new species of polychate worm have been discovered from Sundarban and named as Sigambra sundarbanensis and Ancistrosyllis matlaensis. This study will help for future researcher for building a comprehensive database. Moreover, policymakers can frame policies for the protection and conservation of biodiversity from the fragile ecosystem like Sundarbans which is under the constant threat of climate change and pollution. Total five publications have been published and one PhD has been produced from this project

6.1.6: Earth System Science and Technology Cells (ESTC):

Focussed network R&D is continuing under following ESTCs

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

(a) Studies on the implications of engineered nanoparticles and bio-nanocomposites in aquatic animal health,

(b) Surface modification nanotechnological approach for antifouling and anticorrosion applications,

(c) Enhancement of marine microbial by-products for biomedical applications,

(d) Biofunctionalization nanoparticles for anticancer applications using marine bio-sources,

(e) 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'.

IV. ESTC on Coastal and Ocean Technology (COT) with project entitled "Hydrodynamic performance characteristics of Caisson type Breakwater" at National Institute of Technology (NIT) Surathkal, Karnataka was completed successfully in September 2022.

A total of 12 PG (M.Tech.) dissertations were made out of experiments and 1 Ph.D. submitted on topic 'Studies on caisson type breakwater – A physical and numerical approach'. Three research papers, two book chapters were published and one more is communicated. One of three papers presented in international conferences got best award.

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 fourteen number of Ph.D. are ongoing under the ESTC network projects. A lab of ocean sciences established by Sathybama Inst of Science & Technology (SIST) Chennai under ESTC-MBS. Two MoUs were signed between ETSC-MBS and industries. Twelve papers were published in referred journals.

6.1.7 Human Resource development & Capacity Building

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

6.2: AWARENESS AND OUTREACH PROGRAM

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

participation of school, college and university students. Ministry also supports the National and International Earth Science Olympiad.

6.2.1 Seminars / Conference and Exhibitions

In order to provide a platform to scientists, engineers, technologists, experts, social scientists and user communities to interact and discuss the various aspects of Earth System Science. During the year, the Ministry supported and participated in 10 Exhibitions/Science Fairs and 40 Conferences / seminars/ workshops comprising 8 International ones.

6.2.2 Earth Day Celebration-2022

About hundreds of students participated in activities on Earth Day (22 April 2022) in physical mode in Kashmir, Uttar Pradesh, Odisha, Punjab and Assam. An oath to save the mother Earth was undertaken by more than fifty thousand students in virtual mode (through MyGov) on the occasion of Earth Day, Photos -1. MoES has supported International Ozone day celebrations on 16 Sept.2021 in Punjab.

6.2.3 Azadi Ka Amrit Mahotsav

Panchayti Raj Diwas

Ministry actively conducted public awareness campaigns to showcase advisory/forecasts services and observation on weather, monsoon, climate, extreme temperatuers on Panchayti Raj Diwas (24 April 2022). Honourable PM visited Samaba, in Jammu and graced the occasion by addressing public of Jammu.

Photos : Earth Day Celebrations 2022

Gramodaya Mela 2022

Ministry participated and showcased its achievements and public services in Mela during 09th-12th October, 2022 at Chitrakoot, Madhya Pradesh organised by Deendayal Research Institute.

Panchmahabhoot: Akash for Life

MoES participated and showcased public services in the "Akash For Life" International conference & Exhibition, jointly organized by six Scientific Ministries and Depts. of Govt of India, during 4-6 Nov.2022, in Uttranchal University Dehradun.

December 2-4, 2022. Honourable Governor Orissa, Hon'ble Minister MoEFCC, Hon,ble MoS MoEF&CC and Honble M.P. Bhubaneshwar graced the conference and Expo.

6.2.4 Earth Science Olympiad

Ministry has sponsored the school students (IX to XII) for International Earth Science Olympiad (IESO) and Indian National Earth Science Olympiad (INESO) including training of top 25 students in order of merit. Top seven students out of twenty five were selected from INESO to compete with students in

Photo : Panch Mahabhoot 'Akash Tatva' – Akash For Life, 4-7 Nov.2022, Dehradun.

Sumangalam panchmahabhoot: Vayu - The Vital Life Force

Ministry participated and showcased services by IMD and IITM in conference Series on 'VAYU- The vital Life Force' organised at Siksha 'O' Anusanchan University campus, Bhubaneswar, Odisha during

IESO-2022 from world over. IESO in 2022 was conducted online by host country Italy (due to shadow effect of Covid). Seven students of team India finally took part in online IESO. A few new competitions such as 'Data Mining Test (DMT)', 'Earth Learning Students Idea (ELSI)', apart from

Photo : Figure: Sumngiam Panch Mahabhoot 'Vayu- The Vital Life Force', 2-4 Dec.2022, Bhubaneshwar

conventional competitions namely 'Team Project', 'Team Filed Investigation (TFI)' were also part of the competition. The students won a total of nine Gold medals in IESO-2022. Secretary, MoES has felicitated the medal winners in the ministry Photo-2.

Space was the Chief Guest.

This year the Life Time Excellence Award was awarded to Dr. Harsh K Gupta for his for his significant contribution in the field of Earth System Science. The National Award for Ocean Sciences was

Photo-2 : International Earth Science Olympiad 2022 (Students with Secretary MoES)

6.2.6: MoES Foundation Day

The Ministry of Earth Sciences (MoES) celebrated its foundation day on 27th July 2022 in hybrid mode at Prithvi Bhavan, MoES Hq. New Delhi. Dr. Jitendra Singh, Honourable Union Minister of State (Independent Charge), Ministry of Sciences & Technology, Earth Sciences, DoPT, DAE and Dept of

presented to Dr. Aninda Mazumdar, Principal Scientist, CSIR-National Institute of Oceanography, Goa. The National Award for Atmospheric Science & technology was presented to Dr. K. Mohana Kumar, Retd. Professor, Cochin University of Science and Technology (CUSAT) and Founder-Director of the Advanced Centre for Atmospheric Research Radar

Dr. Jitendra Singh HMoES Chief Guest in Ministry's Foundation Day, 27 July 2022

HMoES with the national awardees

(ACARR), CUSAT. The National award for Geoscience & technology was presented to Dr. Virendra M. Tiwari, Director, CSIR-National Geophysical Research Institute (NGRI), Hyderabad. The National Award for Polar Science/Ocean Technology was presented to Mirza Javed Beg, Director, National Centre for Polar and Ocean Research (NCPOR), Goa. Dr. Swapna Panickal, Scientist at the Indian Institute of Tropical Meteorology, Pune was presented with Dr. Anna Mani award for woman scientist. The Young Researcher Awards were presented to Dr. Anoop Sharad Mahajan, Scientist at the Indian Institute of Tropical Meteorology (IITM), Pune and Dr. Bhaskar Kundu, Asst. Professor, National Institute of Technology, Rourkela.

6.2.7: Swachh Sagar Surakshit Sagar Campaign:

India's coastline of more than 7,500 km reflects our vast ocean resources. Most importantly, the Indian Ocean is the only ocean named after a country, that is, India. Litter especially in the form of plastics in the marine environment are a major concern and growing problem. Considering the dangers of plastic waste, India has implemented a nationwide ban on single-use plastic from July 01, 2022.

Seventy five days long inter-ministerial campaign "Swachh Sagar Surakshit Sagar / Clean Coast Safe Sea" coordinated by Ministry of Earth Sciences (MoES) culminated on 17th September 2022 the

International Coastal Clean up Day. This year's event also coincided with the celebrations of Azadi Ka Amrit Mahotsav in 75th year of the country's Independence; The coastal clean-up drive was carried out at more than 75 beaches across the country with more than 75 volunteers for every kilometre of the coastline. Seventeen Ministries / departments comprising, Indian Coast Guard, Ministry of Science & Technology, Ministry of Environment Forest and Climate Change (MoEFCC), MoYAS, Ministry of Shipping, Ministry of Tourism, Ministry of Education, Ministry of Fisheries, Animal Husbandry and Dairying. ISRO, DAE, Indian Coast Guard, National Disaster Management Authority (NDMA), National Service Scheme (NSS), Seema Jagran Manch, Paryavaran Sanrakshan Gatividhi (PSG), along with other social organizations and educational institutions participated in the campaign.

The campaign started on July 5th 2022 and has 3 strategic underlying goals that target transformation and environmental conservation through behavior change. The three underlying goals of the campaign are to 1. Consume Responsibly 2. Segregate waste at home and 3. Dispose Responsibly. The campaign will culminate with the largest beach cleaning event on Sept 17, 2022 (International Coastal Cleanup Day).

It was the first-of-its-kind and longest running coastal cleanup campaign in the world with highest number of people participating in it. Through this campaign, a mass behavioural change among the masses is intended by raising awareness about how plastic usage is destroying our marine life. Had record maximum number of participants in the coastal clean up activity by any country in the world, so far.

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

Following up The Hon'ble Prime Minister's announcement of India's readiness to contribute 3

Photos : 75 Days 'Swachh Sagar Surakshit Sagar Campaign' @ 75 beaches of about 7500 KM coast line of Indian Ocean, culminated on 17 Sept.2022. Showcasing about campaign 'Swachh Sagar Surakshit Sagar' by MoES with 17 other Ministries / depts at Inter-state conclave of S&T Ministers by DST, Gandhinagar, 10-11 Sept.2022.

million dollars for restarting the work of BCWC at the 5th BIMSTEC Summit on 30 March 2022, BCWC at NCMRWF organized its 2nd GB and SAC meetings during 01-03 November 2022 in coordination with Ministry of External Affairs, Government of India and BIMSTEC Secretariat, Dhaka. The representatives from all the BIMSTEC member nations NHMs and BIMSTEC Secretariat participated in these meetings.

Photo : Second general body & SAC meeting of BIMSTEC

Secretary, MoES and Addl. Secretary, MEA attended the inauguration programme on 1st November'22, and addressed the gathering. The committee members of GB meeting discussed and finalized the draft host country agreement in the GB Meeting. Director General, IMD inaugurated the SAC meeting. The members of SAC made short presentations on the outstanding science issues and discussed the ways of solving those issues through stronger collaboration and cooperation for improving operational weather/climate forecasts for the regions of the member countries. Important action items in terms of future course of action has been worked out.

6.4: INTERNATIONAL TRAINING CENTRE FOR OPERATIONAL OCEANOGRAPHY (ITCOocean):

The International Training Centre for Operational Oceanography (ITCOOcean) has conducted 10 training programs, one seminar and a webinar. A total of **532** persons were trained of which **424 (Male: 257, Female: 167)** are from India and **108 (Male: 68, Female: 40)** are from other countries in Indian Ocean RIM. One of the long cherished objectives of ITCOOcean to conduct short-term course was fulfilled this year. ITCOOcean started a short-term course on 10th October 2022 to officers from School of Naval Oceanology and Meteorology (SNOM), Cochin (Figure 1) and this course spans for 4 months. Details of the full courses and the trainees are given in table below.

ITCOOcean activities during Jan 2022- Till date (i.e.12.10.2022)					No.of Participated						
					Foreigners			Indian			Total (A+B)
S.No	Course Type	Name of the Fund	Duration	Course title &	Male	Female	Total(A)	Male	Female	Total(B)	
1	National	INCOIS	9 February , 2022	Training to Coastal Community Radio Operators	0	0	0	30	19	49	49
2	International	INCOIS	21-22 February, 2022	Training in operational Oceanography for ISBA trainees	11	1	12	0	0	0	12
3	National	INCOIS	2 March, 2022	Sea Glider instrumentation, testing, data acquisition, processing and analysis.	0	0	0	17	0	17	17
4	National	INCOIS	13-14 June, 2022	Operational Oceanography, Marine Meteorology & Operational Ocean Forecasting, Warning and Advisory Services for offshore E&P industries (DG HC)	0	0	0	9	1	10	10
5	International	INCOIS	22 July 2022	Webinar on "Climate Change in the Indian Ocean region"	17	10	27	99	69	168	195
6	National	INCOIS	08 August 2022	Seminar on "The Oceanography of Tropical Cyclones"	0	0	0	18	12	30	30
7	National	INCOIS	11 August 2022	Operational Services Training to National Institute of Hydrography Officers (NIH Advance Hydrography (83:111) Course)	0	0	0	4	0	4	4
8	International	INCOIS	September 05-09, 2022	Fundamentals of Remote Sensing and its Oceanographic Applications	40	29	69	73	64	137	206
9	National	UNESCO/IOC-UNESCAP	13 September 2022	UNESCO/IOC-UNESCAP Phase-2 Project: National Tsunami Evacuation Planning Workshop	0	0	0	4	1	5	5
10	National	INCOIS	10 October 2022	PHASE I: ADVANCE OCENOGRAPHY COURSE "Certificate Couse on Operational Oceanography"	0	0	0	3	1	4	4
11	International	POGO	31 October - 05 November 2022	POGO – IICOcean Training Program on "Ocean Observations to Societal Applications"	*						
12	International	OTGA	December 12 - 16, 2022	OTGA-INCOIS Training Course on "Ocean Colour Remote Sensing - Data, Processing and Analysis"	#						
				GRAND TOTAL :	68	40	108	257	167	424	532

*A total of 22 participants were shortlisted to take part in the training scheduled to be held during 31st Oct – 6th Nov 2022.
#A total of 30 participants will be selected for taking part in the program scheduled to be held during 12 – 16th Dec 2022.

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

Development of Skilled manpower in Earth system science was initiated to create a large pool of trained and dedicated research manpower in the country. Under the MoES Research Fellow Program (MRFP) 12 JRFs were selected for batch 3, and are undergoing the course work at IITM, Pune. The DESK has conducted exams and started annual progress review for for MRFP batch I & II.

23 peer reviewed research papers have been published/accepted by MRFP research fellows in 2022.

Few of the training workshops conducted under DESK include :

Institutes at which MRFP JRFs are recruited to:	Number of JRFs
INCOIS	1
NCCR	1
NCPOR	4
NIOT	1
NCMRWF	1
CMLRE	1
NCESS	1
NCS	0
BGRL	1
IMD-Pune	0
IITM	1
IMD-New Delhi	0

- National Training Workshop on Fundamentals of Data Assimilation (NTDA) from 9th to 21st September, 2022. About 50 participants attended the training workshop, and 9 resource persons gave training on both theory and hands-on practical.
- AI/ML virtual training workshop was organised on 9th and 10th May 2022, for scientists/students of MoES institutes, by the AI/ML virtual centre of MoES in collaboration with the DESK program of MoES.
- DESK has started working on National Training Workshop On: Paleoclimate- Archives, Proxies and Analysis/ Measurement Techniques (NT-PALEO 2023) from 16th to 21st January, 2023.

Apart from the above, DESK has organized and conducted about 8 Virtual lecture series in the area of Cloud and Precipitation Physics and Dynamics.

6.6 MOES-KNOWLEDGE RESOURCE CENTRE NETWORK (KRCNET)

- The Knowledge Resources Centre Network (KRCNET) is a dynamic web portal developed by the MoES which aims to integrate all knowledge and intellectual resources of MoES and its institutes on a single digital platform. Aligned with the concept of Digital India initiative of the Government of India, the KRCNET portal is a unique and one-of-its-kind digital system to collect, collate, catalogue, store, and retrieve knowledge products of MoES and its institutes 24X7 from around the globe.
- E-resources subscribed under DERCON (Digital Earth Sciences Consortium) in 2022 were made available to scientists and employees of MoES institutes through KRCNET

Chapter – 7

DEEP OCEAN MISSION (DOM)

7.1 Introduction

Deep seafloor and its habitats remain unexplored and unmapped, yet, as we learn more, we are beginning to realize that the seafloor associated with above water column is a dynamic environment in which even the ecosystems themselves can change due to external influences. Thus, today researchers are increasingly using multi variant platforms such as research vessels and submersibles of different categories to send specialized laboratories to observe the deep seafloor in order to continuously observe these remote areas that are so important for life on Earth. 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. Considering the importance of Ocean sciences for sustainable development of the country, Ministry has recently launched Deep Ocean Mission which aimed at developing technologies to explore deep ocean resources and their sustainable use, growing the country's marine and maritime economy, tackle climate change and pollution. The 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 deep sea biodiversity
4) Deep Ocean Survey and Exploration.
5) Energy and Freshwater from the Ocean
6) Advance Marine Station for Ocean Biology

Deep Ocean 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) would be Rs. 2823.4 crore.

7.2 Development of technologies for deep sea mining, manned submersible and underwater robotics

7.2.1 Deep Sea Mining

India has two contract areas in Indian Ocean for exploration of deep sea mineral resources at the International Seabed Authority's contracted Area in the Central Indian Ocean (CIO). To harness these deep-sea resources, development of mining system capable of operating in water depth up to 6000m to mine polymetallic nodules from the deep ocean is being developed through National Institute of Ocean Technology. Polymetallic Nodule (PMN) collection and local pumping trials, by a self-propelled mining system - Deep Sea Miner, is planned during early-2023. The Miner would move on the soft water-saturated sediment soil, collecting nodules with a pick-up system, crush it to size the pieces and undertake local pumping, as part of the proving of the development of the first stage of the integrated mining system. The sub-systems and components have been sized and optimized for weight and power and tested in laboratory conditions before the planed tests at sea.

In order to assess the impact on the seabed environment, highly instrumented moorings have been deployed at the site to collect baseline data over a year and localized moorings would be deployed immediately before the testing to capture the changes during the test. The test objectives are to assess the system integrity and the functioning of the developed miner and also to understand the

changes-impact caused on the seabed conditions. These inputs would be used in improving the seabed miner and in ensuring minimal environmental impact and sustainability in seabed mining.

7.1 Self-propelled Miner and integrity tests in a Water Test Tank

7.2.2 Design and Development of Manned (Human) Submersible

To explore the deep ocean basins, National Institute of Ocean Technology has designed 6000 m depth rated manned submersible capable of carrying 3 persons with an operating duration of 12h and emergency endurance of 96h. Most of the subsystems are being realized andSystem Integration Review (SIR) has been completed by the National committee based on inputs from three expert subcommittee to ensureintegration of complex subsystems. A hydrostatic pressure test of 25mm thick, 2.1m inner diameter, steel personnel sphere was conducted at a depth of 620 m in the Bay of Bengal onboard Sagar Nidhi in Oct 2021.

The first Manned Ocean Mission "Samudrayaan" was launched by Hon'ble Minister for Earth Sciences Dr. Jitendra Singh in the presence of the Secretary and Director, NIOT on 30th Oct 2021 at Chennai.

The shallow water personnel sphere is certified by DNV for man-rated operation up to 500m water depth and it is equipped with in-house developed life support systems, power distribution, data acquisition and telemetry systems for human acclimatization. A human acclimatization test in a shallow water sphere was conducted on 26th Mar 2022 with three personnel for 2 hours at 7 m depth at the Acoustic Test Facility (ATF) with the measurement of human health parameters.

Fig. 7.2. Manned ocean mission launched by Hon'ble Minister of Earth Sciences

Subsystems were optimized and general arrangement of the vehicle is finalized based on the binding data, hydrostatics analysis, stability assessment, and CFD simulations for ascent/descent motions. An acoustic data telemetry system with an operating frequency of 7-17kHz, a data rate of 6.9kbps, and an operating range of 12km was realized and its functionality was tested at 30m depth in the open sea at a location in the Bay of Bengal in Oct 2021 onboard Sagar Nidhi. Design of deep water (6000 m depth) Titanium Alloy sphere is completed by VSSC-ISRO.

recovered in the high seas safely to explore deep sea mineral resources site at polymetallic manganese nodule, hydrothermal sulphides, gas hydrates etc apart from other search/engineering operations in deep sea with the defined path. AUV – OMe 6000 was tested up to a depth of 5271 m usingResearch ship Sagar Nidhi to PMN site at Central Indian Ocean during 15th and 16th Dec 2022.The vehicle was operated in predefined selected block for 2 km X 2 km area with all scientific payloads and acquired data sets for more than 26 hours from 30 m altitude at 5271 m depth.

Fig. 7.3. Pressure test, Human acclimatization test with the shallow water sphere and CAD model of Manned Submersible

7.2.3 Deep water Autonomous Underwater Vehicle–OMe 6000

Deep water Autonomous Underwater Vehicle AUV (Ocean Mineral Explorer – 6000 (OMe 6000))fitted with necessary scientific payloads for deep ocean scientific research was successfully launched and

7.3 Development of Ocean Climate Change Advisory Services

Future projections of essential climate variables on decadal to longer time scales for facilitating climate change advisories on various marine climate indicators that directly impact the coastal

Fig. 7.4 AUV - Ome 6000 launching view from the ship Sagar Nidhi at Central Indian Ocean Basin and seafloor image at 5271 m depth with polymetallic manganese nodule distribution

infrastructure, ecosystem, economy, and policy decisions in coastal zone management activities, are being developed based on synthesis of observations and numerical models as indicated in Fig 4.5.

Model version 5 (MOM5) with the LETKF data assimilation system. The development of the LETKF data assimilation system on the MOM5 global model is in the final stage. For the regional model,

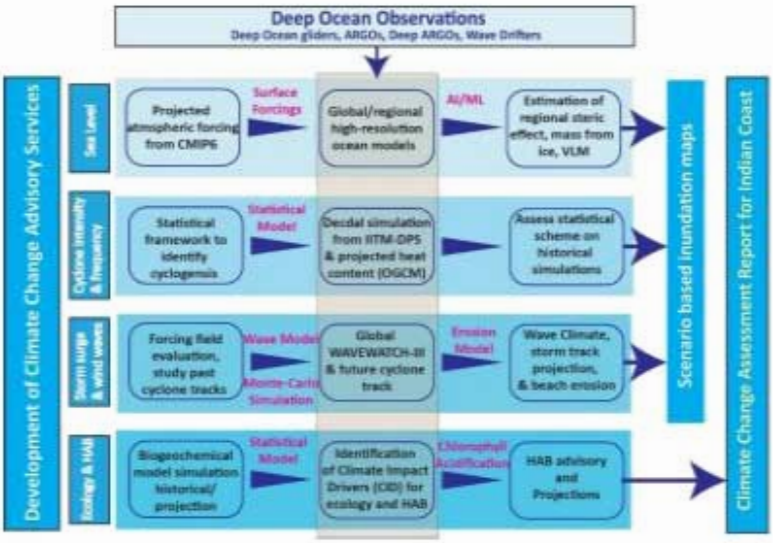


Fig. 7.5. Components of Ocean Climate Change Advisory Services (OCCAS) of INCOIS.

7.3.1. Development of Ocean Models

A suite of ocean models is being developed for downscaling of sea level, wave, storm surge and biogeochemical projections of the Indian Ocean. The modelling framework for ocean general circulation consists of an eddy-permitting global model and a nested very high-resolution regional model. The global model is based on Modular Ocean

Modular Ocean Model version 6 (MOM6) is being configured. MOM6 is the most advanced and complex numerical ocean model developed till data to simulate ocean circulation from the regional scale to the planetary scale.Considering the complexity of the MOM6 model, compared to its predecessors, a bottom-up approach starting with a simpler configuration to gradually enhance the complexity

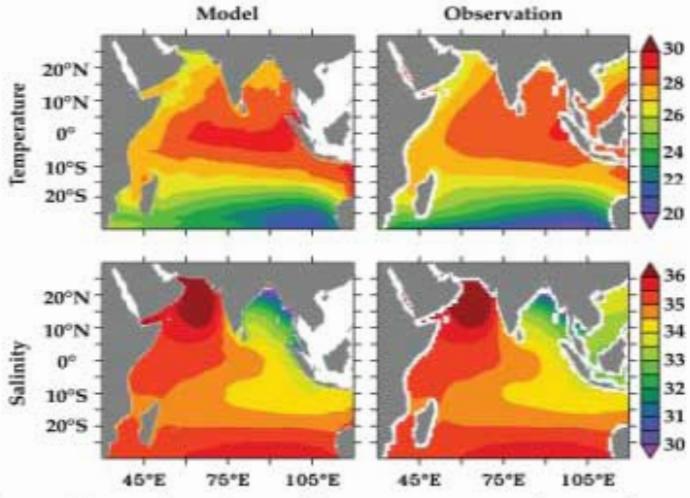


Fig. 7.6. Comparison of annual climatological sea surface temperature and sea surface salinity from MOM6 (left) and World Ocean Atlas 2013 (right).

has been adopted. The model has initially tested with a very coarse (0.25° X 0.25°) spatial resolution with 75 hybrid vertical layers. The initial model simulated climatological surface temperature and salinity compared well with the World Ocean Atlas 2013.

For wave climate projections, a wave model based on WAVEWATCHIII (WWIII) - V6.0.7 for the Indian Ocean is configured. The same configuration is used for carrying out a few sensitivity experiments.

weather conditions. All wave simulations have significant errors in low wind speeds (e.g., in pre-monsoon season) compared to medium (e.g., post-monsoon) and strong (e.g., monsoon season) winds which is independent of the error in the forecast wind. Overall, the ST4 scheme reproduces the wave characteristics in all seasons and different conditions of IO. Hence ST4 scheme has been selected in the WAVEWATCHIII setup for IO climate prediction.

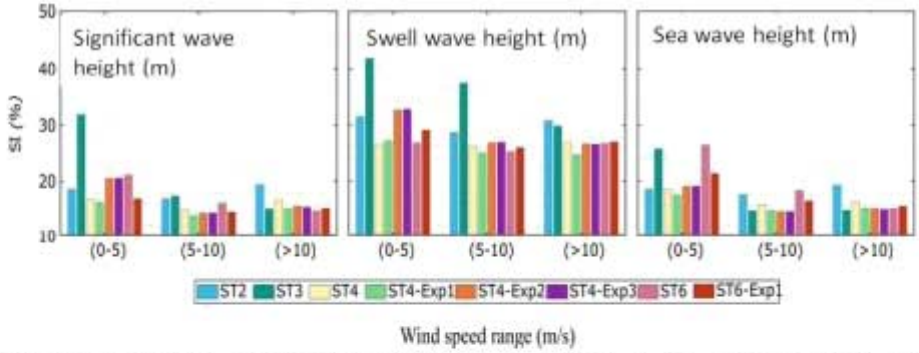


Fig. 7.7. Model error statistics (scatter index) for significant wave height, swell wave height and wind sea height for different wind ranges (low, medium, high)

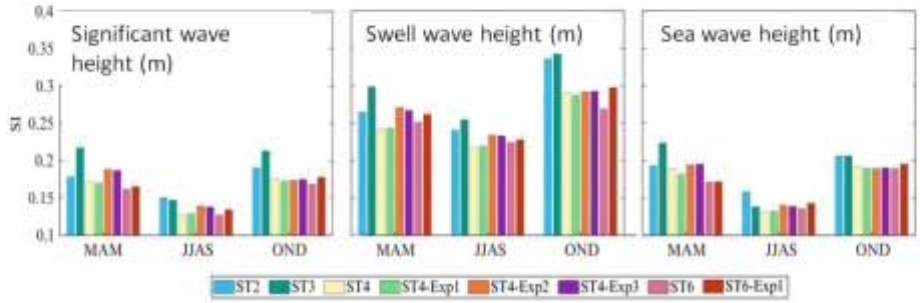


Fig. 7.8. Model error statistics (scatter index) for significant wave height, swell wave height and wind sea height during different seasons in NIO

Initially, the performance of different source term packages of WAVEWATCHIII (WWIII, V-6.07) wave model are assessed for various wave conditions in the Indian Ocean (IO). Eight simulations of WWIII are carried out for the year 2017, four using default source term packages (ST2, ST3, ST4, and ST6) and another four by tuning the wind-wave interaction parameter (β) in the ST4 and ST6 schemes. The simulated wave outputs are compared with in-situ and altimeter wave fields over a wide range of

For storm surge climate projections, historical cyclone tracks over the past five decades were studied for generating projected synthetic tracks over the next hundred years. These tracks will be used to develop a comprehensive analysis of the storm surges in India. The impact of climate change on cyclone path and intensity is also considered while generating synthetic tracks. The Advanced Circulation (ADCIRC) model is used to compute storm surge heights and associated coastal inundation for historical and future cyclone tracks.

The current study uses historical and synthetic tracks to comprehensively analyze storm surge heights and associated coastal flooding along the ECI.

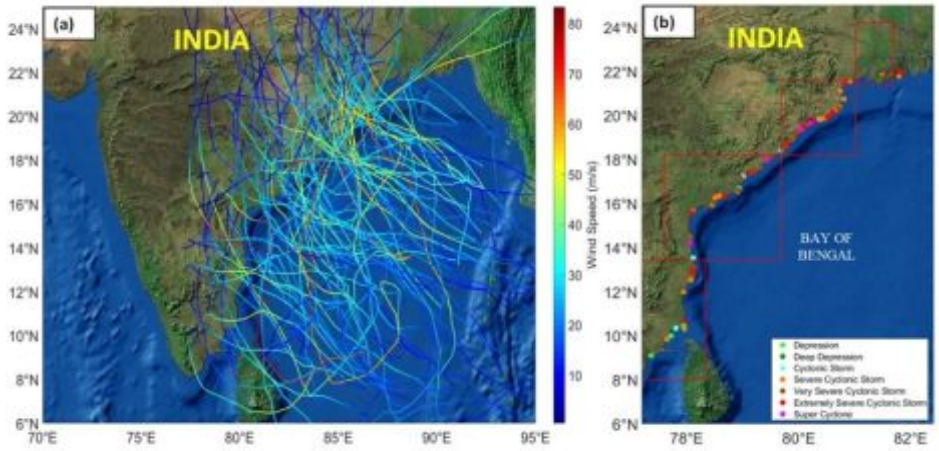


Fig. 7.9. (a) Generated synthetic tracks for the future 100 years along the east coast of India. (b) State wise respective land fall time intensities. (TN-Tamil Nadu; AP-Andhra Pradesh; OD-Odisha; WB-West Bengal)

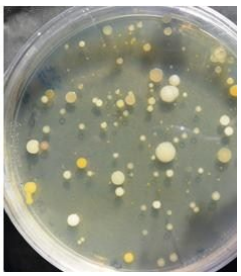
7.4 Technological innovation for exploration and conservation of deep sea biodiversity

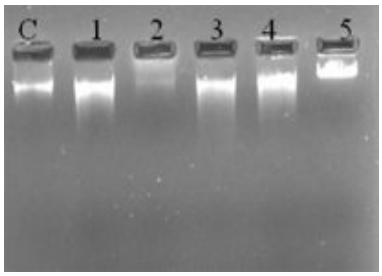
Towards deep sea microbial biotechnology, water and sediment samples collected from three potential sea mount locations in Arabian Sea were profiledfor microbial diversity and isolation of microbes with bioactive potential. The average number of colony forming units (CFU)/ml obtained on ZMA and R2A from water sample was 5.22x103/ml and 5.7x102/ml, and sediment sample was 7.05x103/g and 5.0x102/g, respectively.

Out of a total of 22 EPS producing bacterial strains identified,bacterial strains with significant EPS yield were characterized and sequence revealed Bacillus amyloliquefaciens NIOTSM16 with highest EPS yield. The identified strain was found to be alkali-tolerant and the EPS produced showed bacteriostatic and emulsifying activity. Bio flocculant producing bacteria was isolated from seamount samples and identified as Bacillus licheniformis based on 16srRNA gene sequencing IR spectrum of the bio flocculant displayed the presence of EPS characteristic functions groups, like hydroxyl (~3600 cm−1), amide (~1534cm−1) and carboxyl groups (~1534 and ~1644 cm−1).

Sampling location

Microbes from Sea Mount





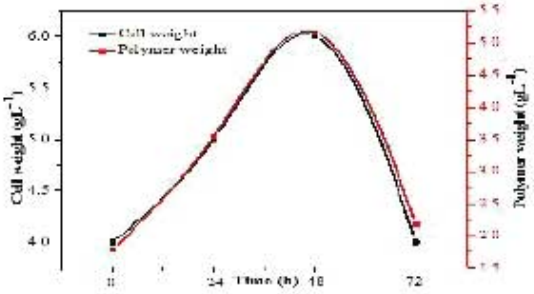
Metagenomic DNA-sediment

DNA library was constructed using fosmid cloning vector on metagenomic DNA extracted from sediment samples collected and transformed into competent E. coli EPI300. A web application (Marine Microbial Information Portal – MMIP) is developed to curate microbial sequence and tested in NIOT web server for development of microbial genomic repository.

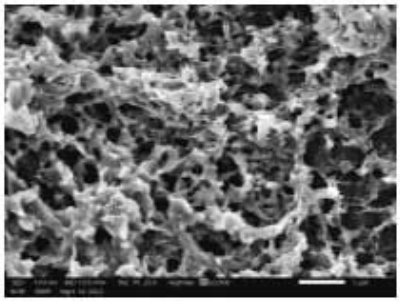
7.5 Energy and Freshwater from the Ocean

A detailed engineering design for high capacity offshore platform mounted OTEC powered desalination plant has been initiated and extensive measurements of ocean currents, temperature and depth at regular intervals from surface to 1000m depth for demonstration of critical offshore component, sub-sensors sensors, buoy and mooring systems have been procured and tested for deployment.

EPS ethanol precipitated



Time course of EPS production



EPS matrix- SEM

7.6 Deep Ocean Survey and Exploration

7.6.1. Exploration of Hydrothermal deposits

India entered into a contract with the International Seabed Authority (ISA) in the year 2016 to explore multi-metal hydrothermal sulphides within a 100,000 km^2 area at the mid-oceanic ridges of the Indian Ocean (Fig.7.12). Detailed reconnaissance surveys and data analysis have been completedto identify the most promising locations for the occurrence of hydrothermal vents and/or mineral deposits. Systematic geological sampling carried out in the area recovered sulphide mineral samples from three sites in the Central Indian Ridge (CIR) and South-West Indian Ridge (SWIR). Evidence for hydrothermal plumes (physical and chemical indicators in the water column) was observed at multiple locations in CIR and SWIR. In addition, analysis of multibeam bathymetry revealed oceanic core complexes (OCC), often associated with active hydrothermal venting. Most of these observations are within the rift valley or associated with intra-rift highs.

To precisely locate and sample the mineral deposits in these promising sites, high-resolution near-seabed geophysical surveys are now planned. Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROV) will be used for the high-resolution surveys and sampling. The AUV-

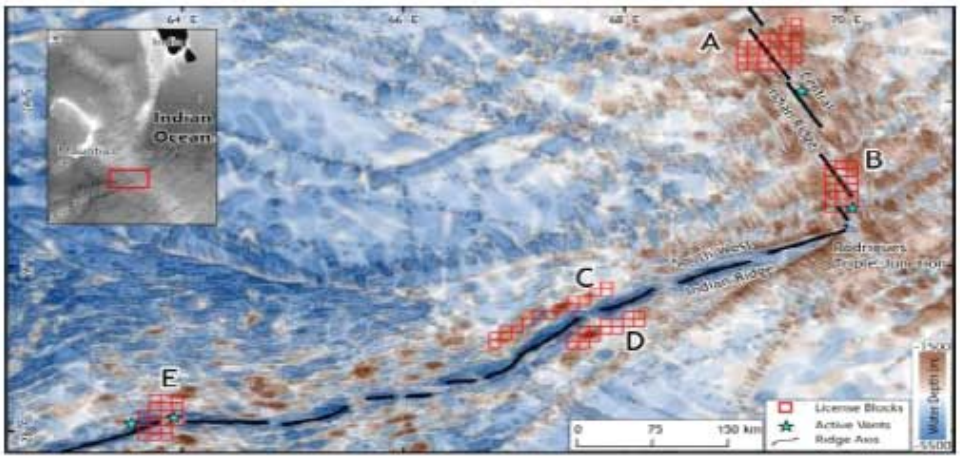


Fig. 7.12. Map of the Indian exploration areas (red boxes) in the Indian Ocean, wherehigh-resolution near seabed surveys and sampling are planned.

based geophysical data acquisition includes multibeam bathymetry, side-scan sonar, sub-bottom profiler, electric self-potential, magnetic, and seafloor imagery. ROV will be used to collect mineral/rock samples, sediments, and biological samples from vent fields and mineral-rich zones and record high-resolution videos of observed vent fields/mineralization zones. Such focused surveys will help conclusively delineate the location and extent of hydrothermal vent fields and mineralization zones.

Further, sampling of sulphide minerals in large volume are required to determine the type and grade of mineral ore. Therefore, a containerized TV-grab system is being acquired along with a Seafloor Observation System (SFOS) to aid in detailed video mapping of the mineralization zone and to collect large volumes of sulphide minerals. Environmental data collection and monitoring at observed hydrothermal vent fields are critical in understanding the existing ecosystem in these unique environments and also assessing the possible impacts of exploration activities. Therefore, oceanographic and biological data are collected routinely from potential vent sites at CIR and SWIR. A clean CTD system is being acquired to aid with this effort, which can collect deep-water samples from hydrothermal fields and keep them safe from contamination. Along with video mapping of the seafloor using SFOS, a clean CTD system will significantly improve the environmental monitoring capabilities.

7.4.2. Acquisition of a new research vessel

A new muti-disciplinary oceanographic research vessel is being acquired for undertaking deep exploration with state of art of equipment and facilities. The concept, functional design and technical specifications have been completed and process of identification of bidders is in progress. The new research vessel will serve as platform undertaking oceanographic research in deep ocean inline with other countries.

Chapter-8

INTERNATIONAL COOPERATION

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

8.1 MoES NOAA MOU

8.1.1 MoES-NOAA OMNI-RAMA Data Portal

The Joint OMNI-RAMA Indian Ocean Data Portal developed by INCOIS jointly with NIOT and PMEL-NOAA is well maintained and updated with the data from the OMNI and RAMA Buoys (https://incois.gov.in/portal/datainfo/buoys.jsp). The Joint Data Portal was launched during the signing Ceremony of the RAMA-OMNI Indian Ocean Moored Buoy Array Implementing Arrangement between NOAA and MoES in August 2021. The OMNI-RAMA portal showcases the large inventory of meteorological and oceanographic data sets with direct access for data display and delivery, and supporting metadata information such as deployment, sensor specification, calibration, sampling strategy, data processing, quality control etc. The portal facilitates the users with visualization of measured as well as estimated parameters along with provisions for data downloading in various formats. Approximately 1900 users have visited the data portal since Aug 2021. The Data Portal is meant to improve access to high-quality moored time series data and is anticipated to stimulate broader utilization for scientific research and applications.

8.2 Collaboration with Norwegian Ministry of Climate and Environment:

Under the Memorandum of Understanding (MoU) signed between India and Norway in January 2019, a letter of intent (LoI) was signed on 18 Feb 2020 between MoES and Norwegian Ministry of Climate and Environment and Norwegian Ministry of

Photo : 2nd Project Steering Committee Meeting of the Indo-Norway Integrated Ocean Management and Research Initiatives

Foreign Affairs on "Integrated Ocean Management & Research Initiative" for a period of five years.

Under the LOI, the Norwegian Environment Agency (NEA) through the Norwegian Ministry of Foreign Affairs (MFA) and MoES have developed a draft framework for the Integrated Ocean Initiative with a focus on Marine Spatial Planning (MSP). Twopilot areas namely Puducherry (a welldevelopedUrban area in the mainland) and Lakshadweep (an ecologically sensitive island ecosystem) have been taken up for development of Marine Spatial Plans in the first phasewith National Centre for Coastal Research (NCCR) as the lead from the Indian side.

The 2nd Project Steering Committee (PSC) meeting of the India-Norway Integrated Ocean Management and Research Initiativewas held on 18th May 2022 in hybrid mode to review the work undertaken in the last one year and plan the future course of actions related to Integrated Ocean Management. PSC also suggested to explore new collaborative areas between Norwegian and Indian Institutes.

As decided in the PSC an Inter-ministerial Indian delegation from MoES and NCCR visited Norway from 05th-10th September 2022 to discuss on "Marine Spatial Planning' aspects and understand the best practices with Norwegian experts.

8.3 Collaboration with Vietnam

A Memorandum of Understanding (MU) between MoES and Ministry of Natural Resources and Environment (MONRE), the Government of Socialist Republic of Vietnam was signed for scientific and technical cooperation in Marine Science and Marine Ecology on 17th December 2021. Under the MoU, MoES and MONRE are mandated to conduct cooperative research in the fields of (i) Coastal Erosion and vulnerability (ii) Coastal Management (iii) Monitoring and Mapping of Marine Ecology and Critical Habitats (iv) Ocean observation system (v) Marine Pollution and Microplastic, and (vi) Capacity Building. Scientists and technical experts from Vietnam Administration of sea and Island VASI, Vietnam and NCCR, India have participated in online workshops to identify potential areas of research and formulation of working groups.

8.4 Indo-UK collaboration

Marine Litter research collaboration has been initiated between UK and India under the Commonwealth Litter Programme (CLIP) with NCCR

Photo : Signing of MoU between MoES and Ministry of Natural Resources and Environment, Vietnam

(India) and CEFAS (UK) as delivery partners. This has now come under the umbrella of Ocean Country Partnership Programme (OCPP) of Blue Planet Fund on UK side. Under this, scientists have been working together to develop strong scientific databases for supporting policy decisions around marine litter through:

- Joint studies on Marine Pollution under CLIP, to measure sea water quality parameters due to plastic and marine litter pollution, which can better protect humans and marine biodiversity.
- In 2021, the group conducted 3 research cruises off the Chennai coast and collected 300 water and sediment samples together; publishing 3 joint research papers on their findings.
- Datasets from phase 1 (CLIP) were used to support Draft action plan for plastic pollution for Puducherry, India.
- Phase 2 (Clip) under OCPP conducted sampling in Chilka Lagoon (Odisha) in September 2022, along with project around use of remote sensing to map marine litter hotspots, to identify sources of litter which are reaching the marine environment, with the aim to support better decision making around tackling marine pollution and conserving biodiversity and mapping socio economic impacts of pollution
- Collaborating on scientific endeavours to share knowledge, techniques and improving understanding of marine plastic pollution

8.4.1Knowledge exchange platform:

The UK Science and Innovation Network and India's Ministry of Earth Sciences have initiated an expert knowledge exchange initiative on marine ecosystems. The first seminar was delivered by NEKTON and the University of Oxford on General Ocean Survey and Sampling Iterative Protocol (GOSSIP).

OCTOPUS (The Ocean Tool for Public Understanding and Science) has been identified as the next topic to support and promote collaborative marine research and improved ocean governance.

As a follow-up of these virtual meetings, the Marine Biodiversity exploration collaboration has received a boost in 2022- with engagement between CMLRE and NEKTON.

Three scientists from CMLRE participated in the Knowledge Exchange trilateral deep sea expedition and associated research programme with, Government of Maldives and UK's NEKTON to collect data, document and map deep sea biological resources to inform international protocols such as 30by30. This will help inform both countries' contribution to the Convention on Biological Diversity and Sustainable Developmental Goals. The expedition has also discovered a new, unnamed, specie. The scientists were able to explore biodiversity upto the depth of 1000 m in the twilight zone of the Indian Ocean.

8.5 Collaboration with France

A Roadmap on the Blue Economy and Ocean Governance has been agreed upon between India and France to promote their bilateral exchanges. The Preparatory meeting of the Blue Economy and Ocean Governance Dialogue between India and France was held in Paris at the Headquarters of the French Ministry of Foreign Affair on 13 June 2022 which was attended by Secretary, MoES and the French Ambassador for Poles and Maritime Affairs. It was decided that India would participate as the 'Guest of Honor' country in the Sea Tech week being organized by France in September 2022 at Brest. Identification of points of contacts on both sides and specific agencies for implementation of the collaborative projects under the framework was also discussed during the meeting.

The French Embassy in India has also proposed thepositioning of an International Technical Expert (ITE) to MoES to provide expertise and knowledge sharing of the French marine and maritime ecosystem and to facilitate various activities related to Indo-French collaboration. The same is being progressed with NIOT and MEA.

8.6 Indo-Japan collaborations (MoES-JAMSTEC)

Memorandum of Cooperation (MoC) between the Ministry Of Earth Sciences (MoES) of the Republic of India and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) on Mutual Collaboration in Marine and Earth Science and Technology was signed in November 2016. New areas of collaborations under this MOC which have been identified between JAMSTEC and Indian Institutes are as follows:

1. Modeling of climate variability and its application incl. ocean biogeochemistry (IITM and INCOIS India)
   - (A) Intercomparison of SINTEX-F (JAMSTEC) and MMCFS (IITM, MoES) model results for understanding monsoon ISO predictability and model biases
   - (B) Ocean downscaling of climate model projections in the Indian coastal regions to assess the coastal impact of the sea level rise under global warming
2. Marine Plastics (NCCR, India)
   - (A) Understanding spatial and temporal distribution of Marine Litter using Satellite and Drone-based Remote Sensing, AI/ML and numerical modelling
   - (B) Microplastic contamination in water and sediments of the Arctic Ocean: Abundance, Distribution, Type and Polymer Profile of Microplastics
3. Glacial Hydrology (NCPOR, India) Discharge from Glacierized Catchments in the Western Himalaya (DIGHA)

8.7 Collaboration with Maldives

A Memorandum of Understanding between Indian National Center for Ocean Information Services (INCOIS) and Ministry of Fisheries, Marine Resources and Agriculture of the Republic of Maldives was signed on 2nd August 2022. Under the MoU, it is proposed to collaborate through capacity building, data and technical expertise sharing to develop integrated potential fishing zone forecasting capabilities for the Maldives and to establish a formal mechanism for capacity building trainings at INCOIS for the official and scientist of Maldives.

8.8 2nd United Nations Ocean Conference, Lisbon, Portugal

An Indian Delegation led by Hon'ble Minister of Earth Sciences (I/C) Dr. Jitendra Singh, Secretary, MoES and members from Department of Fisheries, MEA participated in the 2nd UN Ocean Conference from 27th June to 1st July, 2022 at Lisbon, Portugal. The overarching theme of the Conference was "Scaling up ocean action based on science and innovation for the implementation of Goal 14: stocktaking, partnerships and solutions". A total of 116 Member States delegations including India made their National statements during the conference. In addition 42 other International agencies/ Organizations and Associated Institutes involved in the stock taking of Sustainable Development Goal-14 targets participated in the session. A number of bilateral meetings with Ministers from Morocco, Tajikistan, Norway and UN agency like International Seabed Authority was held during the Conference. The Indian delegation also participated in a number of side events associated with conservation of marine resources and biodiversity

8.9 Cooperation with European Union: Horizon 2020

Joint calls were floated under the established co-funding mechanism with the European Union for funding Indian counterpart of successful projects selected through European Research & Innovation Framework Program 'Horizon 2020' related to Climate Change and Polar Research. Two research projects namely, 'Our common future ocean in the Earth system – quantifying coupled cycles of carbon, oxygen, and nutrients for determining and achieving safe operating spaces with respect to tipping points (COMFORT)' and 'CRiceS -Climate relevant interactions and feedbacks: the key role of sea ice

Photo : Hon'ble Cabinet Minister for Earth Sciences (I/C) delivering his speech at 2nd UN Ocean Conference at Lisbon, Portugal.

and snow in the polar and global climate system' are being funded by MoES.

8.10 Cooperation with Switzerland

A letter of intent was signed between the MoES and the Swiss National Science Foundation (SNSF) and a joint call for research proposals, with thematic focus on "Mountain research, with a focus on glaciers or climate research", was floated on 1st September, 2021. Under this Call, four projects were selected for funding by recommendations of a joint evaluation panel and the Indian and Swiss components are being funded respectively.

8.11 Contract with International Seabed Authority (ISA) on exploration of Polymetallic Nodules (PMN)

The activities related to PMN program are carried out under four components like survey and exploration, EIA study, mining technology development and technology development for extractive metallurgy by implementing institute NIOT in collaboration with two CSIR institutes (NIO, Goa and IMMT, Bhubaneswar). In the Indian contract area High resolution bathymetry survey using Autonomous Underwater Vehicle (AUV) to collect micro-bathymetric data for near seabed mapping is in progress. A cruise was undertaken at the Indian Contract Region in the Central Indian Basin onboard ORV SindhuSadhana for collection of sediment and water samples as well as deployment of the deep-sea and surface moorings. A self-propelled mining system has been developed having components like nodule collector pick-up & conveyor, crushing and slurry pumping system. Component level testing has been completed, integration of systems and onshore tests undertaken satisfactorily. The ongoing PMN exploration contract has been granted extension by ISA for another 5 years (2022-27). An online training program for a duration of 7 weeks was conducted for ISA nominated candidates as a part of the contractual agreement for PMN program at NIOT, Chennai in collaboration with other implementing institutes on the subject 'Deep sea mineral survey and exploration'. Annual report for PMN as per obligation of the contract has been submitted to ISA. All meetings for state parties organized by ISA are attended.

8.12 Contact with International Seabed Authority for exploration of Polymetallic Sulphides

Exploration activities in the contract area with ISA, for the exploration of sulphides in parts of Central and South West Indian ridges were conducted and continued. Detailed analysis, interpretation and integration of data and samples acquired from the contract area provided further convincing evidence of hydrothermal activity in the region. A comprehensive exercise carried out in integration of all the scientific and exploration results could provide a good platform for undertaking detailed planning for the next phase of advanced exploration surveys in the region. Specifications for advanced near-bottom surveys using AUV and ROV have been designed accordingly. Following the ISA guidelines, the development of various baseline parameters, including biological, geological, chemical and physical parameters of the water column and seabed sediments/rocks, have also been developed. India submitted Annual Reports to the ISA indicating the progress of work, as per the work plan submitted.

8.13 Intergovernmental Oceanographic Commission (IOC) of UNESCO related activities

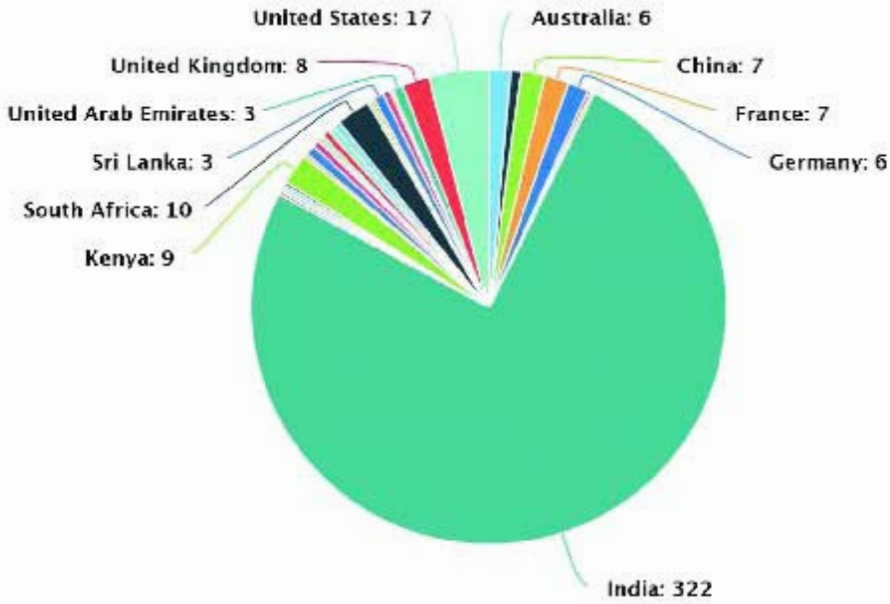
(i) India participated in the 55thsession of the IOC Assembly held in Paris, France during June 13-23, 2022 and took the floor to provide its interventions on the report of the Executive Secretary of IOC, report of the open-ended intersessional working group on the status of IOCINDIO, Report of the UN Decade of Ocean Science for Sustainable Development, Warning and mitigation system for ocean hazards, presentation of the IOC State of the Ocean Report (StOR), Ocean observations in areas under National Jurisdiction, etc. and briefed India's progress and support to IOC activities as well as to the UN Ocean Decade activities. India also submitted its comments on State of the Ocean Report (StOR) as part of the Second consultation on the pilot edition of the StOR report that is being proposed to bring out periodically by IOC.

(ii) India participated in the meetings of Open-ended Intersessional Working Group (OEIWG) on the status of the IOC regional committee for the Central Indian Ocean (IOCINDIO) held virtually and discussed on the existing programmes, projects and activities in the IOCINDIO region. India supported the proposition of elevating IOCINDIO as a sub-commission of IOC.

(iii) UN Decade of Ocean Science for Sustainable Development (UN Ocean Decade):The proposal submitted by India for the establishment of Regional Decade Coordination Centre (DCC) for the Indian Ocean Region (IOR-DCC) at INCOIS, Hyderabad against UN Ocean Decade first 'Call for Decade Action' (CFDA 01) has been endorsed in October 2022.Formal signing of the MoA is under process and mapping of Decade actions have been initiated. India continued its active role in meetings of Decade Collaborative Centres and Decade Coordination Unit and provided India's activities and contribution to the Ocean Decade.

India participated in the meetings of the Scientific Committee for the UN Ocean Decade Tsunami Programme (ODTP-SC) held during January 18-20, 2022 at Paris, France and discussed on the way forward towards development of the draft 10-Year Research, Development and Implementation Plan for the Ocean Decade Tsunami Programme. India took the Chair role for this ODTP-SC.

(iv) Second International Indian Ocean Expedition (IIOE)-2:India successfully organized the International Indian Ocean Science Conference (IIOSC)-2022 through "Virtual Platform" during March 14-18, 2022. The major goal of the conference was to assess the progress and scientific knowledge gained during the second phase of International Indian Ocean Expedition (IIOE) that was launched during December 2015. The conference was inaugurated by Dr Jitendra Singh Minister of State (Independent Charge) of the Ministry of Earth Sciences. The conference was witnessed by 400+ registered participants, representing 20 countries. There was total 179 oral



Country Wise No. of Abstracts for IIOSC-2022 Conference

and 98 poster presentations on Indian Ocean Research across 14 themes.As depicted in the chart below the conference, though held in virtual mode, received extraordinary response from multiple countries.Panel discussions were held on various scientific themes including the UN Ocean Decade for Sustainable Development and a dedicated session for early careers, which were well appreciated by the ocean science fraternity.

(v) Indian Ocean Global Ocean Observing System (IOGOOS) successfully organised the 17th 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 March 21-25, 2022. During IOGOOS 17 meeting, Director, INCOIS has been elected as Chair of IOGOOS for a period of two years.

(vi) India as a Tsunami Service Provider (TSP) under the framework of Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) of the Intergovernmental Oceanographic Commission of UNESCO, continued providing 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.

(vii) India participated in the ICG/IOTWMS 24thCommunication Test conducted on June 08, 2022 to validate tsunami information dissemination process. India participated in COMMs test and issued test bulletins to 25 Indian Ocean rim countries as a Tsunami Service Provider. Tested the dissemination modes of email, fax, GTS, SMS as well as website during the tests.

(viii) India, as part of the IOC-UNESCO and UNESCAP project on "Strengthening Tsunami Early Warning in the Northwest Indian Ocean Region through Regional Cooperation" has conducted the Tsunami Evacuation Planning (TEP) hybrid workshop on September 13, 2022 for North west Indian Ocean Region

8.14 Cooperation with Belmont Forum Countries:
MoES is a member of the Belmont forum which is a group of the world's major and emerging funders of global environmental change research and international science councils. MoES signed an MoU in February 2013 to support Indian Scientists for international collaborative research through joint calls in societally relevant global environmental change challenges. India is participating in the Belmont Forum, Future Earth and JPI Oceans co-branded CRA on "Transdisciplinary Research for Ocean Sustainability" proposed by FORMAS, Sweden and MoES is supporting component of the project "Coastal Ocean Assessment for Sustainability and Transformation (COAST Card)" to be implemented by NIO, Goa under this CRA. First international meeting and workshop on COAST Card is scheduled to be held at Manila, Phillippines from 27 Feb to 3rd March 2023.

8.15 Cooperation with Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)
The 14th RIMES Council Meeting, was held in Bangkok, Thailand from 11 to 12 November 2022. The meeting was presided by Dr.Ravichandran, Secretary, Ministry of Earth Sciences, Government of India, and RIMES Council Chair. The 14th Council Meeting brought together 77 participants from 29 Member and Collaborating countries and several development partners. Executive Secretary UNESCAP ,Secretary General WMO and Minster of State Government Maldives participated and delivered inaugural addresses.

The WMO-RIMES Joint Strategy and Action Plan (JSAP) and the renewed and expanded MoU signed in 2022 reflects deepening and broadening institutional partnership between RIMES and WMO. Built around the centrality of NMHSs, the JSAP aims to contribute to the WMO Global Framework for Climate Services through operational programs with the close engagement of the WMO Regional Office for Africa and the WMO Regional Office for Asia and Southwest Pacific. The establishment and operationalization of the India Meteorological Department (IMD) and RIMES Unit (IRU) within IMD was initiated , to implement an impact-based forecasting program. The IMD-RIMES Unit (IRU) and the Bangladesh National Center for Climate Application (BANCCA) are country-owned institutional mechanisms for transforming meteorological forecast data into impact outlooks and serve as innovative practices for replication in other RIMES Member Countries.

In addition to strengthening the ongoing

Photo : General Body & SAC meeting of BIMSTEC

collaboration and engagement between member countries, development partners and research institutions, the Council meeting has been productive in furthering the objective of RIMES in support of its member countriesrequest theirrespective National Designated Authorities (NDAs) to prioritize NMHS' GCF proposal over any other overlapping proposals, by drawing experiences from Timor Leste, Maldives and Sudan and provide periodic updates to RIMES Program Unit to enable it to report to the Council In the Member States meeting segment held on 12 th November,2022 India's support to RIMES and its leadership role in shaping RIMES policies and program to benefit member countries and communities was appreciated.

8.16 BIMSTEC- CENTER FOR WEATHER AND CLIMATE (BCWC)

Following up The Hon'ble Prime Minister's announcement of India's readiness to contribute 3 million dollars for restarting the work of BCWC at the 5th BIMSTEC Summit on 30 March 2022, BCWC at NCMRWF organized its 2nd GB and SAC meetings during 01-03 November 2022 in coordination with Ministry of External Affairs, Government of India and BIMSTEC Secretariat, Dhaka. The representatives from all the BIMSTEC member nations NHMs and BIMSTEC Secretariat participated in these meetings.

Secretary, MoES and Addl. Secretary, MEA attended the inauguration programme on 1st November'22, and addressed the gathering. The committee members of GB meeting discussed and finalized the draft host country agreement in the GB Meeting. Director General, IMD inaugurated the SAC meeting. The members of SAC made short presentations on the outstanding science issues and discussed the ways of solving those issues through stronger collaboration and cooperation for improving operational weather/climate forecasts for the regions of the member countries. Important action items in terms of future course of action has been worked out.

8.1.7 The International Ocean Discovery Program (IODP) is an international collaborative research endeavor that explores Earth's history and dynamics using rock coring through scientific ocean drilling. The Ministry of Earth Sciences (MoES), is an Associate Member of the IODP consortium and National Centre for Polar and Ocean Research (NCPOR), is the nodal implementing agency for this program. Ever since our association with IODP in 2009, more than 50 young Indian scientists have ben benefited by their exclusive participation in global IODP expeditions. During this year particularly, India researchers from various national organizations participated in the five expeditions: IODP-391 (Walvis Ridge Hotspot), IODP-386 (Japan Trench Paleoseismology), IODP-392 (Agulhas Plateau Cretaceous Climate), IODP-390&393 (South Atlantic Transect 1 and 2) and IODP-397 (Iberian Margin Paleoclimate).

8.18 Cooperation with Natural Environment Research Council (NERC): Implementation Agreement (IA) on "Atmospheric Pollution and Human Health in an Indian Megacity":

The APHH-India collaborative programme "Atmospheric Pollution and Human Health in an Indian Megacity" includes 5 well-coordinated and cross-cutting research projects, involving 4 agencies from UK and India, with 4 years duration and with the main focus on the megacity New Delhi. The duration of the projects was extended by 1 year as some of the collaborative activities under the work packages could not be completed due to the Covid-19 pandemic restrictions in 2020 and 2021. The progress of all APHH projects were reviewed during the Internal Science Meeting held on 19th to 20th May 2022 conducted by the APHH Secretariat. The extended lockdown and slow down due to COVID-19 in the UK impacted the deliverables of the projects due to its inter-dependent nature and further extension till 31st December 2022 have been accorded to some of the APHH projects. During 2017-22, APHH Secretariat has organized six science meetings and 3 observational field campaigns in

Delhi (November 2017-February 2018, May-June 2018 and November 2018- January 2019). The APHH published several peer-reviewed papers in reputed journals including 1 in Nature Geoscience. APHH scientifically contributed in strengthening the SAFAR framework of MoES by developing new parameterization of secondary aerosol mechanism and linking air quality with climate change in CMIP6 models. Results of the Delhi flux campaigns are processed to incorporate in SAFAR emission inventories of Delhi for value addition. APHH led to capacity building in the area and mutual benefits to both the collaborating nations, delivered skilful products with significant potential for sustainable societal needs. The final outcome will yield an integrated framework of air quality to further strengthen application-oriented work for the benefit to society and planning mitigation strategies. On completion of the projects from both the Indian and UK sides, an MySQL data base will be developed by the Indian secretariat of APHH at IITM based on the already developed data repository framework.

8.19 International Monsoons Project Office (IMPO)

International Monsoons Project Office (IMPO), hosted by IITM, is India's contribution to WMO's monsoon research coordination activities under WCRPand WWRP(World Climate Research Programme and World Weather Research Programme), with kind support and guidance from the Ministry of Earth Sciences (MoES), Government of India. IMPO functions as a global hub of monsoon research coordination, covering all monsoon regions(Asian-Australian, American and African monsoons regions) of the world and spanning weather to climate change time scales. One of the core responsibilities of the IMPO is to support the activities of the CLIVAR/GEWEX Monsoons Panel (MP). IMPO also supports cross-panel linkages within the working structure of the WCRP and its core projects as well as WWRP substructures, on monsoon-related matters. Some of the activities carried out by IMPO are :

- IMPO Coordinated with Monsoons panel (MP) Co-Chairs for preparation of Annual Report (2021) of the MP and its submission for consideration by GEWEX SSG (Scientific Steering Group) and CLIVAR SSG meetings.
- IMPO Coordinated with Monsoons Panel (MP) Co-Chairs for organizing 3 online meetings (teleconferences) of MP in 2022and prepared Minutes of the Meetings.
- IMPO Supported membership revision proposals (as per required norms) and submitted it to both ICPO and IGPO for further action to seek the approval of the SSGs of GEWEX and CLIVAR. Both SSGs have endorsed the membership changes, and IMPO has completed the formalities of inviting the new members and thanking the departing members. The full list of the current membership is available at the following web-link: https://impo.tropmet.res.in/wcrp-monsoon.html.

IMPO has impressed upon the Co-Chairs of the Monsoons Panel on making strong linkages with GEWEX in their activities and has offered support to put in place sustained communications with GEWEX governance to seek more explicit involvement of relevant GEWEX expertise.

Chapter-9

PUBLICATIONS, PATENTS, AWARDS AND HONOURS

9.1 Publications in peer reviewed journals:

A total number of 491 research papers were published in 2022 by MoES institutes under its various programs, and the details of which are given below.

	ACROSS	OSMART	PACER	SAGE	TOTAL
Total no. of Publications	276	111	46	58	**491**
Cumulative Impact Factor	939.628	324.499	144.117	212.857	1621.101

Table1: MoES Publications

The number of research papers published and the total impact factor (1621.101) are comparatively much higher as compared to the previous years. The average impact factor of research papers was 3.301.

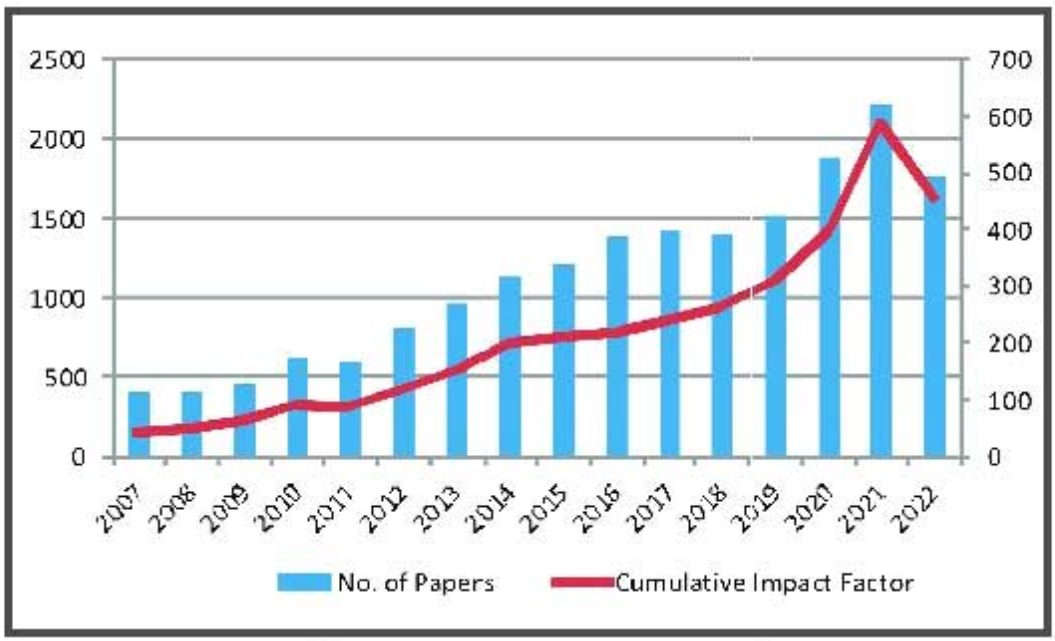


Fig. 8.1 Number of research papers and cumulative impact factor year wise

9.2 Patents Granted

S.No.	Inventors	Title of the patent	Awarded reference	Country
1.	Venkatesan G, Samson, Raju Abraham, Purnima Jalihal	Multi interconnected compartment device with heat exchangers for the production of drinking water from low temperature fluid streams	379234 Dt.12.10.2021	India
2.	Purnima Jalihal, Ashwani Vishwanath	Multi-functional Interface System for connecting floating structures	382215 Dt.22.11.2021	India
3.	Tata Sudhakar. Shijo Zacharia, Thamarai T, Gowthaman V, Atmanand M.A	Automated Tsunami Test Rig	385571 Dt. 30.12.2021	India
4.	M.Ashokan, G.Latha, G.Raguraman, A.Thirunavukkarasu	A computer implemented System for transmitting High frequency Ocean ambient noise in Real time (SHOR)	394789 Dt. 13.4.2022	India
5.	Mary Leema Thilagam, Magesh Peter, Kumar T.S, Thirupathi K, Dharani G, Kirubagaran R, Atmanand M.A	Process for the production of Lutein	No.390089 Dt. 23.2.2022	India
6.	ShijoZacharia DhilshaRajapan Shibu Jacob Atmanand M.A	An anti-biofouling system and a method thereof	400373 Dt.29.6.2022	India

Patents Filed

S. No.	Inventors	Title	Filed Application no.	Country
1.	G.Venkatesan, Purnima Jalihal, S.Srinivasa Rao, Samson Packiaraj, Abhijeet Sajjan, Trisahnu shit, A.Karthikeyan	Eco-Friendly Ocean Thermal Energy Conversion System for Production of Potable Water and Electrical Energy	TEMP/E-1/35804/2021-CIT Dt. 20/07/2021	India
2.	L. Anburajan L, Meena B, Vinithkumar N.V, Kirubagaran R, Dharani G	Recombinant Ectoine: A major compatible solute from halophilic bacteria *Bacillus clausii*	202141056903 TEMP/E1/64548/2021CHE Dt. 07.12.2021	India
3.	R.Venkatesan, K.Ramesh, M.Arul Muthiah K.Thirumurugan	Intelligent Rain Gauge and Method Thereof	202141056904 (TEMP/E-1/63545/2021-CHE) Dt.07.12.2021	India
4.	Muthuvel.P, Sarojani Maurya, Tata Sudhakar	Variable Buoyancy engine for submersible platform	202241003710 (TEMP/E-1/3437/2022-CHE) Dt.22.1.2022	India
5.	R.Venkatesan M.Arul Muthiah B.Kesavakumar K.Thirumurugan G.Vengatesan C.Muthukumar	Artificial intelligence based autonomous data acquisition system and method for deep ocean and subsea environments	202241005052 Dt. 31.01.2022	India
6.	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	202241005053 (TEMP/E-1/5069/2022-CHE) dated 31.01.2022	India
7.	R.Venkatesan M.Arul Muthiah B.Kesavakumar K.Thirumurugan G.Vengatesan R.Sridharan	System and method for fishing vessel based smart network for ocean observations	202241022590 (TEMP/E-1/24933/2022-CHE) Dated17.4.2022	India

Transfer of Technologies (ToT) to Industries

S.No	Title of the technology	Indian Industries	Year of transfer
1.	Recombinant Ectoine from deep-sea Bacteria for skin-care and cosmetic applications (RTB)	M/s. Ambuis Lifesciences on Recombinant Ectoine Technology	January 2022
2.	Bioremediation of petroleum hydrocarbon and oil spill in marine environment by deep sea microbial consortia	M/s Oil Spill Combat LLP, India	August 2022

9.3 Awards and Honours

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

Dr. Mrutyunjay Mohapatra, DG, IMD was conferred upon "Shrikshetra Samman - 2022" for bringing paradigm shift in Cyclone Warning Services and for his laudable contribution to society by voluntary service organization- Shree Shrikshetra Soochana, Puri during the 20th Folk Fair and 13th Krishi Fair-2022 at Puri, Odisha.

Cyclone Warning Services of IMD earned 'place among 100 innovations' that transformed India in a book named "INDIAN INNOVATION" authored by Shri D. C. Sharma.

Dr. Mrutyunjay Mohapatra, DG, IMD has been nominated as Expert Member of Board of Governors of IIIT Vadodara in August, 2022 under the category "Eminent person out of research laboratories".

The Hon'ble Governor of Odisha and Chancellor of the FM University, Dr. Ganeshi Lal conferred Vyasa Gourab Samman upon Dr. Mrutyunjay Mohapatra, DG, IMD for his contribution to the field of Science (Meteorology) that has led to paradigm shift in cyclone warning services in India and enabled minimising death toll to double digit.

Dr. T. Srinivasa Kumar, Director, INCOIS has been elected as 'Chair' of IOGOOS for a period of two years during 17th annual meeting of IOGOOS.

Dr. T. Srinivasa Kumar, Director, INCOIS has been elected as the "Chair" of the Scientific Committee of the UN Ocean Decade Tsunami Programme.

Dr. Kunal Chakraborty, Scientist-E, has been selected as a 'Regular Associate' of the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy for six years from 2023 until 2028. The Associateship Scheme, one of ICTP's oldest programmes, provides support for active scientists from developing countries to maintain long-term, formal contact with the Centre.

INCOIS signed an MoU with theIndian Navyon 9th May 2022, to provide training services by conducting oceanographic courses to the School of Naval Oceanology and Meteorology (SNOM).

IITM was awarded with Rajbhasha Implementation Ratna Samman in the conference and workshop organized by Parivartan Rajbhasha Akademi, New Delhi from 10 to 12 March 2022 in Goa.

Membership of Dr. R. Krishnan, Director, IITM in 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. SuryachandraRao, Sc-G, IITM has taken charge of a Co-Chair of CLIVAR/GEWEX Monsoons Panel (MP) of WCRP this year, in addition to his role in Working Group on Asian-Australian Monsoons (WG-AAM) of MP.

Dr. S.D. Pawar, Sc-G, has been bestowed with Honorary Doctorate Degree by Sanjay Ghodawat University, Atigre, Kolhapur.

Dr. TharaPrabhakaran, Sc-G, IITM has been elected as a Member of Expert Committee to review 4th Tranche FTT-FTC Projects (2022-2024) under Ecology, Environment, Earth, Ocean Sciences and

Water (E3OW) Theme, Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology. And also eected as a member of Air Pollution Measurement Consortium (APMU) of Technical Air Resource Unit (TARU), DST initiative for Technical Air Resource Unit for Scientific Analysis.

Dr. G. Pandithurai, Sc-F, IITM has been elected as a member of the executive committee of Indian Aerosol Science and Technology Association (IASTA) for the period January 2023 to December 2025.

Dr. J. Sanjay, Sc-F, IITM has represented Ministry of Earth Sciences (MoES) as a WMO Observer in the UNFCCC meeting session COP 27, Sharm el-Sheikh, Egypt, 14-18 November 2022.

Dr. Suresh Tiwari, Sc-F, IITM has been nomitaed as Member of Expert Appraisal Committee (EAC) for evaluation of projects relating to NCM sector in the Ministry of Environment, Forest and Climate Change for.

Dr.SuvarnaFadnavis, Sc-F, IITM is selected as an Editor of the Journal of Atmospheric Chemistry and Physics (ACP).

Dr. P. Mukhopadhyay, Sc-F, IITM has been elected as Fellow of Indian Academy of Sciences during 2022 (effective from 2023).

Dr.Padmakumari, Sc-F, IITM has been elected as a Member of the executive committee of Indian Aerosol Science and Technology Association (IASTA) for the period January 2023 to December 2025.

Mr. S. Mahapatra, Sc-F, IITM selected as an "Adjunct Asst. Professor" of the Department of Atmospheric & Space Sciences (DASS), SavitribalPhule Pune University (SPPU).

Dr. Sachin Ghude, Sc-F, IITM has been elected as a Co-Chair by Integrated land ecosystem atmosphere process studies (iLEPAS) from 2022 onwards. Before, he was serving as Co-Chair, he served iLEAPS as Member, Scientific Steering Committee.

Dr. Sachin Ghude has been Member, Expert Group constituted by Commission for Air Quality Management (CAQM) to examine the suggestions before finalization of the policy to curb air pollution in Delhi-NCR. Also nominated as Member for operationalization of Revised Graded Response Action Plan (GRAP), Commission for Air Quality Management (CAQM).

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

Dr. MilindMujumdar, Sc-F, IITM has served as a Member of Board of Studies, Department of Atmospheric Science, Central University of Rajasthan (CURAJ).

Dr. M.C.R. Kalapureddy, Sc-F, IITM has been nominated as Member of the National Committee on Atmospheric & Space Research Facility (ASRF), Chandipur, Odisha for technical Review and realization on wind profiler and invitee for other instruments.

Dr. (Smt.) Swapna P, Sc-E, IITM has been selected as a Member of Sea Level Rise Working Group, WCRP Safe Landing Climates (SLC) Lighthouse Activity.

Dr. (Smt.) Swapna P has been a member to Working Group on Coupled Modeling (WGCM), World Climate Research Program (WCRP) is extended till end of 2022.

Dr. (Smt.) Swapna P has been nomitaed as Member of the "Strategic Ensemble Design team for WCRP CMIP7".

Dr. Roxy Mathew Koll, has been selected a member to the Global Climate Observing System (GCOS) Working Group 2 for the identification of critical sectors and areas of concern regarding global climate observations.

Dr. Roxy Mathew Koll, Scientific Organizing Committee Member of the WCRP Open Science Conference (OSC 2023). The theme of OSC 2023 is - advancing climate science for a sustainable future.

Dr. Roxy Mathew Koll, has been awarded the American Geophysical Union's (AGU) 2022 DevendraLal Medal on 14 December 2022, for his outstanding research in Earth and Space Sciences.

He was also awarded the Lifetime Membership of the AGU.

Dr. Yogesh Kumar Tiwari, Sc-E, IITM has been nominated by Ministry of Environment, Forests and Climate Change as an Expert Member at the United Nations Framework Convention on Climate Change (UNFCC)

Dr.Atul Kumar Srivastava, Sc-E, IITM has been invited as a Guest Editor, Special Issue of the MDPI Journal "Remote Sensing" on "Optical Remote Sensing of the Atmosphere and Oceans".

Ms.AditiModi, Sc-D, IITM has been appointed as Secretary of the International Indian Ocean Expedition 2- Early Career Scientist Network (IIOE-2 ECSN) during the IIOSC-2022.

Dr. Malay Ganai, Sc-D, IITM has been selected for DST SERB International Research Experience (SIRE) fellowship under which he will be visiting NCEP, USA for 6 months starting from August 2022.

Dr.Pramit Kumar Deb Burman, Sc-D, IITM has been awarded the third prize in the NGP-DST Geo-Innovation Challenge: Geospatial Science and Technology in Meteorology and Ocean Science by the National Geospatial Programme (NGP), Department of Science and Technology (DST) at the Sathyabama Institute of Science and Technology, Chennai during 20-22 April 2022.

PoojaPawar was awarded "Certificate of Achievement" by the South Asia Nitrogen Hub and Maldives National University for an exceptional work and presenting a poster entitled "Chloride (HCl/Cl-) dominates inorganic aerosol formation from ammonia in the Indo-Gangetic Plain during winter: modelling and comparison with observations" on 12 December 2022.

PoojaPawar Project Scientist, IITM was appointed as member of Early career scientist network in iLEAPS.

SreyashiDebnath, Project Scientist has been appointed as member of iLEAPS South Asian and Middle East Early Career Scientists Network (SAMEECSN).

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
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.
2	Providing Agro – Meteorological advisories at district level	To provide Agro-meteorological advisories at district level to the farmers
3	Meteorological support for Civil Aviation purpose	Meteorological support for Civil Aviation purpose
4	Rainfall Monitoring	Rainfall Monitoring
5	Ocean Forecast	Timely release of (a) Fishing advisory (b) Tuna Fishing
		Ocean State Forecast (i) General Public
		(ii) Fishing Community
		(iii) Industries
		(iv) Defense/Security/ Researchers
6	Early warning of natural hazards	Timely release of (a) Tsunamis Bulletin
		Earthquake Bulletin (after)
		Cyclone Warning Bulletin
7	Processing of proposals of holding of Seminars/Symposia	Approval of Seminars / Symposia proposals
8	Processing of extra-mural proposals in the field of Earth Sciences	Timely processing of proposals from scientists / scientific institutions
9	Payment to vendors	Timely payment to vendors on submission of bills.
10	Processing of requests for filling of scientific positions received from various centres	Timely processing of proposals received from various centres

11	Grievance redressal	Timely redressal of grievance (a) Acknowledgement
		(b) Final response
12	Release of funds to the responsibility Centers under the control of MoES	Timely processing of proposals received
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

S. No.	Major Head of Accounts	2020-21 Actuals			2021-22 Budget Estimates			2021-22 Actuals		
		Revenue	Capital	Total	Revenue	Capital	Total	Revenue	Capital	Total
REVENUE SECTION										
1	3403- Oceanographic Research	433.56	0.00	433.56	658.92	0.00	658.92	713.78	0.00	713.78
2	3425- Other Scientific Research	45.65	0.00	45.65	72.80	0.00	72.80	67.80	0.00	67.80
3	3451- Secretariat Economic Affairs	34.96	0.00	34.96	42.00	0.00	42.00	559.28	0.00	559.28
4	3455- Meteorology	704.09	0.00	704.09	964.97	0.00	964.97	754.00	0.00	754.00
Total (Revenue)		**1218.26**	**0.00**	**1218.26**	**1738.69**	**0.00**	**1738.69**	**2094.86**	**0.00**	**2094.86**
CAPITAL SECTION										
1	5403- Capital Outlay on Oceanographic Research	0.00	5.85	5.85	0.00	15.00	15.00	0.00	7.15	7.15
2	5455- Capital Outlay on Meteorology	0.00	63.85	63.85	0.00	148.00	148.00	0.00	92.39	92.39
Total (Capital)		**0.00**	**69.70**	**69.70**	**0.00**	**163.00**	**163.00**	**0.00**	**99.54**	**99.54**
Grand Total		1218.26	69.70	1287.96	1738.69	163.00	1901.69	2094.86	99.54	2194.40

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	N L	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	One (Para No. 8.2 of Report No. 02 of 2018 on "Irregular protection of pay NIOT, Chennai").	NIL	NIL

10. 5 Staff Strength

Strength of Ministry of Earth Sciences including its Subordinate, Attached and Autonomous Institutes.

Groups of Posts	MoES+CMLRE +NCCR	NCMRWF	IMD	NIOT	NCPOR	INCOIS	IITM	NCESS	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Group A	151	66	524	93	124	44	172	70	1244
Group B	102	17	3787	59	42	27	79	29	4153
Group C	74	14	2705	43	29	00	68	58	2991
Total	327	97	7016	195	195	71	319	157	8388

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

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 + Kovana Project	66+3+15=84*	171+15=186**	270
CMLRE	27+7 ***	12	46
NCCR	18	8	26
Total	136	206	342

***66 (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.

p	Direct Recruitment								Promotion							
	No. of Vacancies Reserved				No. of Appointments made				No. of Vacancies Reserved				No. of Appointments made			
	VH	OH	HH	Total	Unidentified Posts	VH	OH	HH	VH	OH	HH	Total	Unidentified Posts	VH	OH	HH
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
	NIL	2	NIL	2	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL

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

up	Representation of SCs/STs/OBCs (as on 01.01.2023				Number of appointment made during the calendar year 2022											
					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
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
p A	63	4	3	7	0	0	0	0	2	0	0	1	2	0	0	1
p B	38	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0
p C ding S	43	13	3	10	3	0	0	2	0	0	0	0	0	0	0	0

10.6 PROGRESSIVE USE OF HINDI OFFICEAL LANGUAGE ACT AND RULES

The Hindi Section of this Ministry is working under the supervision of Joint Secretary and to assist him there is one Joint Director (OL), one Assistant Director (OL), two Senior Translation officer and one Junior Translation officer along with 3 Data Entry Operators. Official Language Section is responsible for the entire translation work and implementation of Official Language Policy of the Government of India in the Ministry and its attached and subordinate offices and their field organizations. The important activities undertaken during the year are as under: -

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

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

1. During the year 2020-21, a series of webinars were organized by senior scientists on the topic "Science for All" to popularize science in a simple language for the public at large andto highlight the working of the Ministry.
2. On the Insistenceof the Hon'ble Vice President of India, the Ministry of Earth Sciences formed a platform by contacting the scientific Ministries/Departments of the Government of India. Probably,the Ministry of Earth Sciences was the first ministry taking an initiative towards the development,promotion and protection of mother tongues.It's objective is to respect all the languages included in the 8th Schedule of the Constitution. For this, a 7 Point Charter was prepared with the approval of the Hon'ble Minister for the Earth Sciences. As a part of this charter "Bharat Bharati Bhasha Mahotsav 2022: A curtain raiser" was organized on 22.02.2022 which was presided over by His Excellency the then Vice President Shri Venkaiah Naidu ji through his digital presence.
3. A mega webinar inHindiwas organized on 22 April 2022on the occasion of International Earth Day with a viewto develop scientific

temper Inschool children. About 10,000 children from Kendriya Vidyalayas, government schools of Delhi Govt, MCD, and NDMC participated in the event online. The program has got over 40,000 views on the YouTube channel to date.

4. The 31st meeting of Joint Hindi Salahkar Samiti of Ministry of Earth Sciences and Ministry of Science and Technology under the chairmanship of Hon'ble Minister, Ministry of Earth Sciences was successfully organized by our Ministry on 06 June 2022.

5. A Scheme of OriginalBook Writing in Hindi on Earth Science related topicsstands implemented in the Ministry since 1989. Under this, the books received for the year 2021-22 were evaluated. Dr. D.D. Ojha, and Dr. Kripakarna (both former scientists) jointly got the first prize of Rs 1,00,000/- for their book 'समुद्री जैव प्रौद्योगिकी', Shri Radheyshyam Bhartiya, grabbed the second prize of Rs. 60,000/- for his writing, 'समुद्री पर्यावरण –प्रदूषण और नियंत्रण', and Dr. M.L. Parihar ended with a consolation prize of Rs 20,000/- for his works, 'समुद्री विज्ञान चिकित्सा'.

6. A scheme of the Original Noting and Drafting in Hindi approved by the Deptt of Official Language is implemented in the Ministry of Earth Sciences. Entries were received under the scheme, and 5 staff were selected for the cash awards for the year 2021-22.

7. In the offices and institutions under the control of the MoES, where there is no Hindi staff, senior scientistshave been entrusted with the additional responsibility asNodal Officer for the Official Languageto promote and monitor the use of official language in official work. This is a unique experiment of our ministry. Reports are sought from their Heads of Departmenton the contributions made by these nodal officers towards implementation of the official language policy in respective offices. Based on the scrutiny of the appraisals,the best performing officers are are selected for award of Certificate of Merits.For the year 2021-22, three scientistsnamely Dr. Milind Mujumdar, Scientist-F, IITM, Pune, Dr. Sanjay O'Neil Shaw, Scientist-F, RMC, Guwahati, and Dr. Akhilesh Misra, Scientist-D, NCMRWF, NOIDA were given this honour.

8. In May 2022, the Department of Official Language, MHA, selected 5 Rajbhasha Officersfrom all the Ministries/Depts of the Government of India for Rajbhasha Samman for the year 2022 for their extraordinary contribution in the promotion of Hindi. This is

being the highest honor of the Government of India in the field of official language. Mr. Manoj Abusaria,Joint Directorin our ministry wasone among these 5 officers who received the honor

9. A special drive was launched by the Department of Official Language to popularize the Memory based Translation Tool 'Kanthastha' developed in collaboration with C-DAC, Pune, in which Mr. Manoj Abusaria,Joint Director got the first prize in the 'Vetter'category, while Mrs. Vimla Dahiya,Asst. Director was awarded the first prize in the 'Translator' category.

10. The Ministry of Earth Scienceswas awarded the Second RajbhashaKirtiAward for the year 2021-22 by the Department of Official Language, Ministry of Home Affairs, under the category of the Ministries/Departments with less than 300 staff. Mrs Indira Murthy, the then Joint Secretary received the award for the MoES from Shri Ajay Mishra, MOS, MHA and Shri Harivansh Narayan Singh, Deputy Chairman, Rajya Sabha ata glorious ceremony organized in Surat (Gujarat) on the occasion of Hindi Divas-2022.

11. The period from 14 September to 29 September 2022 was organized as Hindi Pakhwada in the Ministry. During this, many competitions like Hindi Essay, Hindi Noting Drafting, Official Language Quiz, Hindi Poem Recitation, Shrutelekhan, General Hindi Knowledge etc. were organized for all

categories of personnel. During this period, for the first time an online competition was also organized for scientists.

12. Official language inspections of about 20 offices of IMD including the Institutes under the Ministry were carried out by the Second Sub-Committee of the Committee of Parliament on Official Language during the last one year.The latest addition to the tally was the Meteorological Centre, Raipur, and the RMC, Kolkata where a delegation of officers from the MoES and the IMD led by Shri D. Senthil Pandiyan, Joint Secretary, MoES was present.

13. Three offices under the MoES also got regional Rajbhasha prizesfrom the Dept of Official Language as the best performing offices in respective regions during the reported year. In Northern region, NCMRWF, NOIDA got the first prize under the of the central government offices with 11 to 50 staffstrength. In the central and west region, NCPOR, GOA captured the second prize under the central govt offices with more than 50 staff strength, while the Meteorological Centre, Panaji, Goa grabbed the second prize under the central govt offices with less than 50 staff strength.

Thus,In the year 2022-23, the MoES witnessed a series of events happening in the domain of Official Language Implementation. The rigorous inspection tours of the Committee of Parliament on Official Language followed by the spirited and focused attention paid coupled with the highest priority accorded to this domain by the top-level officers of the ministry boosted up the spirit of the staff and it was their collective efforts that made all these possible.

10.7 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.

10.8 Implementation of the judgements/orders of the CAT

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

10.9 Vigilance Activities and Achievements

Dr.Kamaljit Ray, Scientist 'G' is the Chief Vigilance Officer (CVO) of the Ministry w.e.f. 01.01.2020. Senior level Officers have been nominated as Vigilance Officers (VOs) in attached/subordinate offices and autonomous bodies of the Ministry with the approval of CVO. A preventive as well as punitive vigilance monitoring is rigorously pursued through the Chief Vigilance Officer (CVO) and Vigilance Officers (VOs) of various Institutes & Departments under MoES. Dr. S.K. Sarkar, IAS (retd.) & Sh. RakeshGoyal, IRSE (retd.) were appointed as Independent External Monitors by the Ministry with the approval of Central Vigilance Commission (CVC) for monitoring the contracts exceeding Rs. 5 crores, in accordance with the guidelines of CVC. Vigilance Awareness Week was observed from 31st October, 2022 to 6th November, 2022 with the theme "Corruption free India for a developed Nation (भ्रष्टाचार मुक्त भारत–विकसित भारत). During the

Vigilance Awareness Week, one workshop on preventive vigilance measures and one session of Vigilance Officers of Autonomous/Subordinate/attached officers under MoES along with senior officers of MoES were organized. A quiz competition was also conducted for the officers/officials of this Ministry and prizes were awarded to the winners.

10.10 Parliament Section which caters to the correspondence with Parliament Secretariat replied Lok Sabha (90 questions) and Rajya Sabha (68 questions) during the year 2022.

10.11 Significant Audit Points Printed In audit Reports of 2022

No audit point has appeared in the Audit Report of 2022.

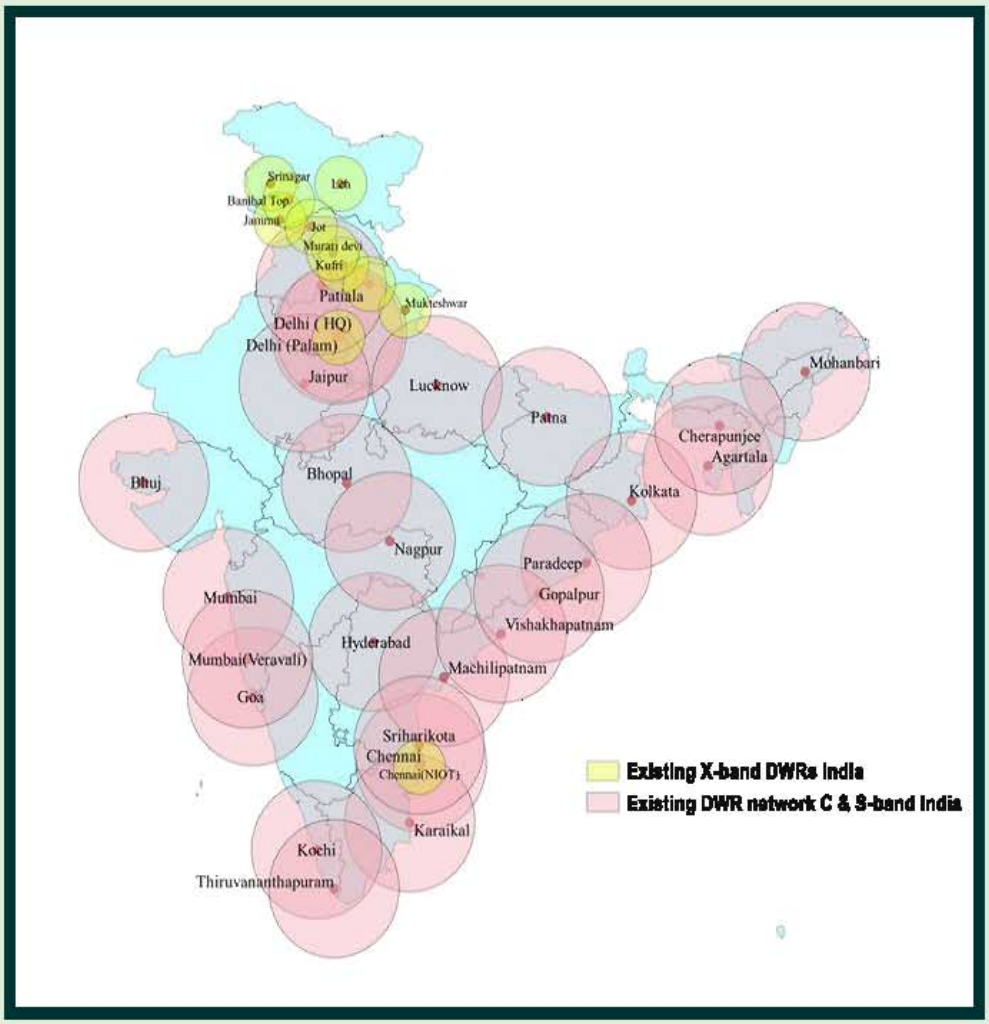
Chapter – 11

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



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