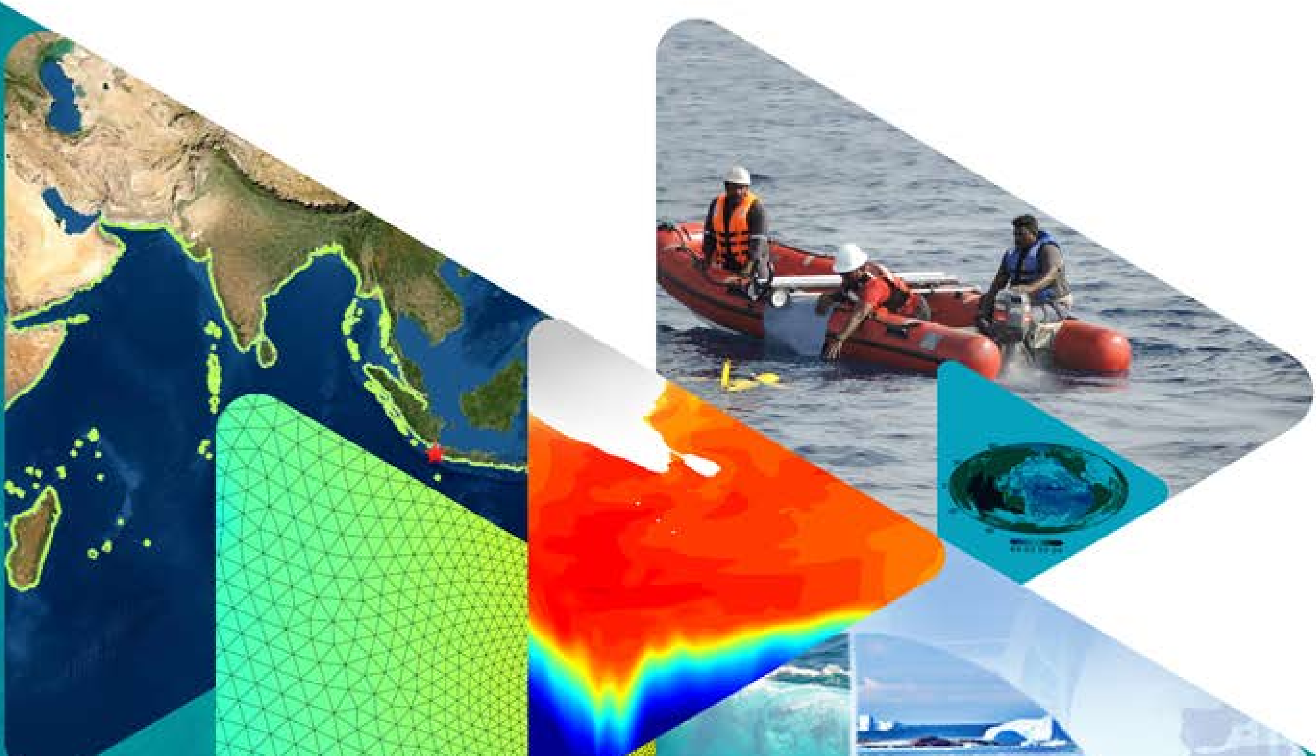
Azadi Ka Amrit Mahotsav

INCOIS



ANNUAL REPORT

2021-22

Annual Report
2021-22

Indian National Centre for Ocean Information Services (INCOIS)
(An Autonomous body under Ministry of Earth Sciences, Government of India)
Hyderabad

Contents

PREFACE

From Director's Desk (2021-22)

The Indian National Centre for Ocean Information Services (INCOIS) is globally recognized as one of the premier organizations for operational oceanography, with a unique mandate to provide ocean data, information and advisory services to society, industry, the government and the scientific community through sustained ocean observations and constant improvements through systematic and focused research. Important operational services provided by INCOIS include Tsunami and Storm Surge Early Warnings, Ocean State Forecasts, High Wave Alerts, Oil Spill Trajectories, Marine Search and Rescue Information, Potential Fishing Zone advisories, Coral Bleaching Alerts, Harmful Algal Blooms, Coastal Vulnerability Assessments, Ocean Data Services, amongst several others. These services have proved to be of immense socio-economic benefit for a wide range of blue economy stakeholders, and enhance the lives and livelihoods of coastal communities. INCOIS today has a truly global reach and impact with its Tsunami early warning centre identified as a Tsunami Service Provider (TSP) for the entire Indian Ocean region, and its International Training Centre for Operational Oceanography (ITCOocean) recognized as a Category-2 Centre (C2C) of UNESCO for training young researchers and professionals from all over the world.

Despite the restrictions posed by the COVID-19 pandemic during the reporting period, INCOIS sustained its 24 x7 operations and delivery of crucial ocean information and advisory services to various stakeholders. The Tsunami Early Warning Centre (TEWC) at INCOIS monitored three tsunamigenic earthquakes of magnitude more than 6.5 Mw in the Indian Ocean and 'No Threat' messages were issued to India and Indian Ocean countries, avoiding public evacuations. Seismic analysis and source zonation for probabilistic tsunami hazard assessment has been carried out during the reporting period to enhance the efficiency of the TEWC. INCOIS prepared high-resolution coastal topography and bathymetry data for Andaman and Nicobar Islands, for better representation in the tsunami, storm surge, and other ocean models. The evolution of the sea state during the passage of five cyclones (Tauktae, Yass, Gulab, Shaheen, and Jawad) and three deep depressions was closely monitored by INCOIS and timely alerts on storm surge inundation and high wave alerts were provided to all stakeholders.

INCOIS sustained the Ocean Observation Network despite severe restrictions and lack of ship-time opportunities due to COVID-19 pandemic. Specifically, on-site pre-deployment performance assessments of coastal autonomous water quality observatories have been carried out. INCOIS established a dedicated glider test facility to test the glider's functionality and instrumentation. The development work of the MoES Earth System Science Data (ESSD) portal has been completed and subsequently, the portal was inaugurated by Dr. Jitendra Singh, Hon'ble Minister for Earth Sciences on 27 July 2021. This portal is expected to ease the search of various datasets collected and maintained under the different MoES programs. Further, INCOIS developed the OMNI-RAMA data portal jointly with NIOT and PMEL-NOAA which was launched on 9 August 2021. It showcases the large inventory of meteorological and oceanographic data sets with direct access to real-time data display and delivery from moored buoys in the Indian Ocean.

Adding an important dimension to its ocean modeling and data assimilation portfolio, INCOIS completed a pilot study on the integration of an ecosystem model with a finite element physical model for the coastal waters off Cochin to develop a marine water quality forecast system. INCOIS made significant progress in assimilating observations to the operational ocean models. A probabilistic storm surge approach has been formulated to improve storm surge warnings to account for uncertainties in track and intensities. INCOIS developed a regional coupled ocean-ecosystem model for the Indian Ocean basin and submitted the model simulated outputs to the MPI-BGC FTP server for participating in the 'REgional Carbon Cycle Assessment and Processes (RECCAP)' Phase 2. INCOIS initiated important work on the development of Ocean Climate Change Advisory Services (OCCAS) under the Deep Ocean Mission (DOM) for assessing sea level, cyclones, storm surges, extreme waves, coastal erosion and coastal ecosystems, and their impact on coastal activities under projected climate change scenarios.

INCOIS continued its active engagement with international and intergovernmental frameworks related to oceans, including the UN Decade of Ocean Science for Sustainable development (UN Decade 2021-30), Indian Ocean Global Ocean Observing System (IOGOOS), International Indian Ocean Expedition (IIOE-2), Partnership for Observation of the Global Oceans (POGO), Regional Integrated Multi-Hazard Early Warning System for Asia and Africa (RIMES), Sustained Indian Ocean Biogeochemical and Ecological Research (SIBER) to name a few. On an important note, India was re-elected as a Member of the Executive Council of the Intergovernmental Oceanographic Commission. I was elected as a Vice Chair of the IOC-UNESCO representing Electoral Group IV, and appointed as Chair of the UN Ocean Decade Tsunami Programme Scientific Committee, Chair of the Indian Ocean Global Ocean Observing System and Co-Chair of the IOC-WMO Joint Collaborative Board.

The International Training Center for Operational Oceanography (ITCOOcean) of INCOIS, which is identified as a UNESCO Category 2 Centre continued to impart training courses to educate the next generation of oceanographers. A total of 14 international/national training courses were conducted in online mode owing to Covid-19 restrictions. INCOIS hosted the International Indian Ocean Science Conference (IIOSC)-2022 in virtual mode during 14-18 March 2022, in partnership with CSIR-National Institute of Oceanography (NIO), National Centre for Polar and Ocean Research (NCPOR), and Goa University. Over 400 participants representing 20 countries participated in this conference and presented their research on the Indian Ocean across 14 themes. The IIOSC provided a great platform for scientists working on different facets of the Indian Ocean to present their ideas and discuss outstanding issues, identify knowledge gaps, and plan a way forward.

INCOIS bagged the CII Industrial Innovation Award-2021 under the category 'Top Innovative Research Institutions-2021' for its development of the GEMINI System for dissemination of Ocean Information Services while out of mobile range. Dr. Kunal Chakraborty and Dr. Remya P G, respectively, were elected as Fellow and Associate Fellow of the Telangana Academy of Sciences for the year 2020 in recognition of their contributions to science and technology. INCOIS entered into several agreements with partner agencies, including an MOU with the Directorate General of Hydrocarbons for the provision of general forecasts and warnings to various Oil & Natural gas offshore E&P companies. An integrated user interaction workshop was conducted to ascertain the utility of INCOIS services and to explore the future needs of the users. Scientific publication is the strength of any research organization highlighting its global presence and impact on research. INCOIS scientists have published a total of 70 research papers in peer-reviewed journals with a cumulative impact factor of 226.96 during the reporting period.

The dedicated efforts of our scientists and scientific and administrative support staff ensured that INCOIS continues to remain at the cutting edge of operational oceanography. I sincerely acknowledge the unflinching support and guidance of Dr. M. Ravichandran, Chairman of INCOIS Governing Council (GC), and the Members of GC. I also thank the Chairs and Members of the Finance Committee and Research Advisory Committee for their advice and support in conducting and improving the financial and scientific affairs of INCOIS. Colleagues in the Ministry of Earth Sciences, especially the Programme Officer and his team, and at the Centres of MoES: NIOT, NCPOR, IITM, NCESS, NCMRWF, IMD, NCS, CMLRE, and NCCR were always there to support. I thank them all.

The Annual Report was prepared by the Editorial Committee Chaired by Kunal with the support of its members Venkat Shesu, Girish, Arya, Padmanabham, Ajay, Dipankar, Sanjiba, and Sidhartha. I thank them for doing a wonderful job.

Thank you

Jai Hind

T. Srinivasa Kumar

In the memory of
Dr. Satya Prakash

Dr. Satya Prakash, a leading scientist at our centre, passed away on 22 July 2021, from a cardiac arrest while recovering from COVID-19, leaving the INCOIS family inconsolable. Dr. Prakash completed his master's studies in applied geology at the Indian Institute of Technology (Roorkee) and earned a doctoral degree from the Physical Research Laboratory, Department of Space, Ahmedabad. Dr. Prakash began working with INCOIS in 2008 as a Project Scientist and remained here, rising to the position of Scientist-E, until his untimely demise in 2021. Even though he was only 42 years old, he co-authored / published more than 40 peer-reviewed articles that made a significant contribution to the present knowledge on the Indian Ocean biogeochemistry. At INCOIS, he had been conducting research on the ocean's biogeochemistry, climate change, and carbon/nitrogen cycle. Before joining INCOIS, Dr. Prakash had carried out research on ocean primary production and provided new insights into understanding the new production in relation to the high biomass algal bloom of the Arabian Sea. His broad area of research was on the biogeochemistry of the Arabian Sea and the Southern Ocean, utilizing isotopes. During his tenure at INCOIS, he made a significant contribution to the deployment and validation of new-generation Argo-floats with biogeochemical sensors in the Indian Ocean. Dr. Satya Prakash was the master architect of INCOIS's Coastal Monitoring programme which aims at establishing an array of buoy-based real-time water quality observatories for the Indian coastal waters. He was also proactively involved in several international research programmes such as the Second International Indian Ocean Expedition (IIOE-2), Climate and Ocean-Variability, Predictability, and Change (CLIVAR), Intergovernmental

Oceanographic Commission-Global Ocean Observing System (IOC-GOOS), Sustained Indian Ocean Biogeochemistry, and Ecosystem Research (SIBER), BGC-Argo, etc. Dr. Prakash played a key role in planning various activities leading to the formal launching of the IIOE-2, including the first research cruise under IIOE-2 (Goa-Mauritius). He served as the JPO coordinator for the India node of IIOE-2. He also served as the Editorial Team member of the IIOE-2 newsletter and the Indian Ocean Bubble. He was a committed scientist, and a valued and well-respected teammate. He was a kind and modest man who left a lasting impression on everyone he came into contact with. These characteristics made him a superb collaborator who encouraged thoughtful and courteous interactions with colleagues and research scholars. He accomplished a lot behind the scenes that were essential to support the SIBER and IIOE-2 programmes. It is not an overstatement to suggest that Dr. Prakash played a significant role in the success of the aforementioned programmes. His demise is a great loss to the field of oceanography. In this brief remark, it would be difficult to mention all of his significant contributions to the coordination and advancement of Indian Ocean research. The INCOIS community mourns his demise deeply and sends condolences to Dr. Satya's family and his colleagues worldwide.

2 INCOIS ORGANIZATIONAL STRUCTURE

2 INCOIS ORGANIZATIONAL STRUCTURE

Indian National Centre for Ocean Information Services (INCOIS) is an autonomous institute under the administrative control of Ministry of Earth Sciences (MoES), Government of India.

INCOIS was registered as a society under the Andhra Pradesh (Telangana) Public Societies Registration Act (1350, Falsi), at Hyderabad on 3 February 1999. The affairs of the society are managed, administered, directed and controlled by the Governing Council, subject to the Bye Laws of the Society.

2.1 INCOIS Society

Secretary to Government of India, Ministry of Earth Sciences	President
Director, National Remote Sensing Centre, Hyderabad	Vice President
Joint Secretary, Ministry of Earth Sciences	Member
Advisor, Ministry of Earth Sciences	Member
Director, National Institute of Oceanography, Goa	Member
Director, National Institute of Ocean Technology, Chennai	Member
Director, National Centre for Polar and Ocean Research, Goa	Member
Director, Indian National Centre for Ocean Information Services	General Secretary

2.2 INCOIS Governing Council

1.	Secretary, India, Ministry of Earth Sciences	Chairman (Ex-officio)
2.	Additional Secretary & Financial Advisor/ Joint Secretary & Financial Advisor, MoES	Member (Ex-officio)
3.	Additional Secretary/ Joint Secretary, MoES	Member (Ex-officio)
4.	Dr. Satish R Shetye, Former Vice Chancellor, Goa University & Chairman, INCOIS–RAC	Member
5.	Dr. R. R. Navalgund, ISRO, Bangalore	Member
6.	Director, NRSC, Hyderabad	Member (Ex-officio)
7.	Director, IITM, Pune	Member (Ex-officio)
8.	Director, NIO, Goa	Member (Ex-officio)
9.	Head, NCMRWF, Noida	Member (Ex-officio)
10.	Programme Head (INCOIS), MoES	Permanent Invitee (Ex-officio)
11.	Representative, NITI Aayog	Invitee
12.	Director, INCOIS, Hyderabad	Member Secretary

2.3 INCOIS Finance Committee

1.	Additional Secretary & Financial Advisor/ Joint Secretary & Financial Advisor, MoES	Chairman (Ex-officio)
2.	Additional Secretary/ Joint Secretary, MoES	Member (Ex-officio)
3.	Programme Head (INCOIS), MoES	Member (Ex-officio)
4.	Director (Finance) /Deputy Secretary (Finance), MoES	Member (Ex-officio)
5.	Director, INCOIS, Hyderabad	Member (Ex-officio)
6.	Dy. Chief Administrative Officer, INCOIS, Hyderabad	Member (Ex-officio)
7.	Sr. Accounts Officer, INCOIS, Hyderabad	Member (Ex-officio)

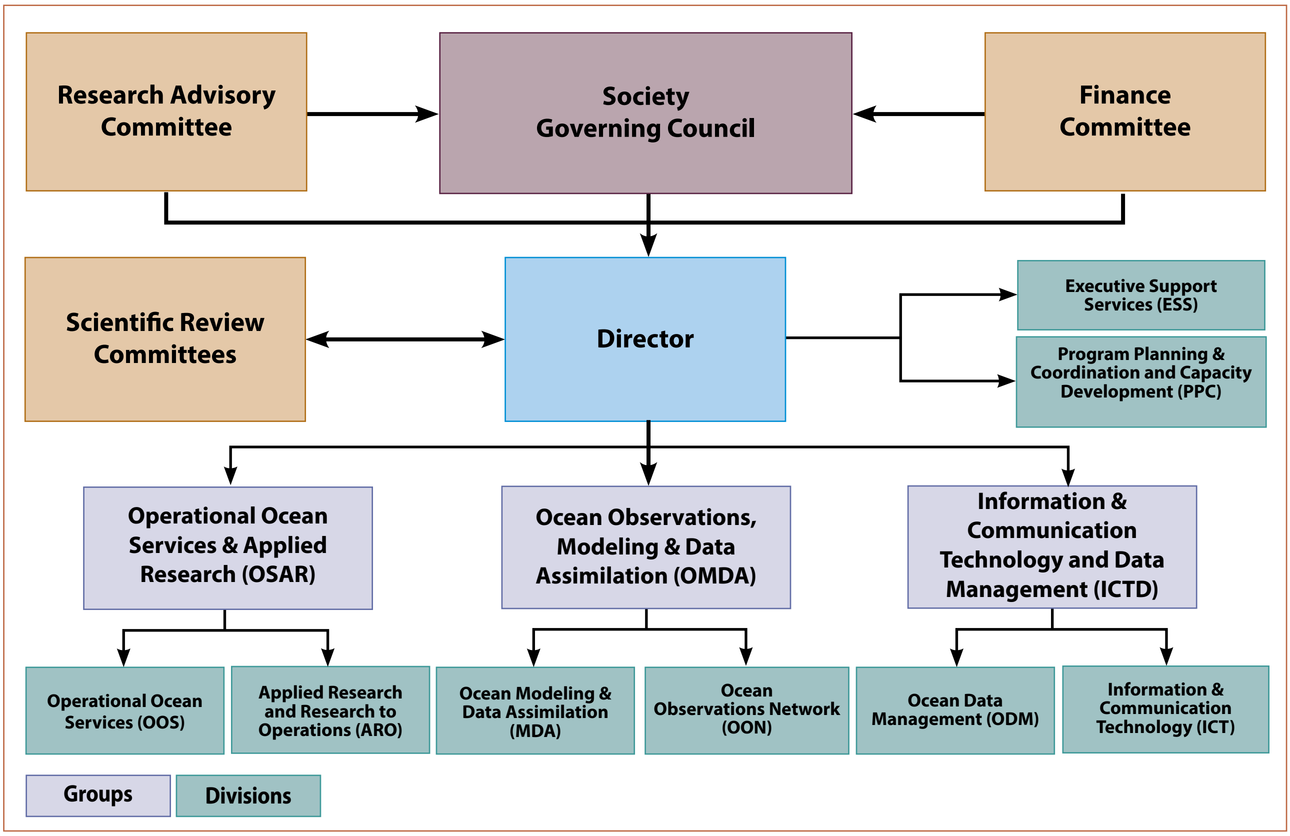
2.4 INCOIS Research Advisory Committee

1.	Dr. Satish R Shetye, Former Vice Chancellor, Goa University	Chairman
2.	Dr. Vijay Kumar, Scientist 'G', MoES & Program Head, INCOIS	Member (Ex-officio)
3.	Dr. T. Srinivasa Kumar, Director, INCOIS, Hyderabad	Member (Ex-officio)
4.	Dr. R. Navalgund, Former ISRO Distinguished Professor	Member (Expert)
5.	Prof. Sunil Kumar Singh, Director, NIO, Goa	Member (Expert)
6.	Dr. V.M. Tiwari, Director, NGRI, Hyderabad	Member (Expert)
7.	Dr. Y.V.N Krishna Murthy, Senior Professor, IIST, DOS-ISRO	Member (Expert)
8.	Prof. Raghu Murtugudde, Professor, University of Maryland, USA	Member (Expert)
9.	Prof. Karumuri Ashok, Professor, University of Hyderabad	Member (Expert)
10.	Prof. P. N. Vinayachandran, Professor, CAOS, IISc, Bengaluru	Member (Expert)
11.	Dr. R. Jeyabaskaran, Director General, FSI	Member (Expert)
12.	Prof. Prasad Kumar Bhaskaran, Professor, IIT-Kharagpur	Member (Expert)
11.	Dr. Sudheer Joseph, Scientist-F & Division Head, ARO, INCOIS	Member Secretary

2.5 Scientific and Administrative structure of INCOIS

INCOIS has three major Scientific Groups headed by respective Group Directors and each group has two divisions headed by respective Division Heads. In addition to the scientific groups, there are two divisions, one division to support the program planning & coordination and capacity building and another division to tender the administrative support for the functioning of the organization.

2 INCOIS ORGANIZATIONAL STRUCTURE



Organization Structure of INCOIS

2.6 The Mission

To provide ocean data, information and advisory services to society, industry, the government and the scientific community through sustained ocean observations and constant improvements through systematic and focused research in information management and ocean modelling.

The major objectives of INCOIS are:

1. To establish, maintain and manage systems for data acquisition, analysis, interpretation and archival for ocean information and related services.
2. To undertake, aid, promote, guide and co-ordinate research in the field of ocean information and related services including satellite oceanography.
3. To carry out surveys and acquire information using satellite technology, ships, buoys, boats or any other platforms to generate information on fisheries, minerals, oil, biology, hydrology, bathymetry, geology, meteorology, coastal zone management and associated resources.
4. To generate and provide data along with value added data products to user communities.

5. To cooperate and collaborate with other national and international institutions in the field of ocean remote sensing, oceanography, atmospheric sciences/meteorology and coastal zone management.
6. To establish an Early Warning System for Tsunami and Storm Surges.
7. To support research centres in conducting investigations in specified areas related to oceanic processes, ocean atmospheric interaction, coastal zone information, data synthesis, data analysis and data collection.
8. To organise training programmes, seminars and symposia to advance study and research related to oceanography and technology.
9. To publish and disseminate information, results of research, data products, maps and digital information through all technologically possible methods to users for promoting research and to meet societal needs for improvement of living standards.
10. To provide consultancy services in the fields of ocean information and advisory services.
11. To coordinate with space agencies to ensure continuity, consistency and to obtain state-of-the-art ocean data from satellite observations.
12. To encourage and support governmental and non-governmental agencies/organizations for furthering programmes in the generation and dissemination of ocean information.
13. To undertake other lawful activities as may be necessary, incidental or conducive to the attainment and furtherance of all or any of the above objectives of INCOIS.

2.7 Quality Policy

The Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences (MoES) is committed to provide the best possible ocean information and advisory services to society, industry, the government and the scientific community through sustained ocean observations and constant improvement through systematic and focused research. To achieve this, we will continue to align our actions with organizational values & shall ensure our commitment to continually improve our performance with our Quality Management System, by setting and reviewing quality objectives.

3 HIGHLIGHTS

- **Multi-Hazard Early Warnings**
  - **Tsunami Advisories:** INCOIS monitored three tsunamigenic earthquakes of magnitude more than 6.5 Mw in the Indian Ocean and 'No Threat' messages were issued to India and Indian Ocean countries for these events. Also monitored tsunamis that occurred in South Atlantic and the Pacific Ocean, and issued 'No Threat' bulletins to Indian Ocean countries.
  - **Storm Surge Early Warnings:** INCOIS issued Strom Surge and inundation advisories for five cyclones (Tauktae, Yass, Gulab, Shaheen, and Jawad) and three deep depressions to stakeholders. INCOIS also provided Storm Surge information to IMD to support the ESCAP services.
  - **High Wave Alert/Warning:** INCOIS issued a total of 590 High Wave Alerts/Warnings. INCOIS also monitored the evolution of the sea state during the passages of five cyclones and issued necessary high-wave alerts and warnings to the public.

- **Ocean Forecast, Advisory and Value-added Services**
  - **Ocean State Forecast:** INCOIS provided daily operational forecasts of the ocean state during the reporting period.
  - **Oil Spill Advisory:** INCOIS issued Oil spill advisories to ICG-East zone for MVX-Press pearl vessel sunk and Maldives Meteorological Service for cargo vessel wreckage.

- **Ecosystem Based Services**
  - **PFZ Advisories:** INCOIS provided 328 PFZ advisories and 252 Yellowfin Tuna advisories across the year. INCOIS also initiated nine broadcast channels for different coastal states on the TELEGRAM platform for dissemination of PFZ Advisories.
  - **Coral Bleaching Alert:** INCOIS provided 122 advisories on Coral Bleaching Alerts for Andaman, Nicobar, Lakshadweep, Gulf of Kutch, and Gulf of Mannar.
  - **Algal Bloom Information:** INCOIS monitored algal blooms on daily basis in select ecological hotspots of the Indian waters (Northeastern Arabian Sea, coastal waters of Kerala, Gulf of Mannar, and coastal waters of Gopalpur) and issued timely alerts.

- **Tsunami Mock drill:** INCOIS conducted a tsunami mock drill to Odisha stakeholders for evaluating their SOPs and communication channels on 05 November 2021.

- **ESSD Portal:** INCOIS completed the development of the MoES Earth System Science Data (ESSD) portal which was inaugurated by Dr. Jitendra Singh, Hon'ble Minister for Ministry of Earth Sciences on 27 July 2021. This portal is expected to ease the search of various datasets collected and maintained under the different MoES programmes. The portal facilitates data providers to submit metadata and data access links.

- **Joint OMNI-RAMA Indian Ocean Data Portal:** INCOIS developed the OMNI-RAMA data portal jointly with NIOT and PMEL-NOAA which was launched on 09 August 2021. It showcases the large inventory of meteorological and oceanographic data sets with direct access for data display and delivery.

- **NDMA CAP alerting system 'SACHET':** INCOIS successfully integrated alert system services (Tsunami, High wave Alerts, Swell Surge & Rough Sea Alerts) on NDMA's Common Alert protocol-based alerting system known as SACHET web platform for dissemination of alert messages directly to the public.

- **Upgradation of VSATs:** 42 VSATs of Andaman and Nicobar SMA & GNSS Network were upgraded and established the connectivity to Tsunami Warning Centre for real-time data reception.

- **National Glider Lab:** INCOIS established a National Glider Lab with a dedicated test facility at INCOIS to test the Glider's functionality and its instrumentation at the lab.

3 HIGHLIGHTS

- **High-resolution Coastal Topography and Bathymetry:** INCOIS prepared high-resolution coastal topography and bathymetry data for Andaman and Nicobar Islands, which is useful for tsunami, storm surge, and other ocean circulation modeling. Generated Multi-Hazard Vulnerability Map (MHVM) using this dataset, which is vital for disaster management.
- **North Andaman Seismicity:** INCOIS generated a micro-seismicity map for the northern Andaman Islands and developed a 1D velocity model for the region, which will be used for the precise location of earthquakes in the region.
- **User Interaction Workshops/Meetings:** INCOIS conducted an integrated user interaction workshop on 02 February 2022 as a part of commemorating the INCOIS foundation day using an online platform for improving and expanding its services. Additionally, a total of 25 user interaction workshops/meetings were organized online during the reporting period.
- **Consultancy Projects:** INCOIS signed an MOU with the Directorate General of Hydrocarbons for serving the general forecasts and warnings to various Oil & Natural gas offshore E&P companies.
- **Ocean Observation Network:** INCOIS sustained the existing observation platforms under the Ocean Observation Network in spite of having various restrictions and a lack of ship-time opportunities caused by the COVID-19 pandemic.
- **Coastal Water Quality Observatory:** INCOIS carried out on-site pre-deployment performance assessments of coastal autonomous water quality observatories and initiated the process of development of a web page for the water quality now-casting system.
- **Scientific Cruises:** INCOIS conducted a scientific cruise to collect ship-based direct covariance flux measurements in the southwestern Bay of Bengal.
- **Finite Element Model Development:** INCOIS completed a pilot study on the integration of ERSEM with physical FVCOM configuration by enabling their coupling via a universal generic coupler 'FABM' resulting in a high and flexible resolution, coupled, and nested modeling framework (FVCOM-FABM-ERSEM) for the coastal waters off Cochin.
- **Probabilistic Storm Surge Estimation:** INCOIS formulated a Probabilistic storm surge (P-surge) approach to improve the storm surge warnings considering the uncertainties in track and intensities. The P-surge system generates multiple tracks from the IMD forecasted track and forecasts storm surges utilizing the ADCIRC model.
- **Data Assimilation**
  - **Assimilation in OGCM:** INCOIS developed a Local Ensemble Transform Kalman Filter (LETKF) data assimilation scheme that assimilates tracers in the high resolution (~ 2 km) operational model for the northern Indian Ocean and satellite track data of absolute dynamic topography in the basin-wide Indian Ocean operational model.

- **Assimilation in Wave Model:** INCOIS implemented the assimilation of significant wave height (SWH) measurements from the SARAL/AltiKa, Jason-2, and Jason-3 altimeters in the wave forecasting system at INCOIS resulting in ~15% improvement in the SWH forecast in the northern Indian Ocean.

- **Participation in RECCAP-2:** INCOIS developed a regional coupled ocean-ecosystem model for the extended Indian Ocean region following the 'REgional Carbon Cycle Assessment and Processes (RECCAP)' Phase 2 Ocean Modeling Protocol for the regional oceans to participate in RECCAP-2. The model simulated data for a period from 1980 to 2019 has been submitted to the MPI-BGC data server.

- **Training/Workshops:** ITCOOcean of INCOIS conducted 14 training courses (ten international and four national) and two webinars during the reporting period. A total of 1514 participants were trained, of which 851 participants (Male: 460, Female: 391) are from India and 663 participants (Male: 432, Female: 231) from other 61 countries.

- **Azadi Ka Amrit Mahotsav:** INCOIS organized several activities as part of Azadi Ka Amrit Mahotsav focused on better outreach of its activities and services and India's achievements in the past 75 years in the field of Earth sciences with special emphasis on Ocean sciences. INCOIS also adopted a village in Andhra Pradesh to make the village Tsunami Ready and mitigate disaster risk.

- **IIOSC 2022:** INCOIS hosted International Indian Ocean Conference (IIOSC) 2022 in the Hybrid mode in partnership with CSIR-NIO, NCPOR, and Goa University. Dr. Jitendra Singh, Hon'ble Minister for Ministry of Earth Sciences inaugurated this conference and delivered an inaugural address. Over 400 participants representing 20 countries participated in this conference and presented their research on the Indian ocean across 14 themes.

- **UN Ocean Decade:** INCOIS submitted a proposal for the establishment of the Indian Ocean Region Decade Collaborative Centre (IOR-DCC) against the Call for Ocean Decade 01/2021 made by IOC-UNESCO.

- **IISF-2021:** INCOIS placed its pavilion in the India International Science Festival (IISF) 2021 in Goa from 10 to 13 December 2021. Thousands of visitors (~5000/day) including school students and divyangjan were introduced to the unique activities of INCOIS at the Mega Science Technology and Industry Expo event.

- **Research Publications:** A total of 70 research papers were published during the reporting period with a cumulative impact factor of 226.96.

- **Awards/Honors:**
  - **International:** Dr. T. Srinivasa Kumar, Director, INCOIS was elected as a Vice Chair of the IOC-UNESCO representing Electoral Group IV, and appointed as Chair of the UN Ocean Decade Tsunami Programme Scientific Committee, Chair of the Indian Ocean Global Ocean Observing System, and Co-Chair of the IOC-WMO Joint Collaborative Board.
  - **National:** INCOIS bagged the CII Industrial Innovation Award-2021 under the category 'Top Innovative Research Institutions-2021' for its development of the GEMINI System for dissemination of Ocean Information Services while out of mobile range. Telangana Academy of Sciences elected Dr. Kunal Chakraborty and Dr. Remya P G, respectively, as Fellow and Associate Fellow of the Academy for the year 2020.

4 SERVICES

4.1 Multi-Hazard Early Warning Services

4.1.1 Tsunami Early Warning Services (TEWS)

The Indian Tsunami Early Warning Centre (ITEWC) has monitored 28 earthquakes of magnitude ≥ 6.5 during the period April 2021 to March 2022. Out of 28 earthquakes, only 3 earthquakes have occurred in the Indian Ocean region. ITEWC meticulously assessed the situation during each of the earthquakes in the Indian Ocean. In all cases, ITEWC had declared that there were no tsunami threat for India. Being the Tsunami Service Provider (TSP) for Indian Ocean, the necessary bulletins were also sent to Indian Ocean rim countries and IOC through E-mails, GTS, FAX and SMS. The locations of these earthquakes are shown in fig. 4.1.

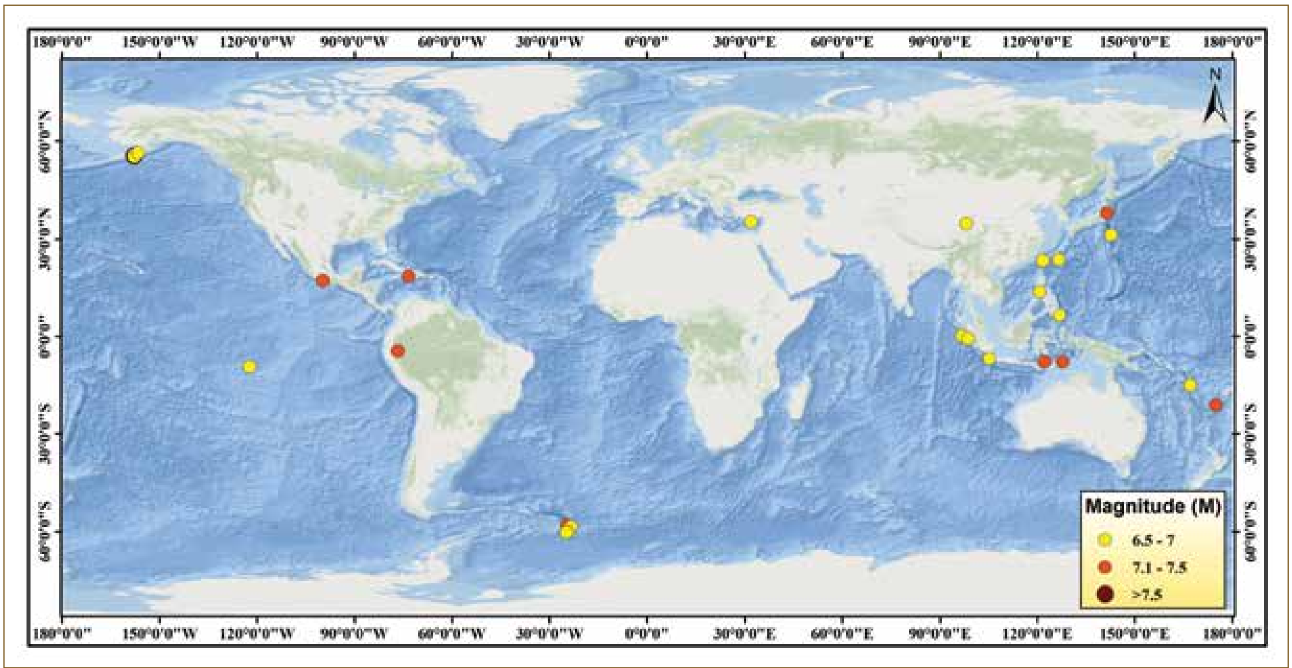


Fig. 4.1 Location map of earthquakes of magnitude ≥6.5 monitored at ITEWC during 2021-22

4.1.1.1 Key Performance Indicators (KPI) of ITEWC

S. No.	Key Performance Indicator	Target	ITEWC Performance
KPI 1	Elapsed time from earthquake to issuance of first Earthquake Bulletin	10 min	10.5
KPI 2	Probability of detection of IO EQ with Mw >= 6.8	100%	100%
KPI 3	Accuracy of earthquake magnitude in comparison with final USGS parameters	0.3	0.13
KPI 4	Accuracy of earthquake hypocenter depth in comparison with final USGS parameters	25 Km	14.7
KPI 5	Accuracy of earthquake hypocenter location in comparison with final USGS parameters	30 Km	14.2
KPI 6	Elapsed time from earthquake to issuance of first Threat Assessment Bulletin	20 Min	26

4 SERVICES

4.1.1.2 Monitoring of Tsunamigenic Earthquakes

Indian Ocean:

An earthquake of magnitude 6.6 occurred off west coast of northern Sumatra, Indonesia on 14 May 2021 at 06:33 UTC (12:03 IST). The epicentre of the event was at 0.19° N, 96.8° E with Focal depth of 10 Km. ITEWC issued the first bulletin at 06:42 UTC (9 minutes from earthquake occurrence) with a tsunami evaluation statement. Tsunami threat map and travel time maps are shown in fig. 4.2. Another earthquake of magnitude 6.5 occurred at Sunda Strait, Indonesia on 14 January 2022 at 09:05 UTC (14:35 IST). The epicentre of the event was at 0.88° S, 105.23° E with focal depth at 10 km. ITEWC issued the first bulletin at 09:17 UTC. One more event occurred with an earthquake magnitude of 6.7 at southern Sumatra, Indonesia on 13 March 2022 at 21:09 UTC (14 March at 02:39 IST). ITEWC issued the first bulletin at 21:19 UTC with a tsunami evaluation statement. For these three earthquakes, ITEWC issued second bulletin stating, "Based on pre-run model scenarios, there is NO THREAT to India and to countries in the Indian Ocean".

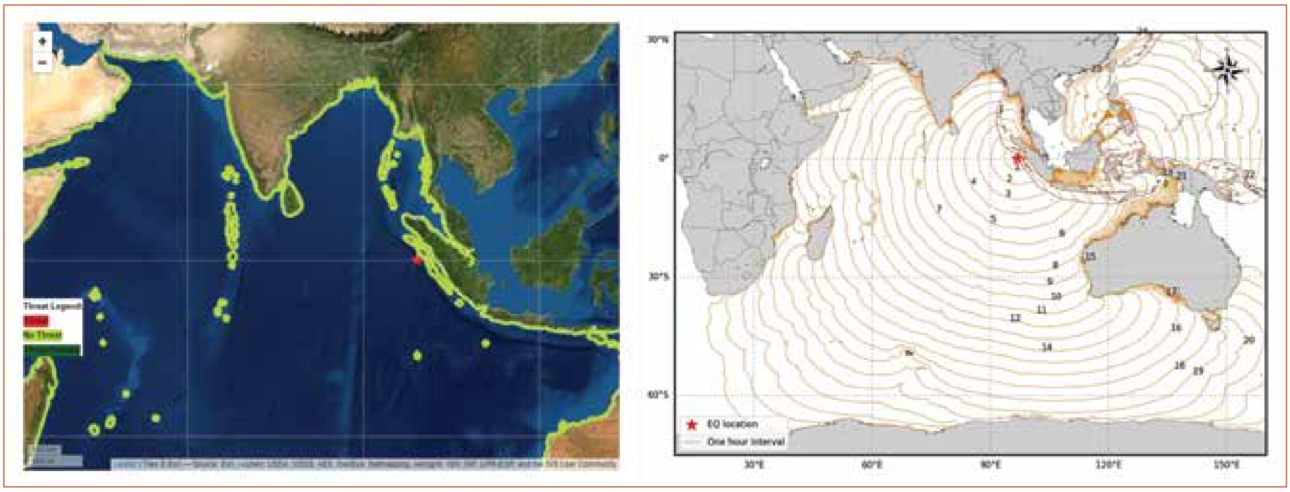


Fig. 4.2 Tsunami Threat details and Travel time Map for Northern Sumatra, Indonesia event on 14 May 2021

Outside Indian Ocean:

During the reporting period, an earthquake of magnitude 7.4 at south of Sandwich Islands Region (south Atlantic Ocean) occurred on 12 August 2021 at 18:32 UTC (13 August 2021 at 00:02 IST). A minor tsunami was observed with maximum sea level, height of 64 cm at King Edward Point tide gauge in Indian Ocean. ITEWC issued three bulletins with revised estimates and sea level observations.

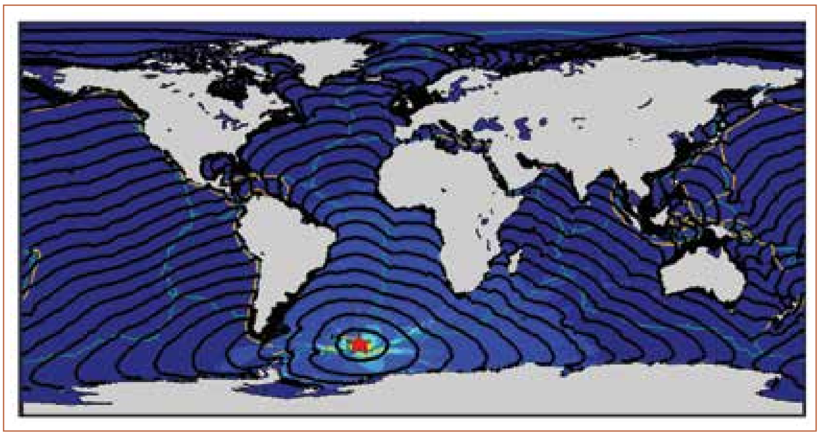


Fig. 4.3 Epicentre (star) and travel time map of south Sandwich Islands' earthquake occurred on 12 August 2021.

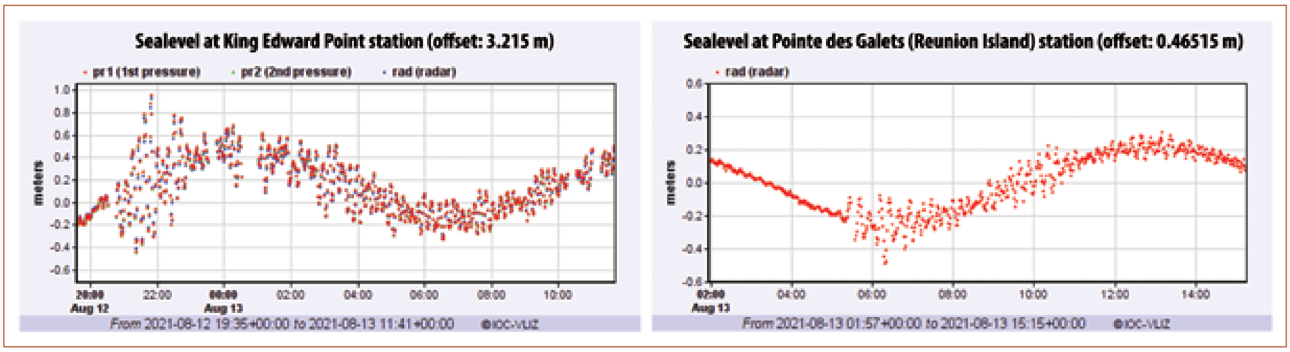


Fig. 4.4 Sealevel observations in tide gauges during South Sandwich tsunami (Courtesy-IOC Sea level)

ITEWC monitored a tsunami wave generated in Pacific Ocean on 15 January 2022 at Hunga Tonga-HungaHa'apai under sea volcano with an explosive caldera-forming eruption. The eruption led to tsunami, causing further damage in Tonga and affecting other destinations in the South Pacific. The eruption caused tsunami in Tonga, Fiji, American Samoa, Vanuatu, and along the Pacific rim, including damaging tsunamis in New Zealand, Japan, the United States, the Russian Far East, Chile and Peru. The maximum wave heights were reported in Tonga, Chile, New Caledonia and Vanuatu, with wave heights reaching greater than 1 meter in amplitude. Many other countries reported tsunami waves of more than 30 cm triggering tsunami advisories to the coastal communities with instructions to stay away from beaches and low-lying coastal areas. Preliminary data indicate that the event was probably the largest volcanic eruption in the 21st century. Volcanic eruption, tsunami travel times and sea level observations are shown in fig. 4.5.

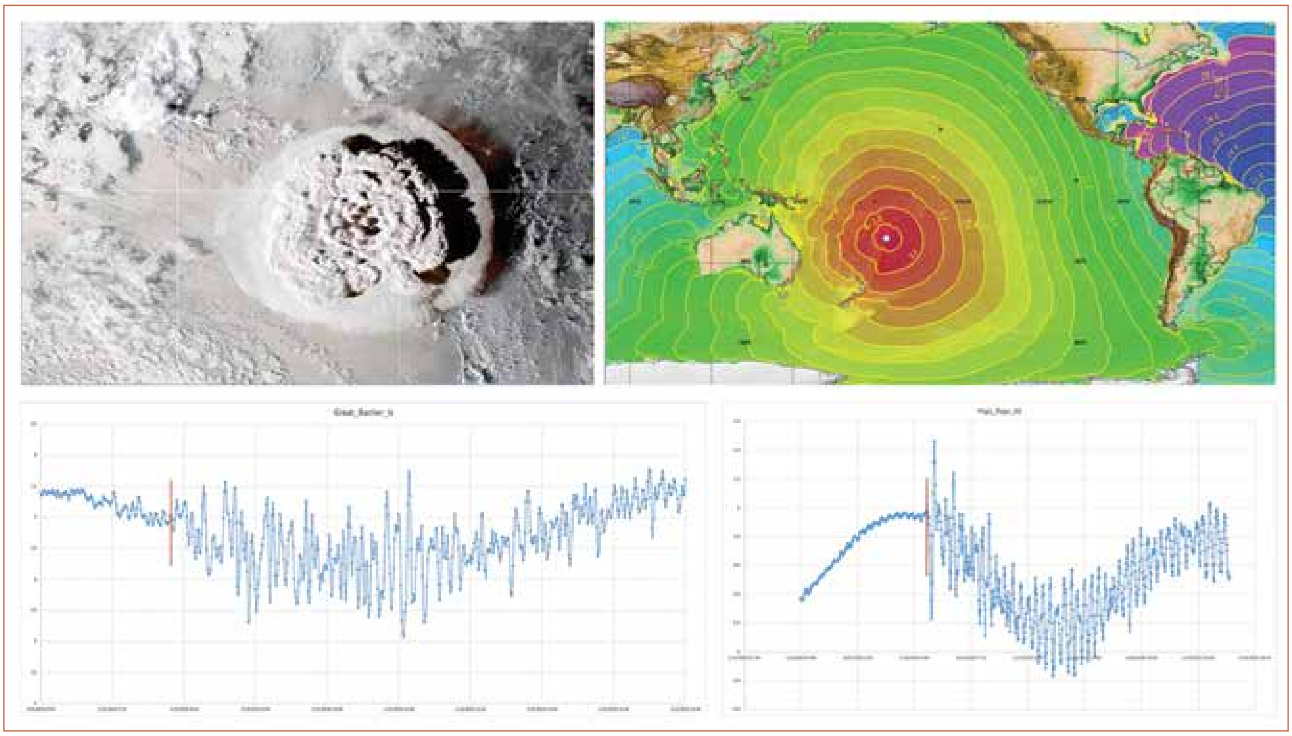


Fig. 4.5 Hunga Tonga-Hunga Ha'apai undersea volcanic eruption, tsunami travel times and sea level observations on 15 January 2022

4.1.1.3 Communication Test

22nd and 23rd Communications (COMMs) tests of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) were conducted on 09 June 2021 and 08 December 2021 to validate the TSPs (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 and the access by NTWCs to TSP password-protected web sites. During the COMMs test, the scenarios of magnitude 9.0 at Sunda Strait, and M9.1 at Java, Indonesia region were evaluated and ITEWC disseminated notification messages through email, fax, GTS, SMS as well as website to 25 NTWCs and including two TSPs (Australia & Indonesia) in the Indian Ocean Region. TSP-India success rate is shown in fig. 4.6.

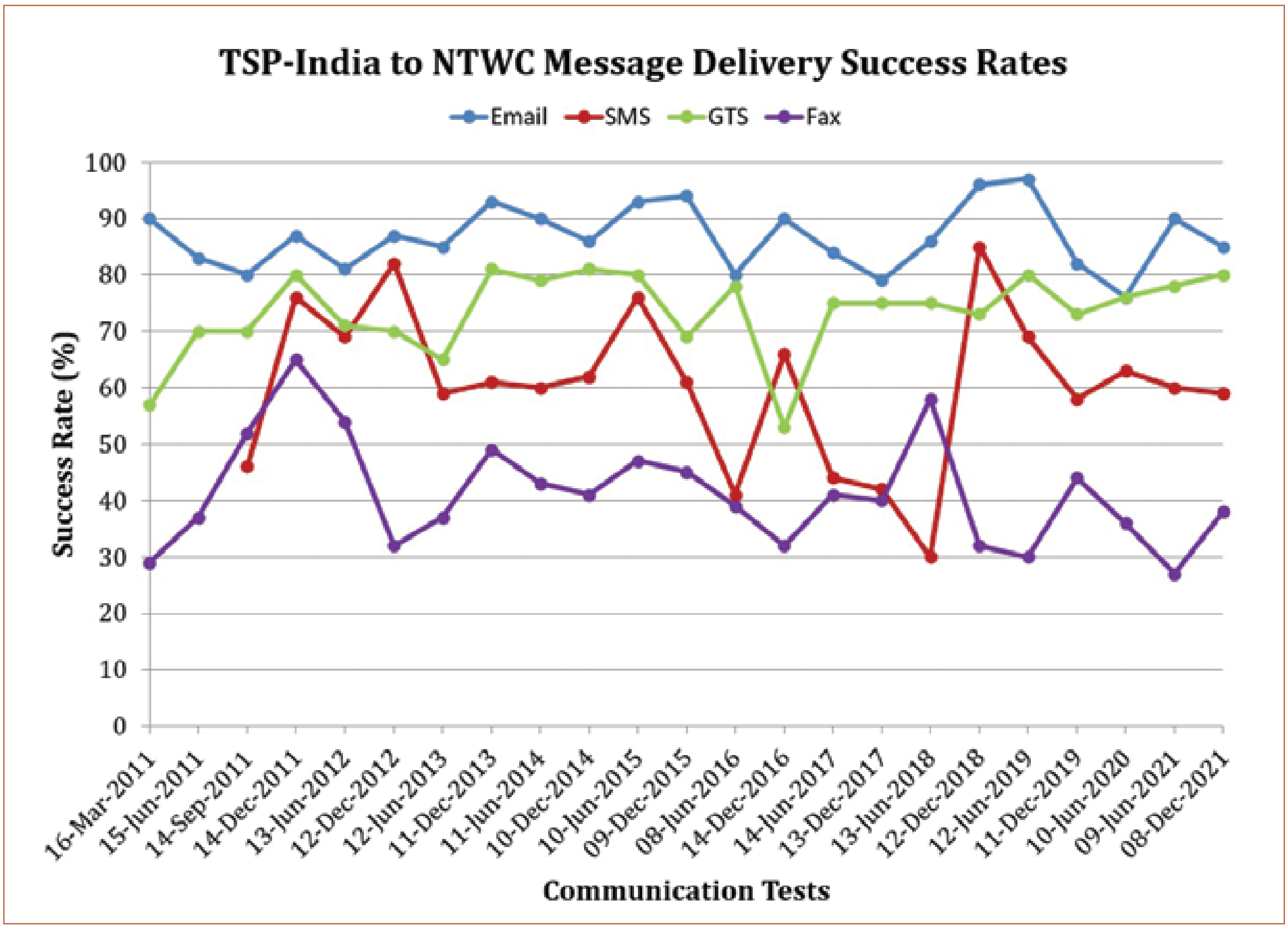


Fig. 4.6 Success rates of TSP-India message delivery during COMMs Tests

4.1.1.4 Tsunami Mock drill in Odisha

On 05 November 2021, a tsunami mock drill was conducted in coordination with Odisha State Disaster Management Authority (OSDMA) and Odisha State Emergency Operation Centre wherein INCOIS issued bulletins to Odisha stakeholders for evaluating their SOPs and communication media. As part of mock drill, ITEWC had simulated a tsunami for an earthquake of magnitude 9.2 at Andaman & Nicobar Islands. A total of 69 coastal communities/wards public actively participated and were evacuated during tsunami mock drill. The tsunami ready indicators were also tested.

Table 4.1 Scenarios details for Tsunami Mock drill

Magnitude	9.2 Mw
Latitude	12.65° N
Longitude	93.50° E
Depth	10 km
Origin Time	09:30 IST
Date	05 November 2021
Region	Andaman Islands, India

Fig. 4.7 Odisha community participation during tsunami mock drill on 05 November 2021

4.1.1.5 Tsunami Ready Programme Implementation

Tsunami Ready programme is essential for enhancing preparedness and INCOIS continued its support to the programme. Post the recognition of Venkatraipur and Noliasahi villages of Odisha as Tsunami Ready communities by IOC-UNESCO, Odisha State Disaster Management Authority (OSDMA) took up implementation of Tsunami Ready programme in its other coastal villages / wards and work is in progress. Andhra Pradesh State Disaster Management Authority (APSDMA) identified Nachugunta of Nagayalanka (M) in Krishna District to implement Tsunami Ready programme. INCOIS adopted this village as part of Azadi Ka Amrit Mahotsav (AKAM). INCOIS is coordinating with other coastal States/UTs as well to initiate the program in their communities.

4.1.2 Storm Surge Early Warning Service

During 2021-22, INCOIS successfully monitored 05 cyclones and 03 deep depression systems and issued timely storm surge and inundation advisories through Indian Meteorological Department (IMD). Storm surge and inundation forecast for cyclones are shown in fig. 4.8.

Table 4.2 Cyclones and deep depressions during 2021-22

Cyclone Id	Cyclone Name	Dates Active	No of Advisories / Graphic product issued
ARB/01/2021	Tauktae	14-19 May 2021	12
BOB/02/2021	Yaas	23-28 May 2021	12
BOB/03/2021	Deep Depression	12-15 September 2021	05
BOB/04/2021	Gulab	24-28 September 2021	10
AS/02/2021	Shaheen	30 September- 04 October 2021	04
BoB/05/2021	Jawad	02-06 December 2021	09
BOB/01/2022	Deep Depression over southwest Bay of Bengal	03-06 March 2022	05
BOB/02/2022	Deep Depression over north Andaman Sea	20-23 March 2022	09

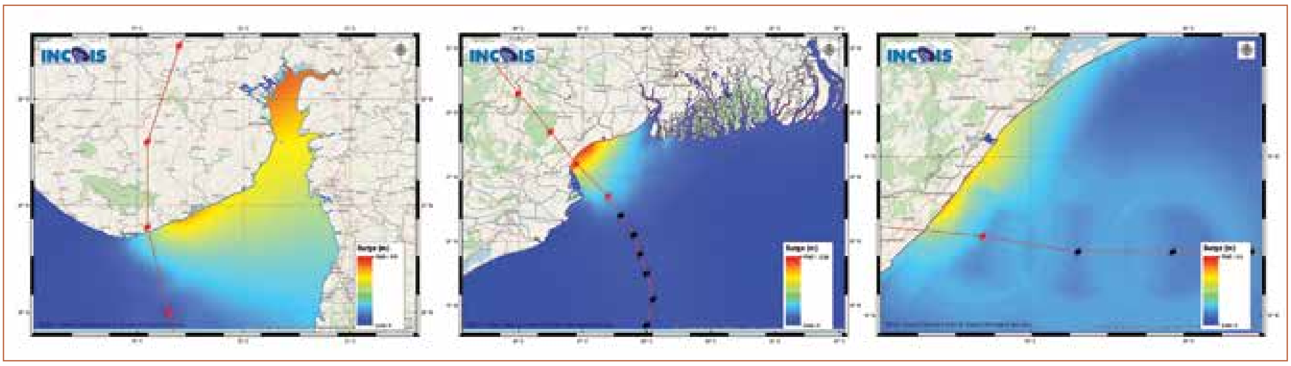


Fig. 4.8 Real-time storm surge and inundation forecast for Tauktae, Yass and Gulab cyclones, respectively

4.1.3 Ocean State Forecast (OSF)

INCOIS successfully issued daily operational forecasts seamlessly during the entire period (365 days), covering the parameters of waves, winds, currents, tides, SST, MLD and D20 for various regional and coastal domains. In addition, INCOIS monitored cyclone/depression conditions, issued joint INCOIS-IMD bulletins and disseminated the warnings through multiple modes to the user communities. Advisory services have been provided to specific users like disaster management authorities, fishermen, ports and harbours, ships plying in the seas, offshore industries and the defense authorities. INCOIS also provided daily OSF data to Sri Lanka, Maldives, Seychelles, Comoros, Mozambique and Madagascar.

During the reporting period, INCOIS issued OSF services seamlessly, supporting the operational requirements as well as safety of a diverse and large user community, through multiple dissemination modes. A total of 590 High Wave Alerts/Warnings were issued. Month-wise and state-wise alerts are shown in fig. 4.9 and 4.10, respectively.

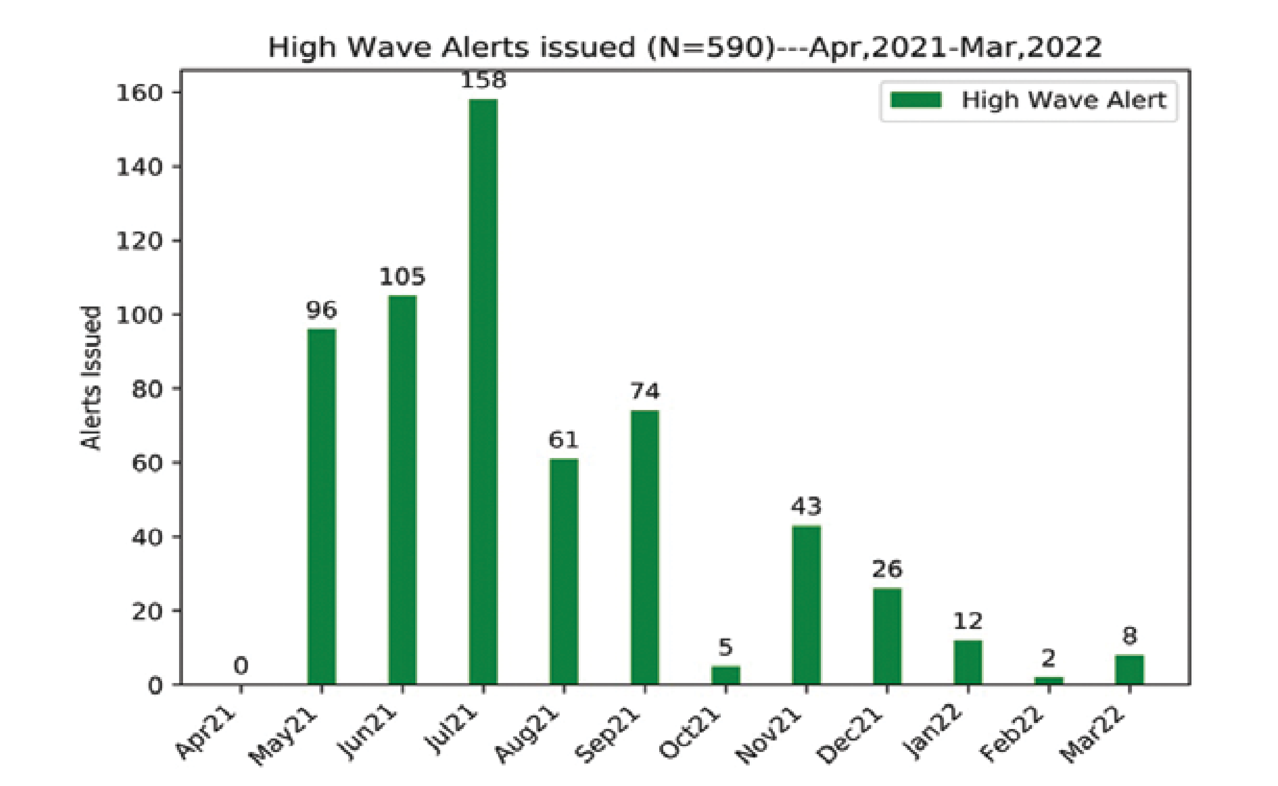


Fig. 4.9 Number of High Wave Alerts issued during April 2021 – March 2022

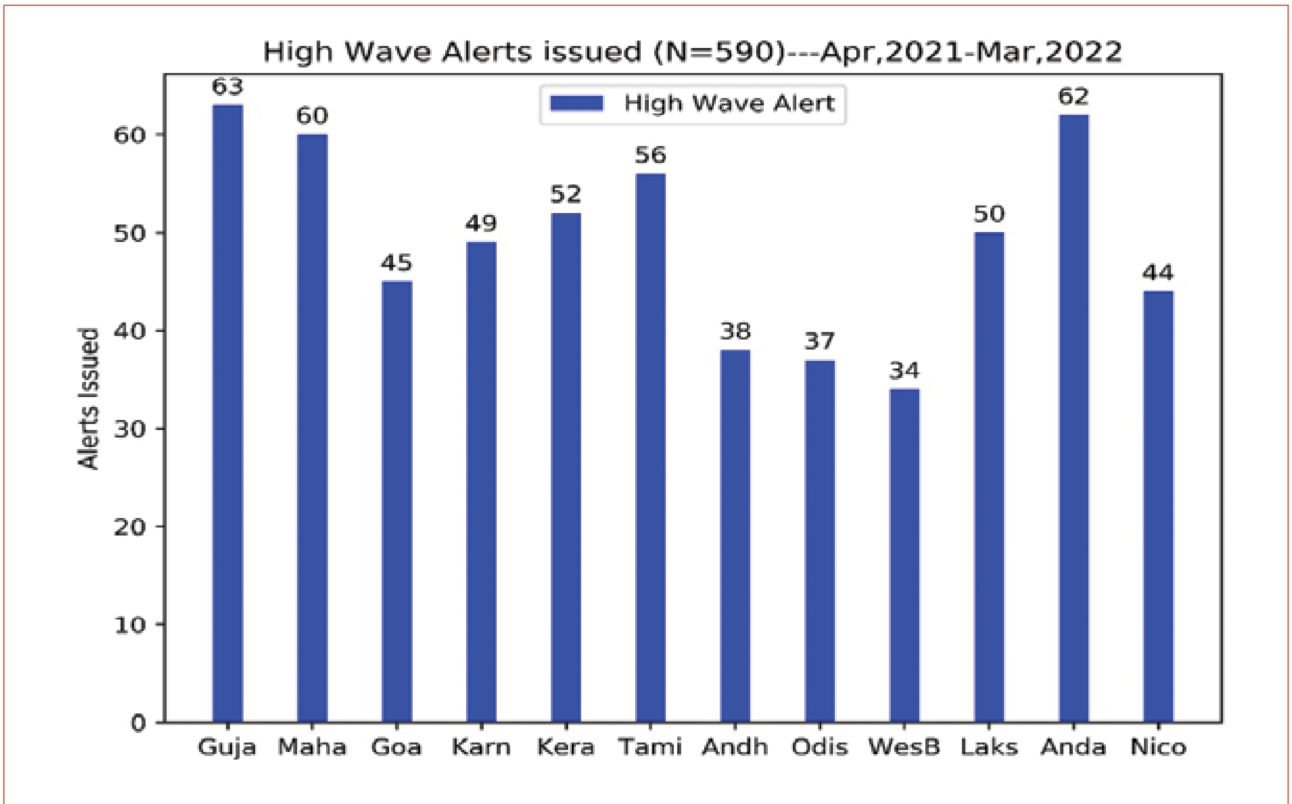


Fig. 4.10 State wise distribution of the high wave alerts during the period

4 SERVICES

INCOIS continued to extend the necessary support required to the users through customization and providing location-specific services. INCOIS provided ocean state forecast services to ONGC, AFCONS, NIOT, etc. There were 61,082 visitors on the OSF webpage with the maximum user visits occurring during the southwest monsoon season.

4.1.3.1 Ocean state forecast during the passage of cyclonic storms in the Bay of Bengal and Arabian Sea

INCOIS continuously monitored the wave, wind, sea level and current regime in the nearshore region as well as far offshore for the cyclones Tauktae, Yass, Gulab, Shaheen and Jawad using the models, in-situ instruments as well as satellite observations. Extreme events during the period are displayed in the below table 4.3, detailing all the phases of the events e.g. depression – cyclone – depression and its dissemination statistics.

Table 4.3 OSF forecast for cyclones and depressions during the reporting period

Extreme weather event	Period	States/UTs affected
Tauktae Cyclone	13-18 May 2021	Tamil Nadu- southern region, Kerala, Karnataka, Goa, Maharashtra, Gujarat, Lakshadweep Islands
Yaas cyclone	22-27 May 2021	Odisha, West Bengal, Andhra Pradesh, Andaman & Nicobar Islands
Deep Depression	12-15 September 2021	Odisha, West Bengal, Andhra Pradesh, Andaman & Nicobar
Gulab Cyclone	24-28 September 2021	Andhra Pradesh, Odisha, West Bengal and Andaman & Nicobar
Shaheen Cyclone	29 September-02 October 2021	Gujarat, Maharashtra and Lakshadweep Islands
Depression	07-09 November 2021	Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Lakshadweep Islands
Depression	10-12 November 2021	Andhra Pradesh, Tamil Nadu, Kerala
Depression	18-19 November 2021	Tamil Nadu, Andhra Pradesh
Jawad Cyclone	02-06 December 2021	Andhra Pradesh, Odisha, West Bengal
Deep Depression	03-06 March 2022	Tamil Nadu, Andhra Pradesh
Deep Depression	20-23 March 2022	Andaman & Nicobar

Spatial plots of the forecast waves and wind during the cyclones are presented in fig. 4.11. Validation of forecast wave with WRB observations during cyclones is shown in fig. 4.12.

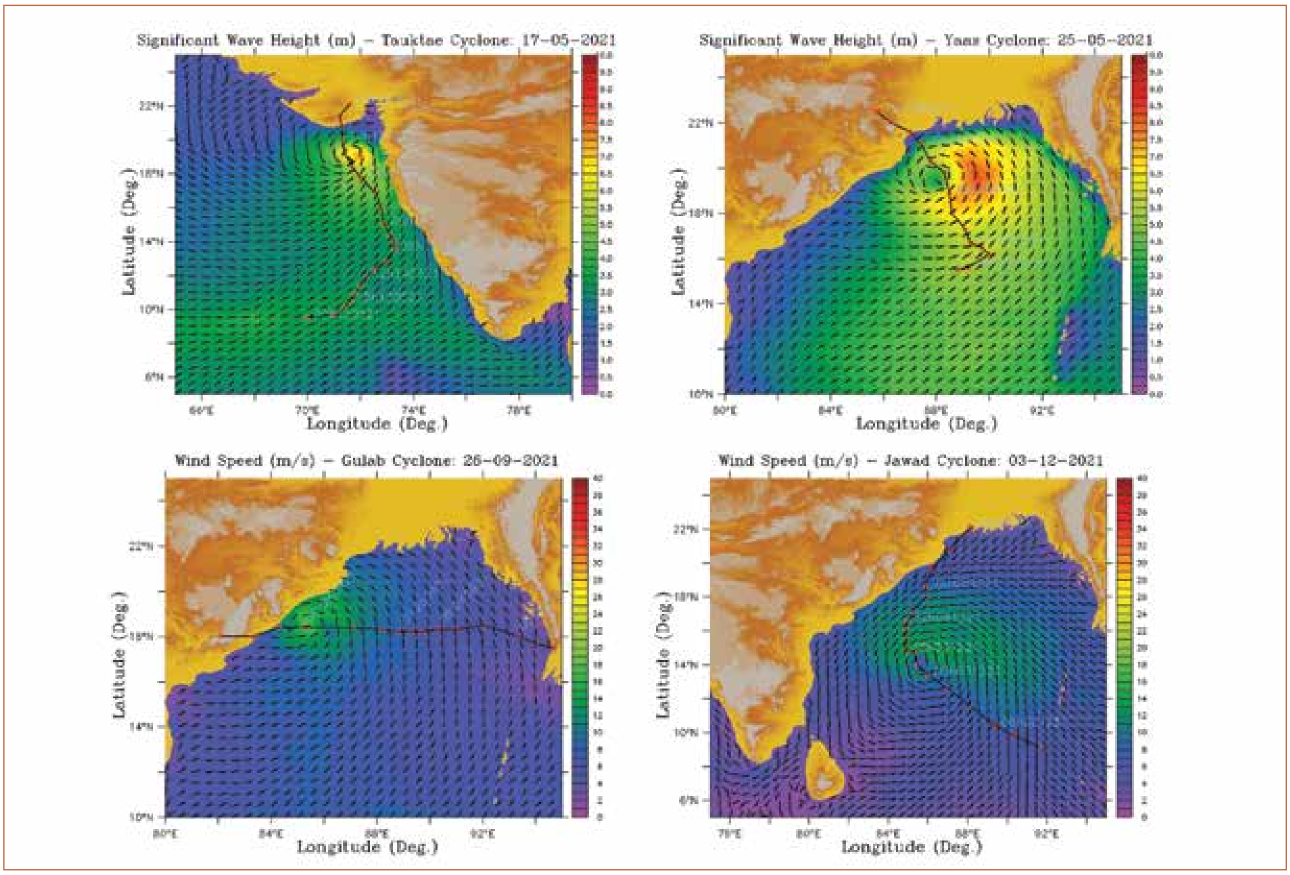


Fig. 4.11 OSF Spatial plots of significant wave height and wind speed forecasts for cyclones a) Tauktae, b) Yass, c), Gulab, d) Jawad

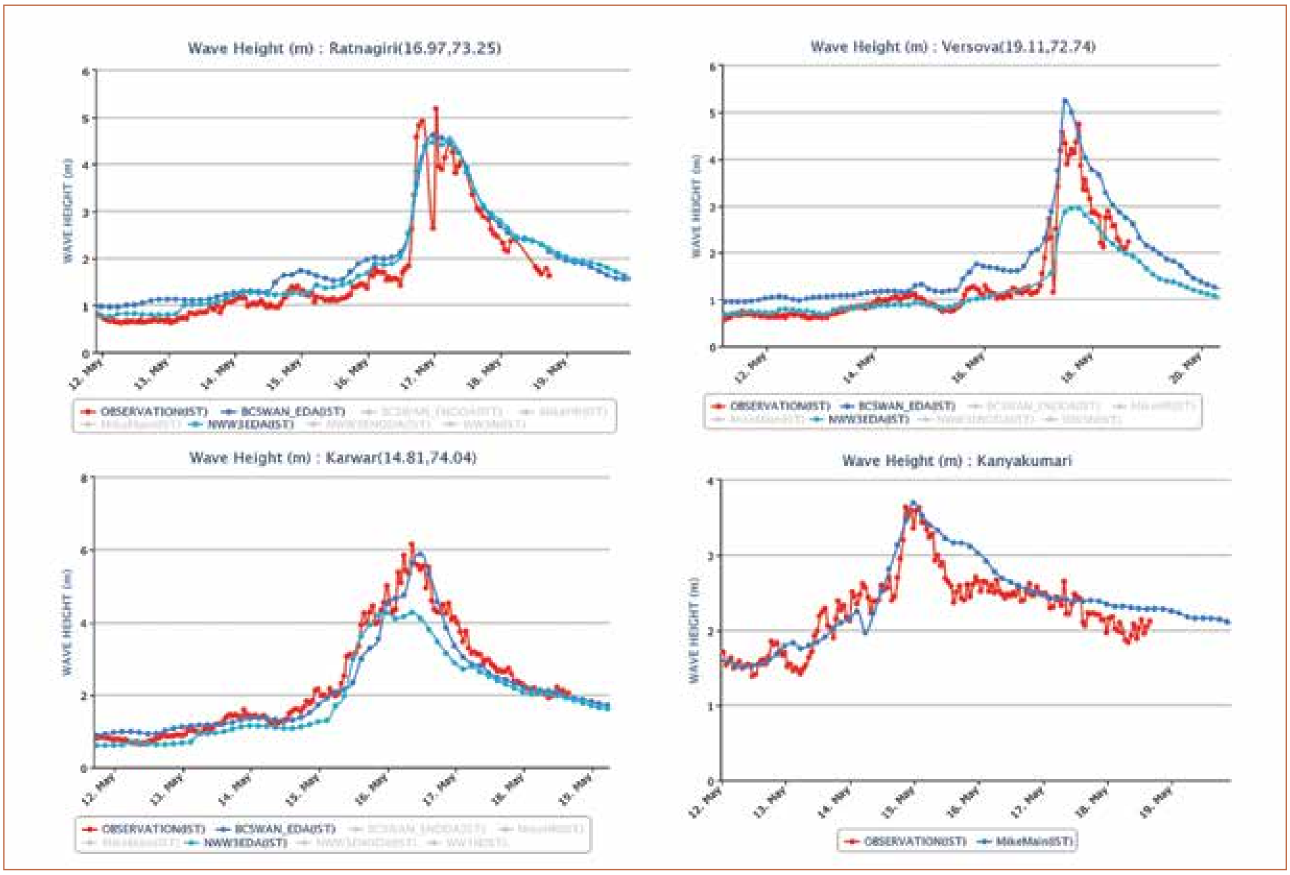


Fig. 4.12 Validation plots of the forecast waves during the Tauktae cyclone at Ratnagiri, Versova, Karwar and Kanyakumari locations

4 SERVICES

Number of INCOIS-IMD joint bulletins issued and States/UTs affected during cyclones, deep depressions and depressions are shown in figure 4.13 and 4.14, respectively.

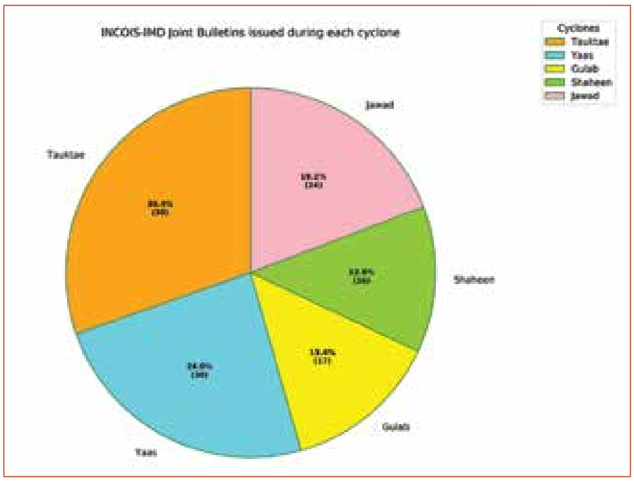


Fig. 4.13 INCOIS-IMD number of joint bulletins issued during cyclones

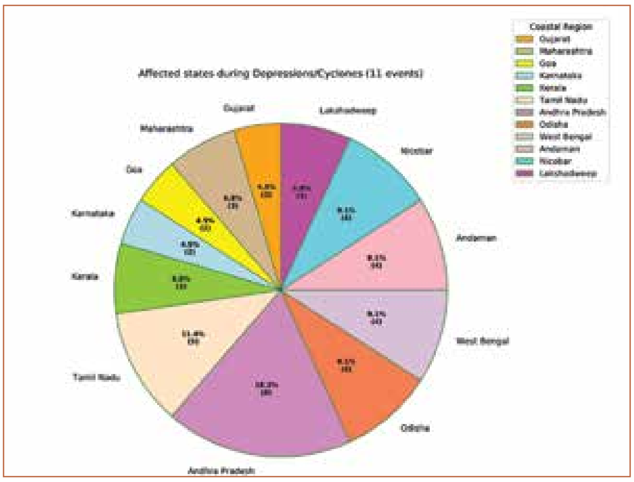


Fig. 4.14 States/UTs affected during depressions and cyclones

4.1.3.2 Rough Sea Alerts and Swell Surge Warnings

INCOIS continued to monitor and issue rough sea alerts. INCOIS issued two rough sea alerts (i) for the states of Kerala, Tamil Nadu (south) and Lakshadweep Islands during 17-18 October 2021 and (ii) for the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu-south and Lakshadweep Islands, during 25-29 January 2022.

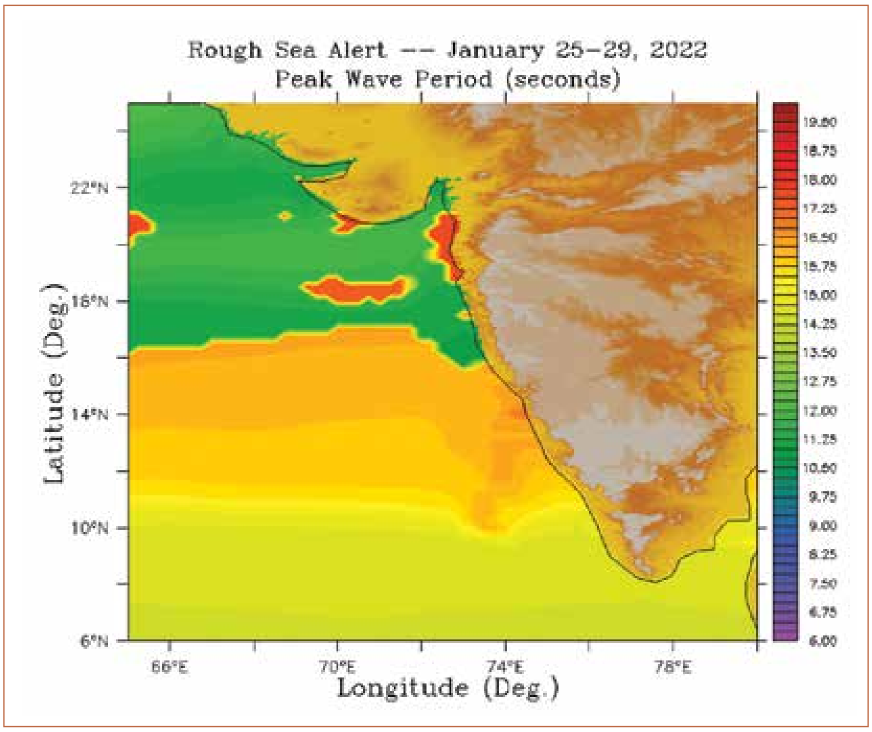


Fig. 4.15 Rough Sea Alert to West Coast of India in January 2022

4.1.3.3 Tidal Flooding Alert

Tidal flooding alert was issued in connection with the perigean spring tides during 25-30 May 2021, for the entire coastline of India.

4.1.3.4 Oil-spill trajectory advisories

During the reporting period, two oil-spill trajectory advisories were provided. The first oil spill advisory was issued to ICG- East zone for MVX-Press Pearl vessel which sank at 79° 45'E, 7° 04'N and had ~276 MT of Heavy Fuel oil on board. Oil drift patterns were generated from the location of the stricken vessel during 03-08 June 2021 and sent to Indian Coast Guard (ICG). The simulated oil drift pattern on 08 June 2021 was validated with the Sentinel-1A data (fig. 4.16). The second advisory was issued to Director Meteorology, Public Weather Service, Maldives Meteorological Service, Male on hypothetical basis for the period 30 August 2021 to 02 September 2021.

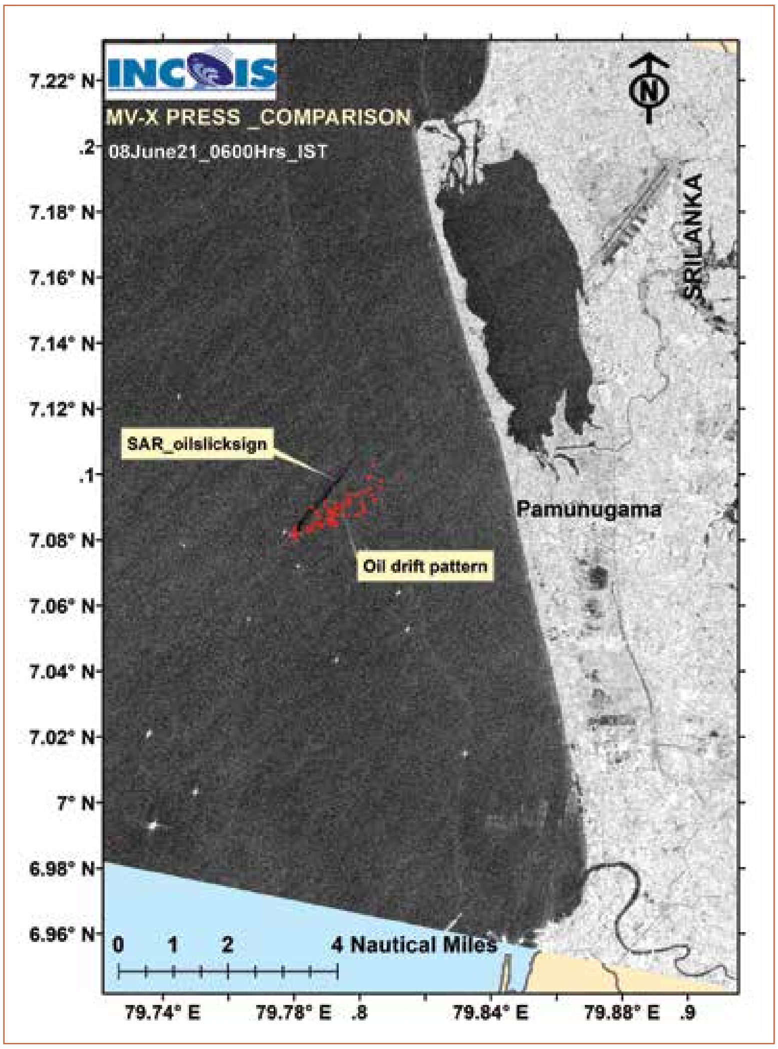


Fig. 4.16 Comparison between the simulated and observed oil drift for MVX-Press pearl vessel

4.1.3.5 Support to other users

- INCOIS supported NIOT with its cruise to the CIOB (35 days cruise) onboard Sagar Nidhi for mining trials at the Test Mining Site. This started on 14 March 2021 and included along the track forecast, as well as for the Test Mining Site, for undertaking delicate operations.
- Provided sea state data and advice for the sea trial of Tug 'Veeran' of Hindustan Shipyard Limited (Visakhapatnam) off Visakhapatnam coast during 16-31 July 2021.
- Provided sea state forecasts to NIOT for the period 24-30 September 2021 in connection with some field experiment plans involving the autonomous profiler, off Chennai.

4.2 Ecosystem-based Service

4.2.1 Marine Fisheries Advisory Services (MFAS)

4.2.1.1 Potential Fishing Zones (PFZ) and Tuna PFZ Advisories

PFZ advisory have become part of the value chain of the fishing community of India. INCOIS continued to provide the advisories on Potential Fishing Zones (PFZ) generated using the satellite-derived Sea Surface Temperature (SST), chlorophyll, water clarity and sea level data. The advisories were disseminated in the form of smart map and text on a daily basis, except during fishing-ban period and during adverse sea-state conditions. During the period April 2021 to March 2022, multilingual Potential Fishing Zones (PFZ) advisories and Yellowfin Tuna advisories were provided for 328 and 252, days respectively. The number of PFZ and TUNA advisories issued are shown in fig. 4.17 and 4.18, respectively.

4 SERVICES

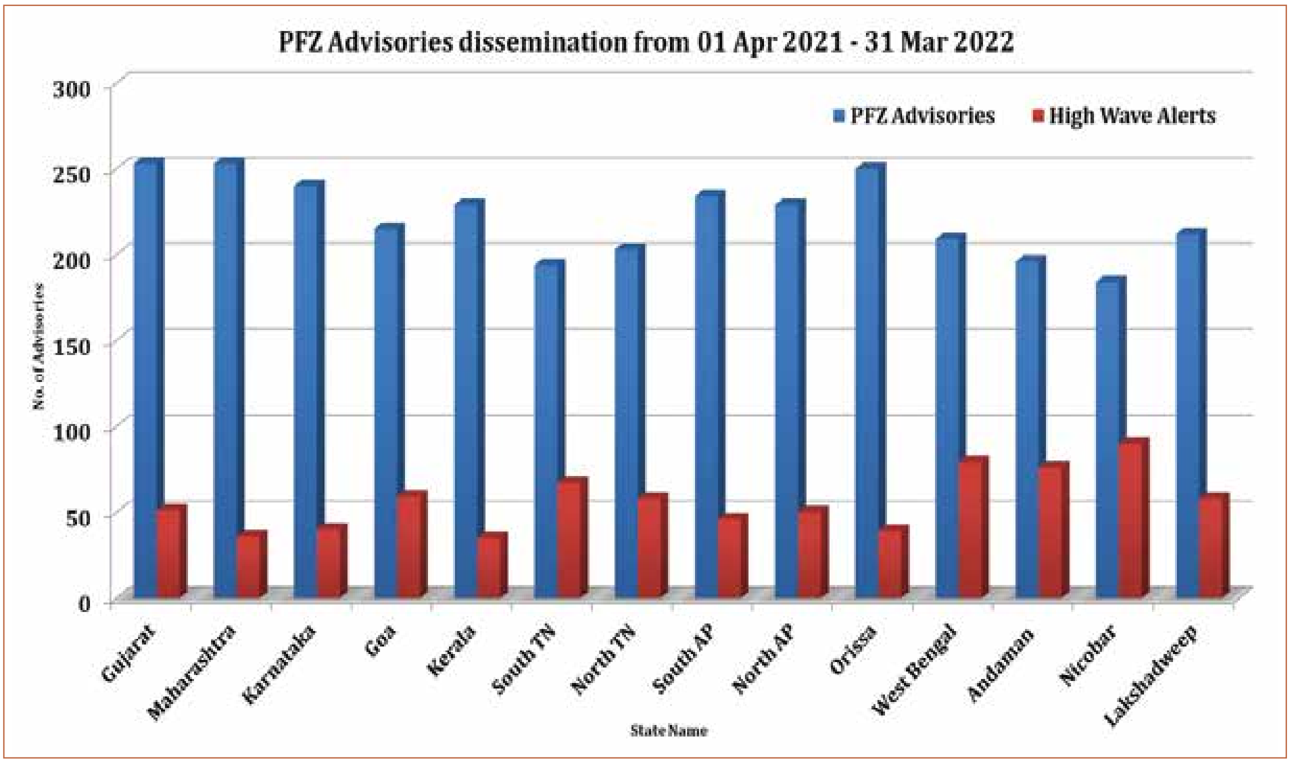


Fig. 4.17 Number of PFZ advisories issued during 2021-22.

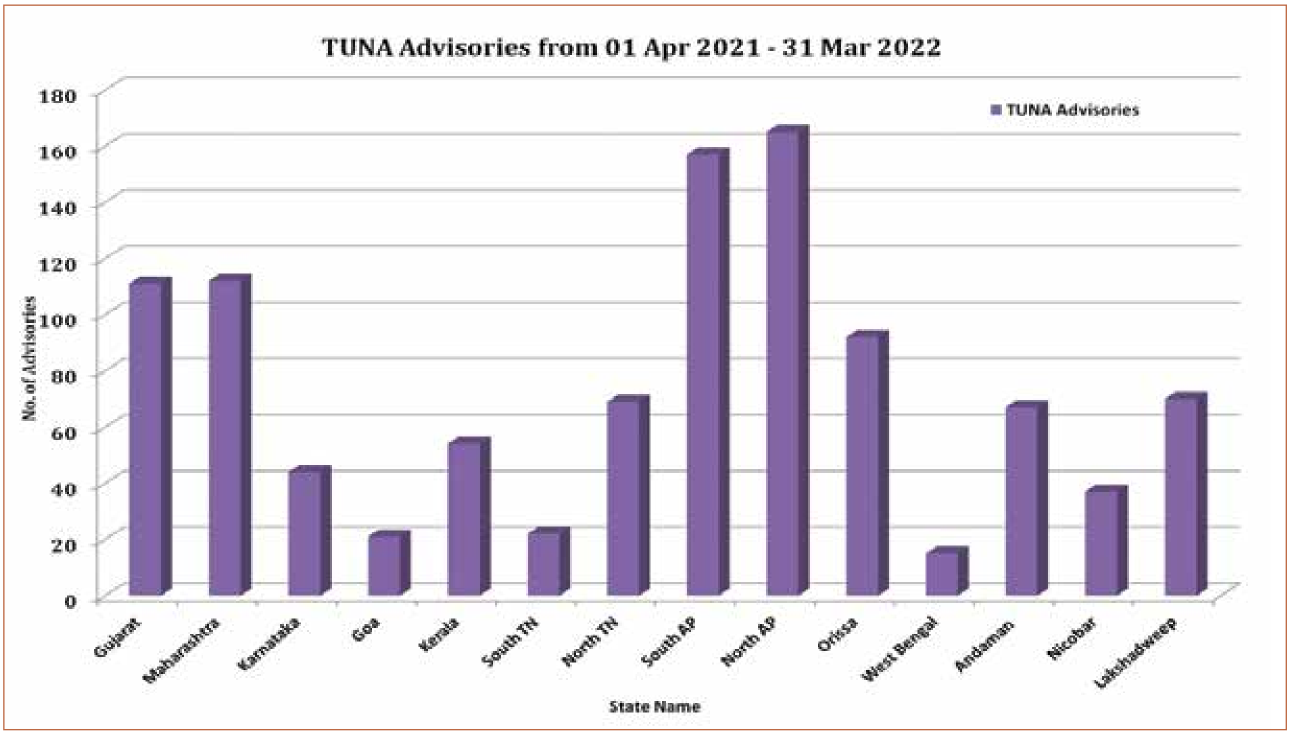


Fig. 4.18 Number of Tuna PFZ advisories issued during 2021-22.

4.2.1.2 PFZ Dissemination

INCOIS initiated 09 broadcast channels for different coastal states (i.e., Gujarat, Maharashtra, Karnataka & Goa, Kerala, Tamil Nadu, Andhra Pradesh, Odisha & West Bengal, Andaman & Nicobar, Lakshadweep) on TELEGRAM platform for dissemination of PFZ Advisories. These 09 PFZ Telegram Channels gets updates on daily advisory maps along with textual information.

Fig. 4.19 Number of PFZ and Tuna PFZ advisories web page views and visitors

A total of 1,26,669 page views and 24,016 visits recorded for INCOIS PFZ advisories.

4.2.1.3 Android App for Fishermen Feedback

INCOIS designed a mobile app for collecting feedback from fishermen society which can help in improving & fine tuning of advisories. The fishermen feedback mobile app is updated in Google play store for accessing more users. The same is also integrated with Fisher Friend Mobile Application (FFMA) of MS Swaminathan Research Foundation (MSSRF).

4.2.2 Coral Bleaching Alert System

Coral Bleaching Alert System (CBAS) provided 122 advisories on Coral Bleaching Alerts for Andaman, Nicobar, Lakshadweep, Gulf of Kutch and Gulf of Mannar during April 2021 to March 2022. These advisories

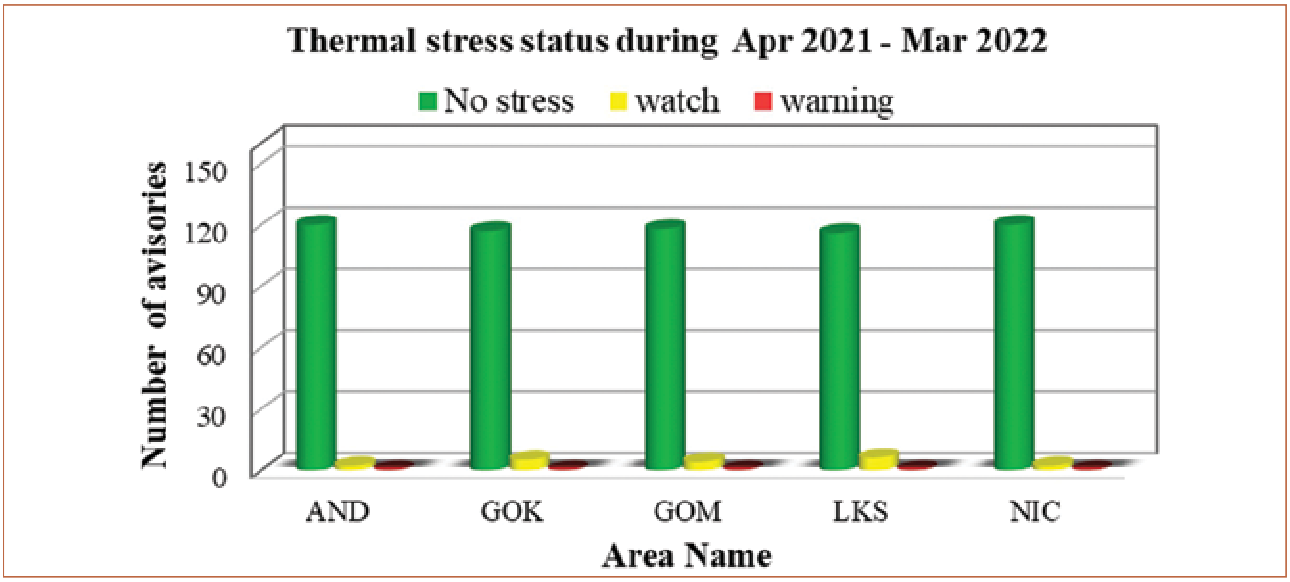


Fig 4.20 Total number of Coral Bleaching advisories generated and their alert status during 2021-22.

comprise HotSpots (HS) and Degree of Heating Weeks (DHWs), estimated using SST anomalies derived from satellite data on a bi-weekly basis. No warning was recorded during this reporting period. Coral bleaching advisories issued and Hotspot values are shown in fig. 4.20 and 4.21, respectively.

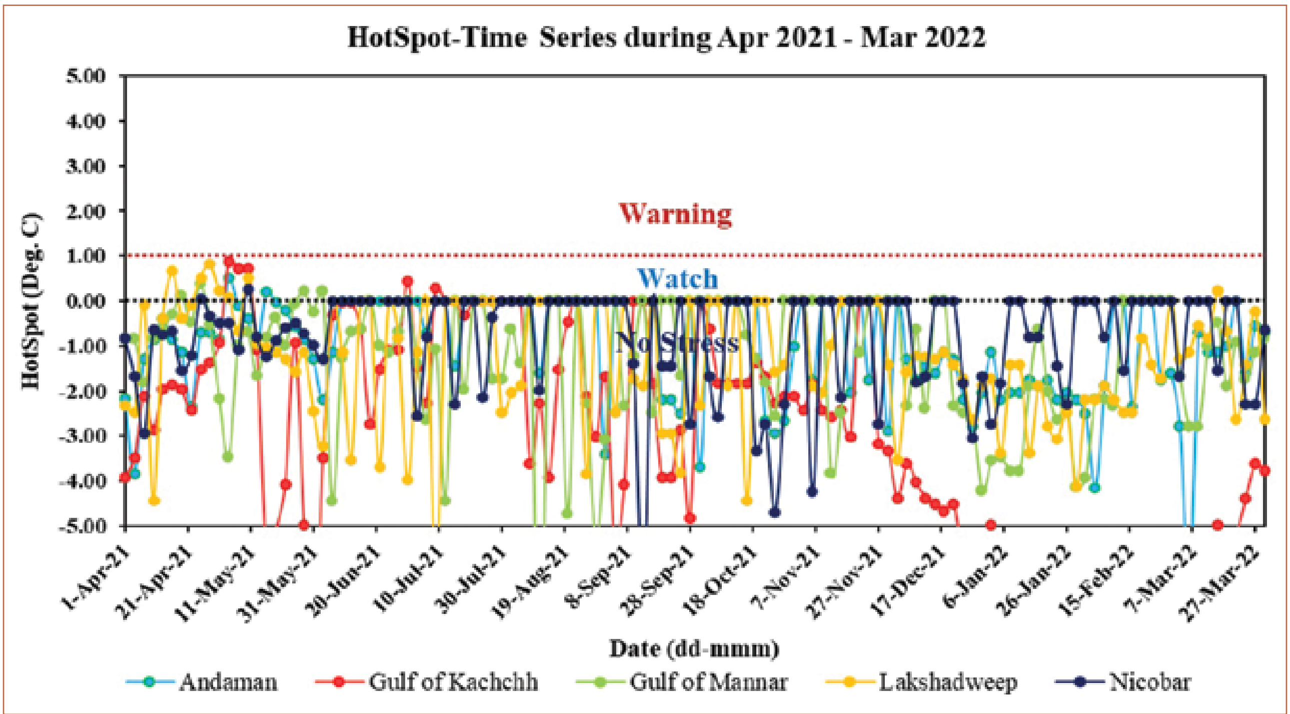


Fig. 4.21 Line-chart depicting variations of HotSpot (HS) values during 2021-22 pertaining to Indian coral environs.

4.2.3 Automatic Data Processing Chain (ADPC) and Algal Bloom Information Services (ABIS)

Ocean colour satellite products at near-real time are being generated and disseminated through Automatic Data Processing Chain (ADPC) for Indian Ocean region and other Indian Ocean countries. The ADPC provides both MODIS-Aqua (for ABIS, PFZ & TUNA) and VIIRS-SNPP (for PFZ & TUNA) on daily basis to provide near real time data. MODIS-Aqua based Algal Bloom Information Services (ABIS) is sustained, and information has been disseminated daily.

ABIS Product Generated	364 days
Alert issued	22 days
NRT ocean colour satellite products generated by ADPC	
MODIS-Aqua	350 days
VIIRS-SNPP	345 days

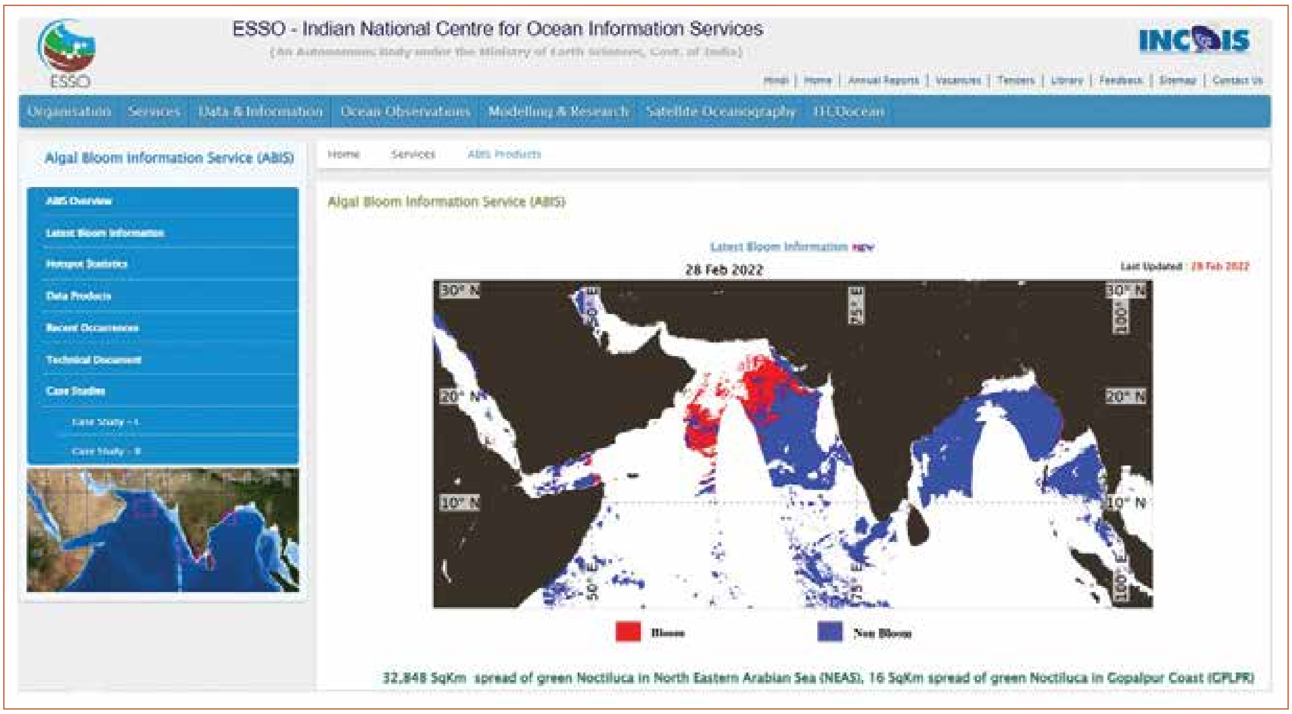


Fig. 4.22 A screenshot from INCOIS ABIS web page disseminating algal bloom information for 28 February 2022.

4.3. Data services

Data is the backbone for all research activities. INCOIS, designated as the National Oceanographic data Centre (NODC) by the International Oceanographic Data Exchange (IODE) Programme of the IOC, continued its data services and served heterogeneous oceanographic data to various stake holders in the country. The data centre sustained and strengthened the real-time data reception, processing, and quality control of in-situ and remote sensing data from a wide variety of ocean observing platforms such as Argo floats, moored buoys, drifting buoys, wave rider buoys, tide gauges, wave height meter, ship mounted autonomous weather stations, HF radars, XBT/XCTD, Met observations from NODPAC, dedicated scientific cruises, ADCP moorings and remote-sensing satellites. Most of the data received is being regularly disseminated to various operational agencies in the country using various means such as email/website/FTP in near-real time. The data centre continued to provide value added data products to various users. Details of data received in the present reporting period are provided in Table 4.4 (from remote-sensing platforms) and Table 4.5 (from in-situ platforms).

4.3.1. Operational Remote sensing data products

INCOIS established three Ground stations to meet the requirements of in-house operational advisory services and acquire data from AVHRR (Metop-1, NOAA-18 & NOAA-19), VIIRS (Soumi-NPP), MODIS (AQUA & TERRA) & OCM (Oceansat-2) sensors. Satellite data were distributed to the user community for Operational and R&D activities. Details of the remote sensing data products are given below in the Table 4.4.

Table 4.4 Details of remote sensing data holdings till date.

Satellite	Sensor	Products	Time period
MetOp- A&B NOAA-18&19	AVHRR	• L1b • Sea Surface Temperature • FOG • Cloud top Temp • Normalized Difference Vegetation Index (NDVI)	September 2006 to till date
Oceansat-2	OCM	• L1b • Chlorophyll-*a* • Total Suspended Sediments • Diffuse Attenuation Coefficient (Kd490) • Aerosol Optical Depth (AOD)	February 2011 to till date
Suomi-NPP	VIIRS, CrIS & ATMS	• L1b • Ocean Color (chlor_*a*, chl_ocx, Kd_490, par, pic, poc) • SST (Split Window, Triple Window) Other (Fire Points, FOG, NDVI, Cloud products etc...) • Short Wave (SW) • Medium Wave (MW) • Long Wave (LW)	May 2016 to till date

- **For external Users:** Operational Near-Real time data distribution to the ASIA-Pacific RARS (Regional ATOVS Retransmission Services) network in collaboration with IMD & NCMRWF.
- **Marine Fishery Advisories:** Dissemination of Real-time Remote sensing data of SST (AVHRR & VIIRS) and Chlorophyll-*a* (OCM-2 & VIIRS).
- **Data Assimilation:** SST (AVHRR & VIIRS) & Chlorophyll-*a* (OCM-2 & VIIRS) products are operational for near-real-time data assimilation as input to in-house operational models.
- **Coral Reef Mapping and Reef Health Monitoring:** Real-time Remote sensing data of Night-SST (AVHRR).
- Continuation of Off-line data sharing for R&D activities by Academic & Research institutions.

4.3.2. Oceansat-2 OCM data products

Oceansat-2 OCM product quality is enhanced with a moment-matching based de-striping algorithm that removes the residual striping noise observed in the data and released it to users as a second version product (Fig. 4.23). The data products from OCM-2 are available at 360m spatial resolution for regional studies, called local area coverage (LAC) products. From the OCM instrument to obtain quantitative information on ocean-colour variables e.g., chlorophyll-a concentration, vertical diffuse attenuation of the light (Kd) and total suspended matter (TSM) concentration, apart from ocean-colour information OCM data will also be useful for studying the aerosol Optical Depth (AOD).

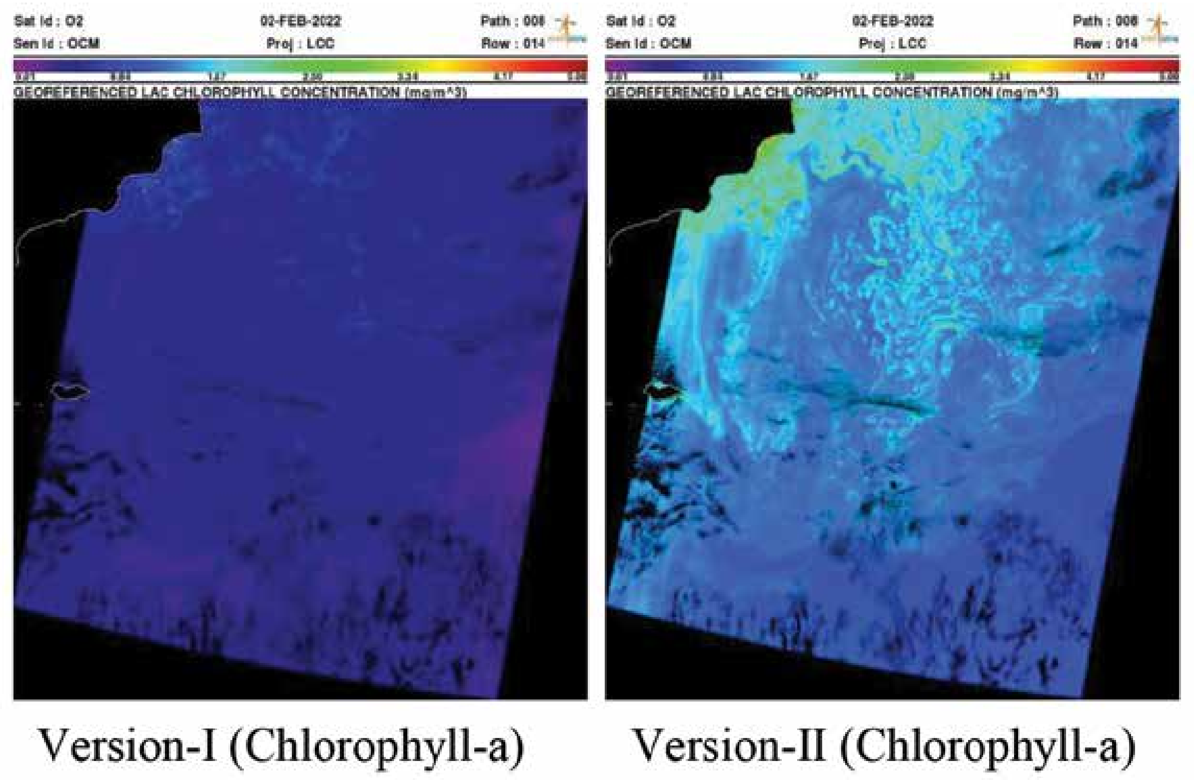


Fig. 4.23 OCM-2 Data Products

4.3.3. In-situ data

The data centre at INCOIS obtained and archived the real time in-situ data from the various ocean observing systems. The data centre also obtained and archived 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. Details of data received in the present reporting period is provided in Table 4.5.

Table 4.5 Details of data received from April 2021 to March 2022

Institute / Programme	Parameters	Period of Observation	No. of Platforms / Stations Reported	Status
NODPAC (Met Observations along Ship track)	Surface met parameters	Nov 2020 - Dec 2021	2760 observations	Archived
NODPAC (XBT data)	Temperature profiles	Sep 2018 – Dec 2019	918 profiles	Archived
NIOT - NDBP (Moored buoys)	Met-ocean parameters	Apr 2021 – Mar 2022	16 buoys	Added to the database
NIO & INCOIS (Drifting buoys)	Met-ocean parameters	Apr 2021 – Mar 2022	18 buoys	Added to the database
INCOIS (Ship-mounted AWS)	Met parameters	Apr 2021 – Mar 2022	29 stations	Added to the database

INCOIS (Wave rider buoys)	Wave parameters	Apr 2021 – Mar 2022	17 stations	Added to the database
INCOIS (Tide gauges)	Sea level	Apr 2021 – Mar 2022	33 stations	Added to the database
INCOIS-NIOT (Tsunami Buoy)	Sea level	Apr 2021 – Mar 2022	03 stations	Added to the database
NIOT (HF RADAR)	Currents	Apr 2021 – Mar 2022	05 pairs of stations	Added to the database
INCOIS (Argo CTD)	Temperature and Salinity	Apr 2021 – Mar 2022	28339 profiles	Added to the database

In-situ data was served to different user groups based on their request. In total 143 data requests were received from various government organizations, research institutes, academic institutes, and commercial

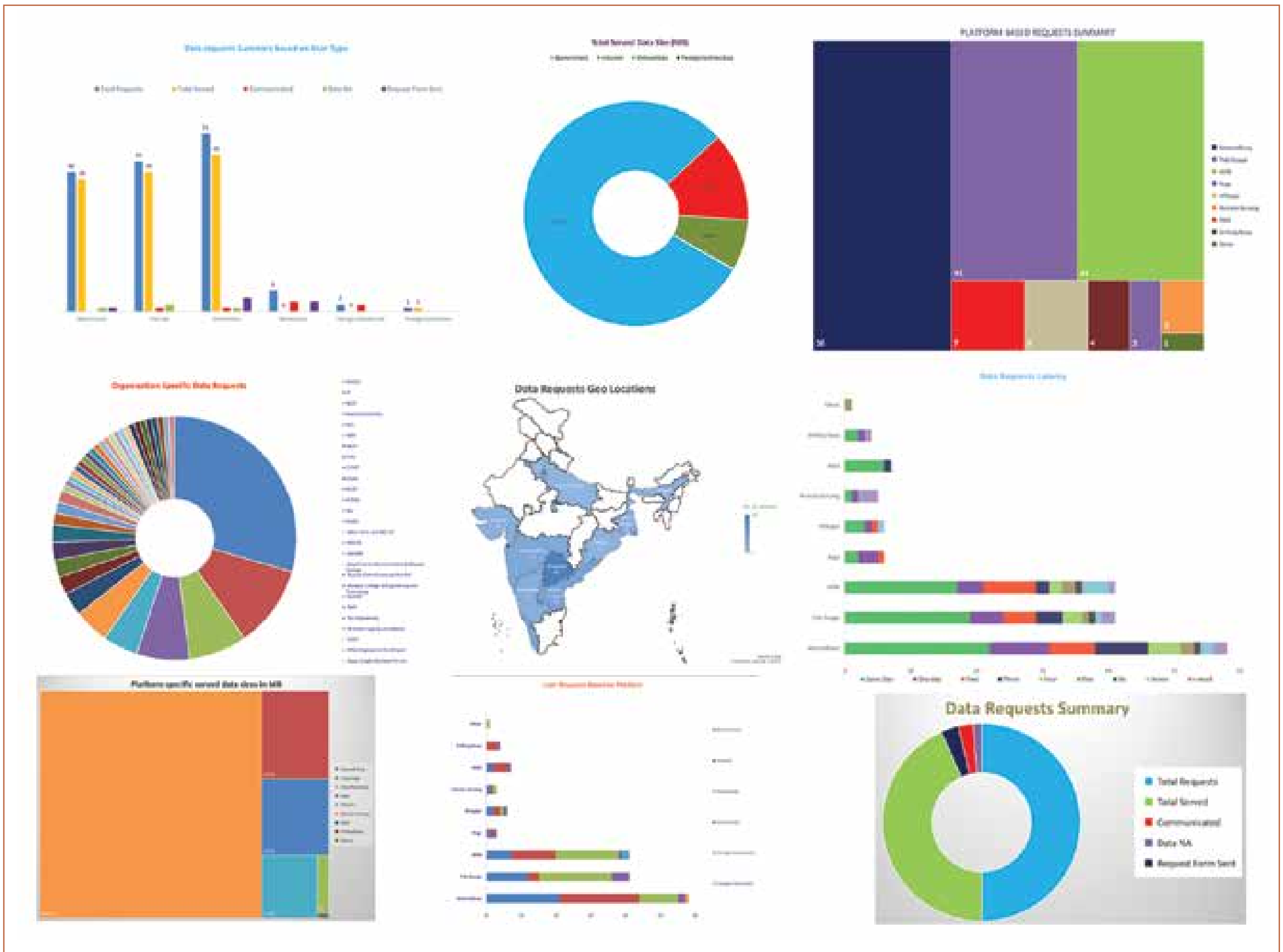


Fig. 4.24 Summary of In-situ data request provided to different user groups

agencies. INCOIS provided data for 124 requests. A detailed analysis of data request processed in terms of size, number, type and latency in providing the data is given in Fig. 4.24.

4.3.4 Digital Ocean

Digital Ocean (www.do.incois.gov.in), an interactive data analysis, visualization and analysis platform allows for downloading available data (in-situ and spatial) and on-fly analysis results in various formats and the details for the year 2021-22 are as follows.

- Total number of registered users = 644
- New registrations = 345
- Workspace created = 106
- Data download requests = 69
- Data download size = 82 GB
- Average bandwidth usage per day = 232 MB

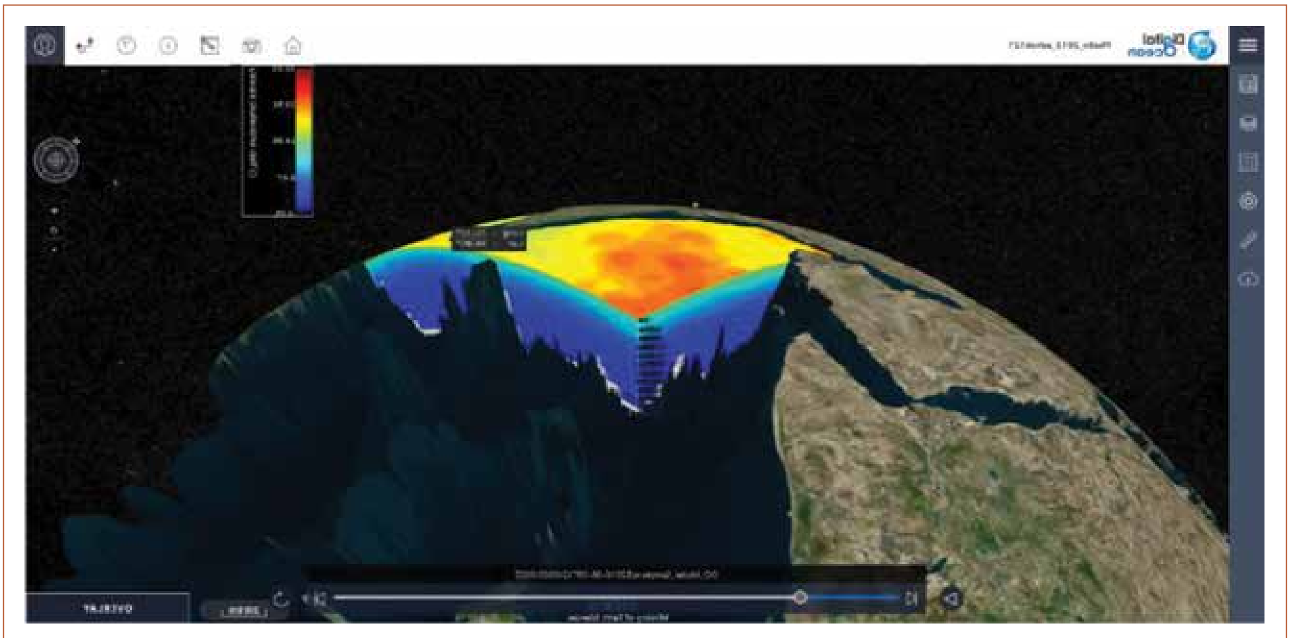


Fig. 4.25 3-D visualization of Ocean temperature

4.4. Information & Communication Technology (ICT) Services

ICT Division's mission is to deliver information and communication technology services that enable the operations, R&D, and functions of INCOIS. It provides reliable, high-quality solutions and products to support INCOIS missions. Broader services are Computing Facilities, Application Software Development and services, Communication Facilities, Engineering Services and Estate Management.

4.4.1. Computing Facilities

ICT provides mission-essential enterprise-wide computing services such as web hosting, administrative computing, networking, security monitoring, High-Performance Computing systems and supercomputing support to INCOIS research and forecasting missions. INCOIS data centres hold the capacity for more than 150 high-end servers and support a wide range of technologies. It includes more than 415 TB storage, ERP servers, FTP server, web and application servers, Live Access Server, workstations, desktops, laptops, link load balancers, application load balancers, DNS, firewalls, core switches, edge switches and a 45 km long campus-wide networking. The network and the compute infrastructure are redundant to avoid any single point of failure.

ICT division initiated various tenders for the upgradation of enterprise storage, Computing Infrastructure of Operational Ocean Services and technology refreshment of existing INCOIS Web Environment.

4.4.2. Application Software Development and Services

4.4.2.1. INCOIS Website

INCOIS website (https://incois.gov.in) is the primary medium to disseminate ocean information on the products/services. This responsive website enables the web-based online delivery system to facilitate the users across multiple languages. It has WebGIS capabilities to deliver Ocean information and advisory services on different spatial and temporal resolutions. The following are the critical implementations on INCOIS Website.

- INCOIS hosted the MoES Earth System Science Data (ESSD) Portal. It aims to link and deliver the geo-spatial datasets across MoES institutes.
- Joint OMNI-RAMA Indian Ocean Data Portal developed by INCOIS jointly with NIOT and PMEL-NOAA. It was launched during the Signing Ceremony of the RAMA-OMNI Moored Buoy Implementing Arrangement between NOAA and MoES. This portal facilitates the unified framework to deliver data from OMNI and RAMA buoy networks in the Indian Ocean.
- GO-Live of e-Office – A digital workplace solution was implemented at INCOIS from 30 April 2021 onwards.

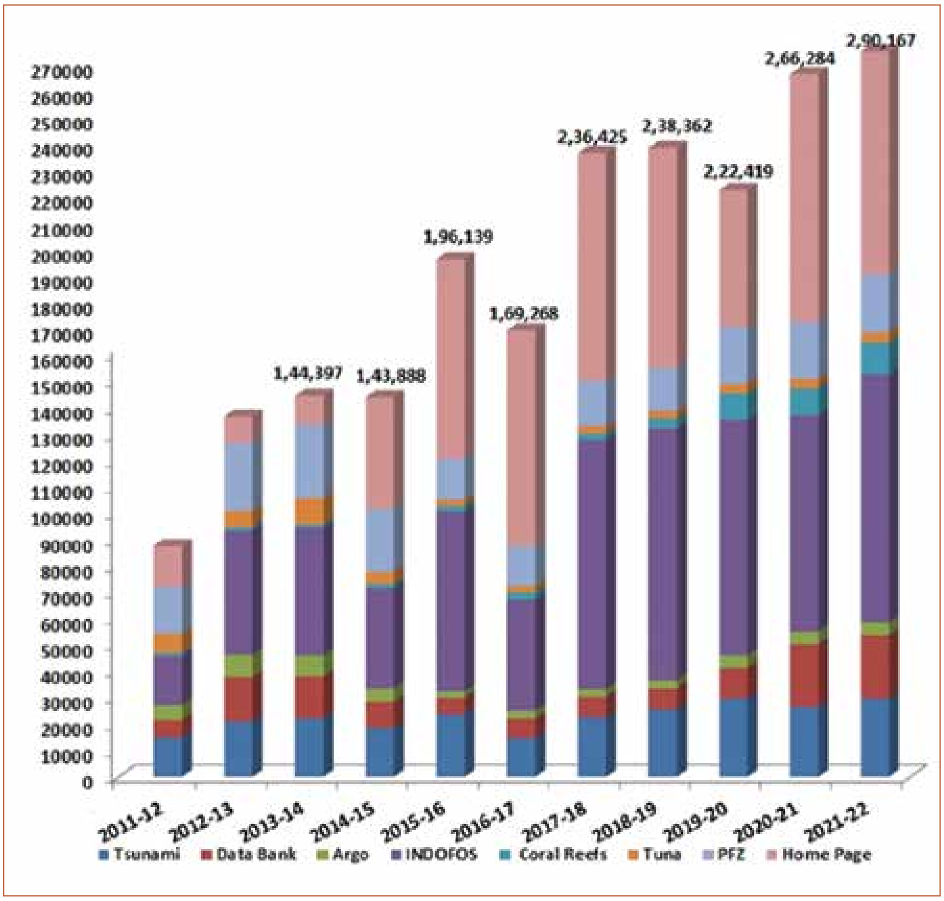


Fig. 4.26(a) Growth of visitors to INCOIS web page over the past 16 years

- INCOIS hosted the online recruitment portal for various positions at INCOIS, MoES, NCPOR, NCMRWF, NCESS, IMD, CMLRE & NIOT organisations.
- INCOIS streamlined various web applications like Algal Bloom Information Service (ABIS), ITCOocean E-learning /Training Course website, report generation applications and Contributory Medical Scheme & Reimbursement applications.
- Released an online web application to support the student academic projects at INCOIS.

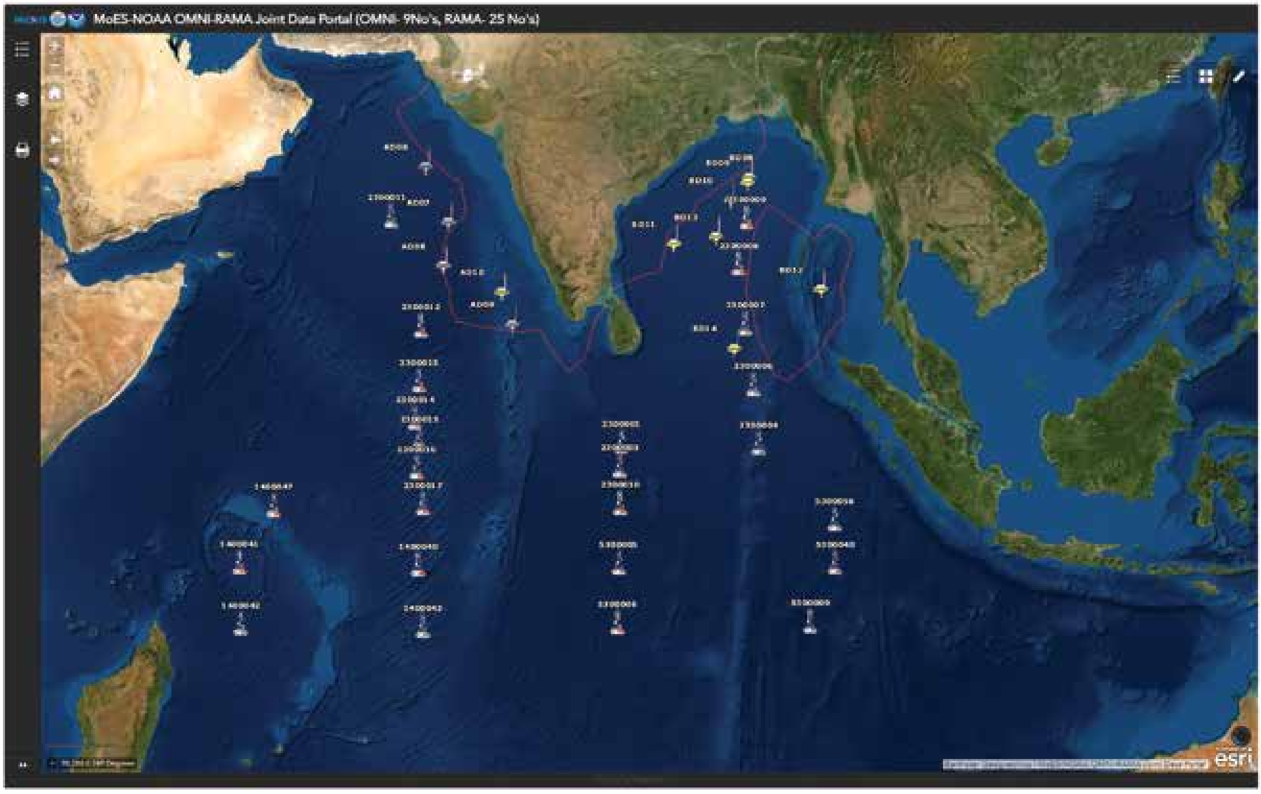


Fig. 4.26(b) MoES-NOAA OMNI-RAMA Joint Data Portal.

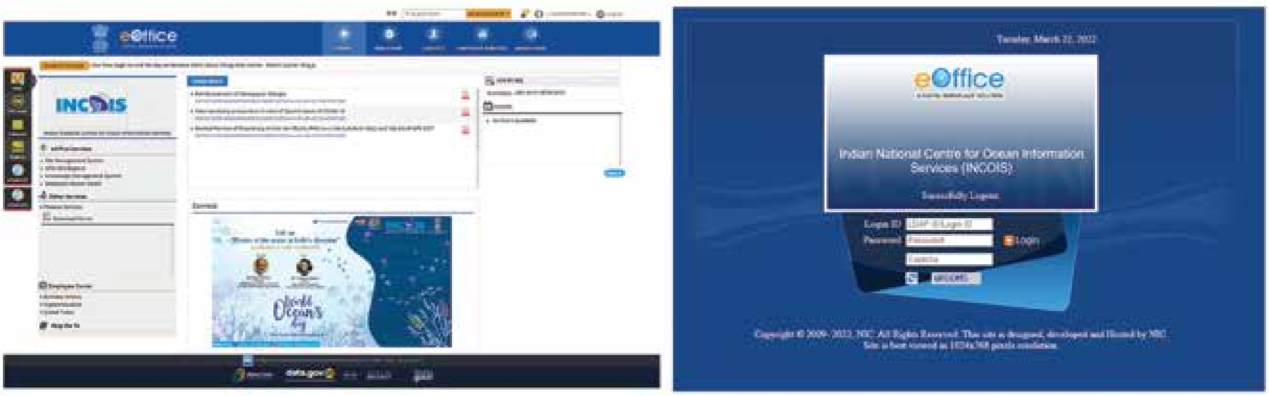


Fig. 4.26 (c) e-Office – A digital Workplace Solution

4.4.2.2. Tsunami Application Software and Website

The in-house team supports the mission-critical application software of the Tsunami Early Warning centre. The tsunami website (https://tsunami.incois.gov.in) is the primary medium that serves India and 25 Indian Ocean rim countries. During the reporting period, the tsunami application software delivered all tsunamigenic events (including 3 Indian ocean events) and successfully disseminated as per the Standard operating procedure (SOP) to the stakeholders using a multi-channel mechanism. As per the ICG/IOTWMS communique on the need for enhanced data sharing, INCOIS continued to share the tsunami buoys and tide gauges data in real-time with NDBC and IOC-Sea Level facility to support tsunami warning and analysis capabilities in the Indian Ocean region.

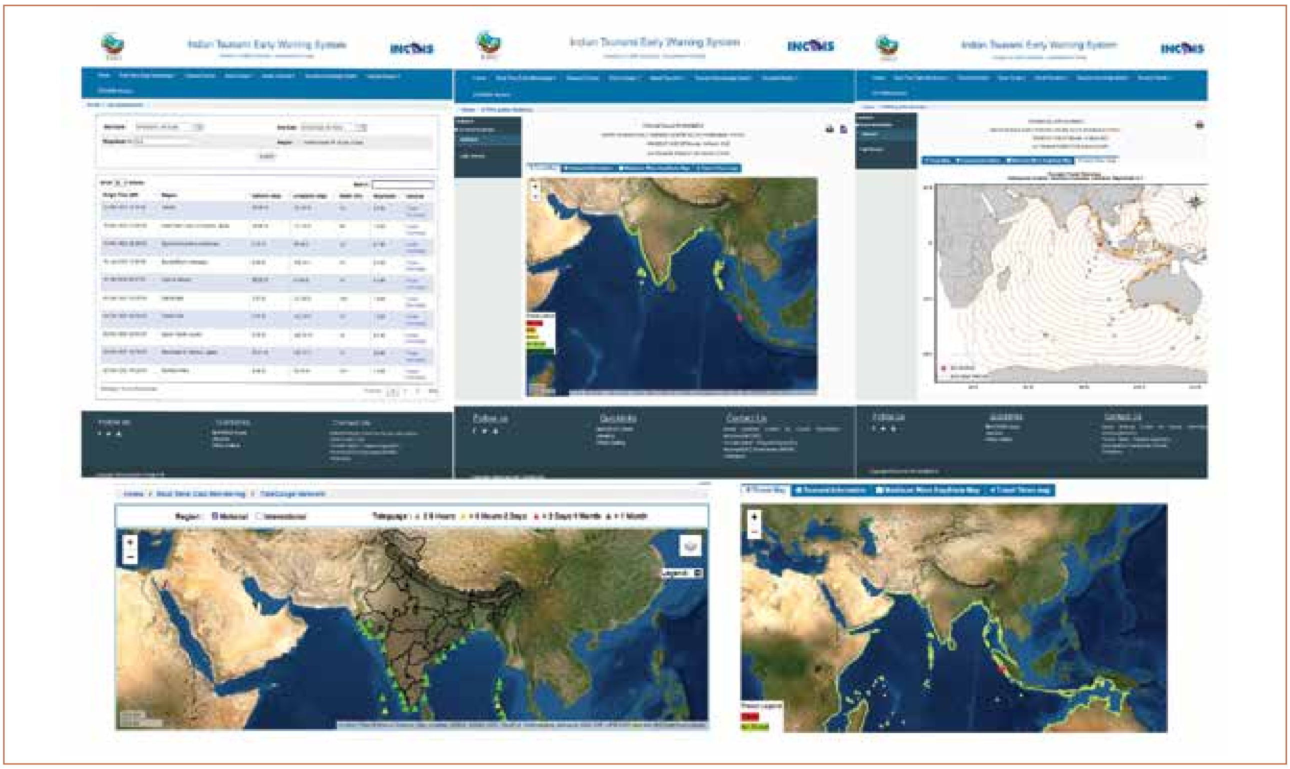


Fig. 4.27 From top to bottom: Tsunami Website showing Tsunamigenic Events list, National Tsunami Bulletin, Tsunami Travel time map, Tsunami webGIS Information for 25 rim Indian Ocean Countries and Sea-level monitoring facility

4.4.2.3. Earth System Science Data Portal (ESSDP)

On 27 July 2021, Union Minister Dr Jitendra Singh launched the MoES-ESSDP (Earth System Science Data Portal), an integrated digital web portal of MoES institutes, which makes data available on various themes of earth system science for public use.

The portal was developed and hosted by INCOIS and is available at https://incois.gov.in/essdp. The portal is aligned with the Digital India initiative of the Government of India to transform India into a digitally empowered society and knowledge economy. It facilitates the search and retrieval of earth system science data (of atmosphere, ocean, poles, geosciences and seismology) for societal benefit.

4.4.2.4. International Indian Ocean Science Conference (IIOSC) – 2022 Web Portal

INCOIS has developed and hosted the IIOSC–2022 web portal (https://iiosc2020.incois.gov.in.) with the latest web technologies. The IIOSC-2022 was sponsored by the Ministry of Earth Sciences (MoES), Govt. of India, and was held virtually during 14-18 March 2022. INCOIS co-hosted this event along with CSIR-NIO, NCPOR and Goa

Fig. 4.28 MoES Earth System Science Data (ESSD) Portal

University. ICT team coordinated the end-to-end conference process, such as the online user registrations, submission of abstracts, payment of registration fees, and online availability of conference proceedings. The conference was hosted on a virtual event platform (https://iiosc2022.virtualmnc.com) that supported parallel scientific sessions of various themes and large-scale exhibitions, which made unlimited scientific interactions possible, from having interactive talks to generating the scientific leads.

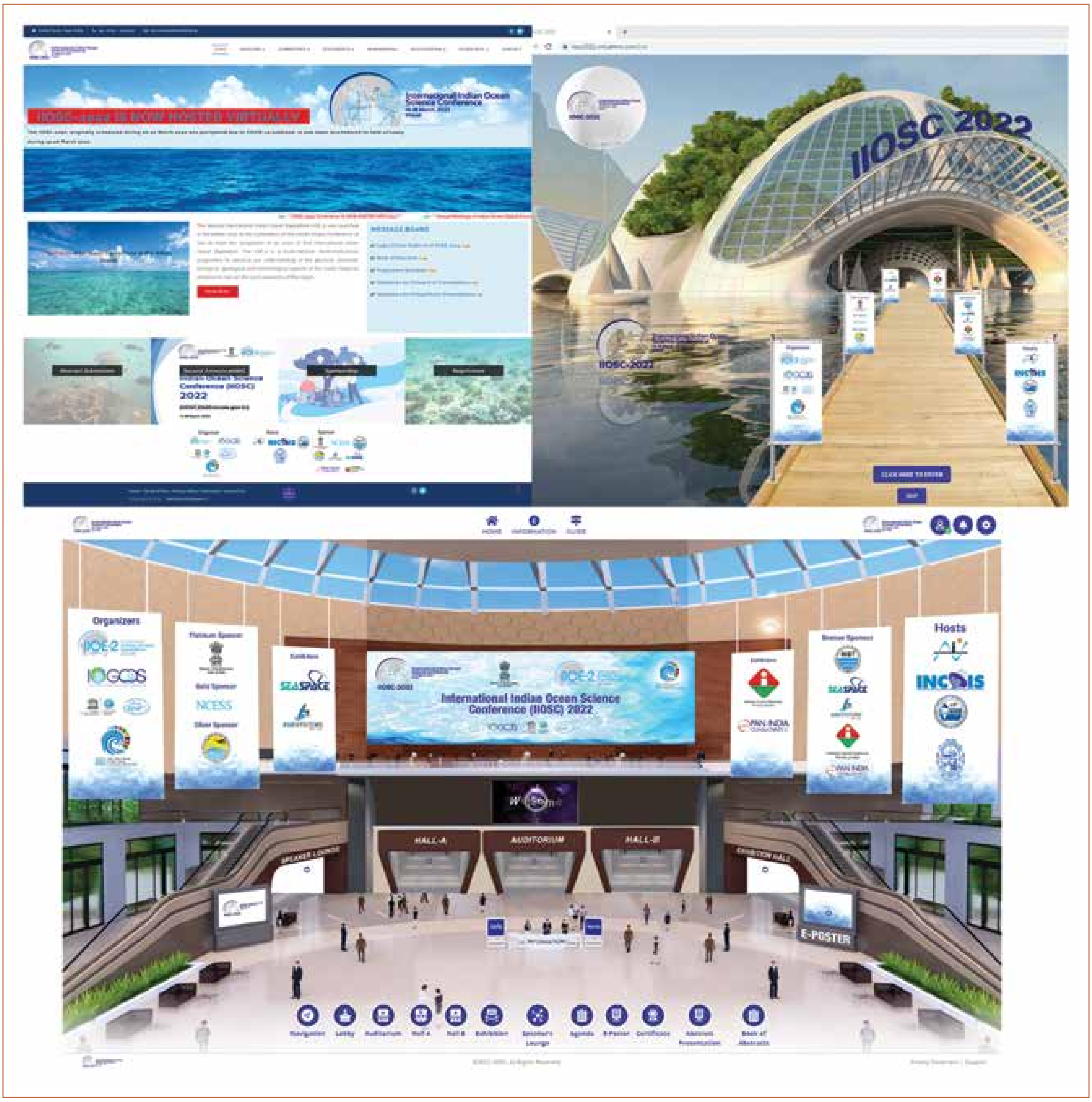


Fig. 4.29 IIOSC-2022 website at https://iiosc2020.incois.gov.in & Virtual Conference Platform

4.4.2.5. Common Alerting Protocol-Based Integrated Alert System-SACHET (सचेत):

In partnership with technical partner C-DOT, National Disaster Management Authority (NDMA) has developed a Common Alert protocol-based alerting system known as SACHET to disseminate alerts from various alert-generating agencies.

INCOIS has successfully integrated its alerting/early warning services for Tsunami, High-wave alerts, Swell Surge, etc., on the 'SACHET' web platform. This system can effectively send location-based INCOIS alerts across multiple vernacular languages to the public in disaster-prone areas during various natural oceanogenic hazards.

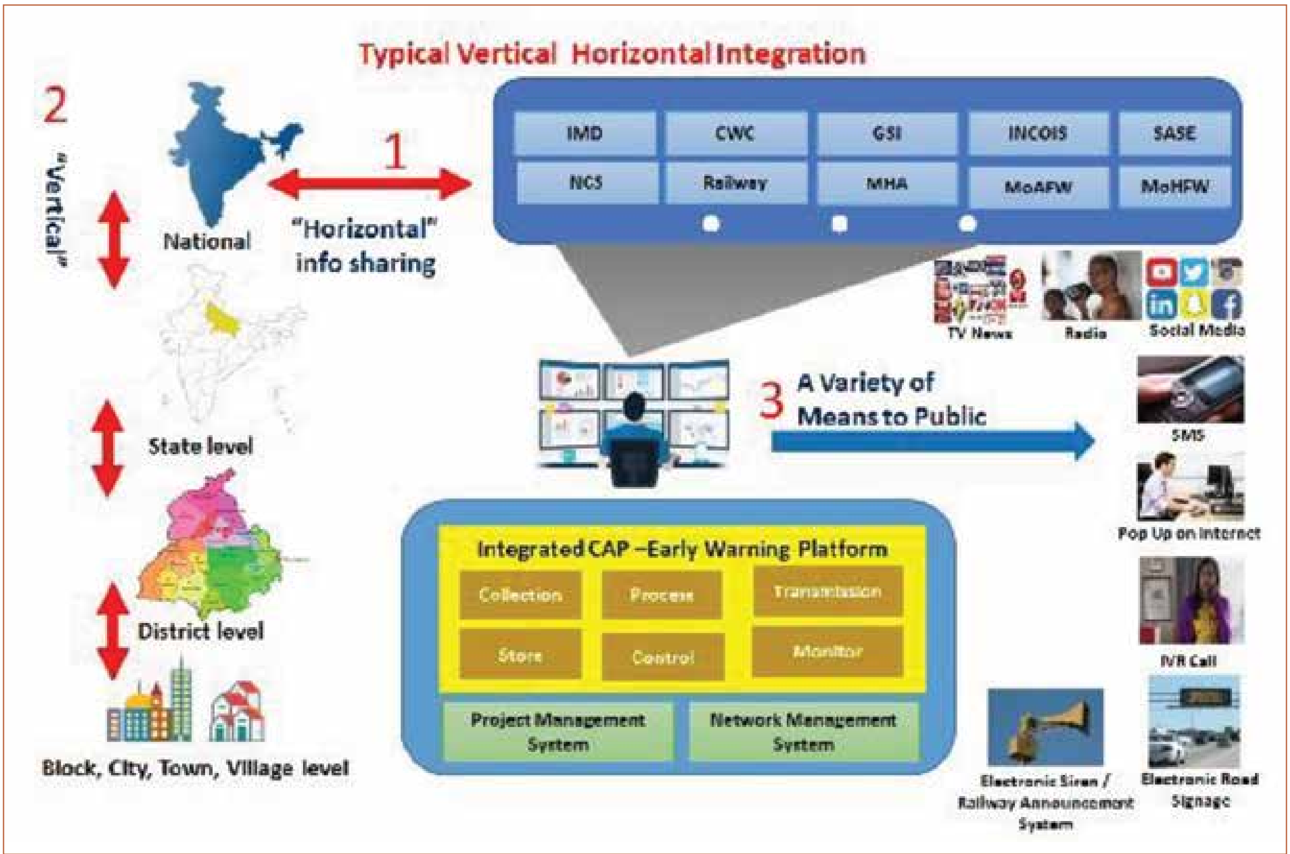


Fig. 4.30 SACHET Working Model

4.4.2.6. Second International Indian Ocean Expedition (IIOE-2) Website

The IIOE-2 is a multi-national, multi-institutional program to advance our understanding of the physical, chemical, biological, geological and climatological aspects of the Indian Ocean.

On behalf of Working Group-3, JPO (India Node), the ICT team developed, hosted and maintained the dedicated IIOE-2 website at https://iioe-2.incois.gov.in. This website endorsed about 45 scientific projects that align with IIOE-2 objectives. It has a GIS facility for better reaching to scientific data and expeditions.

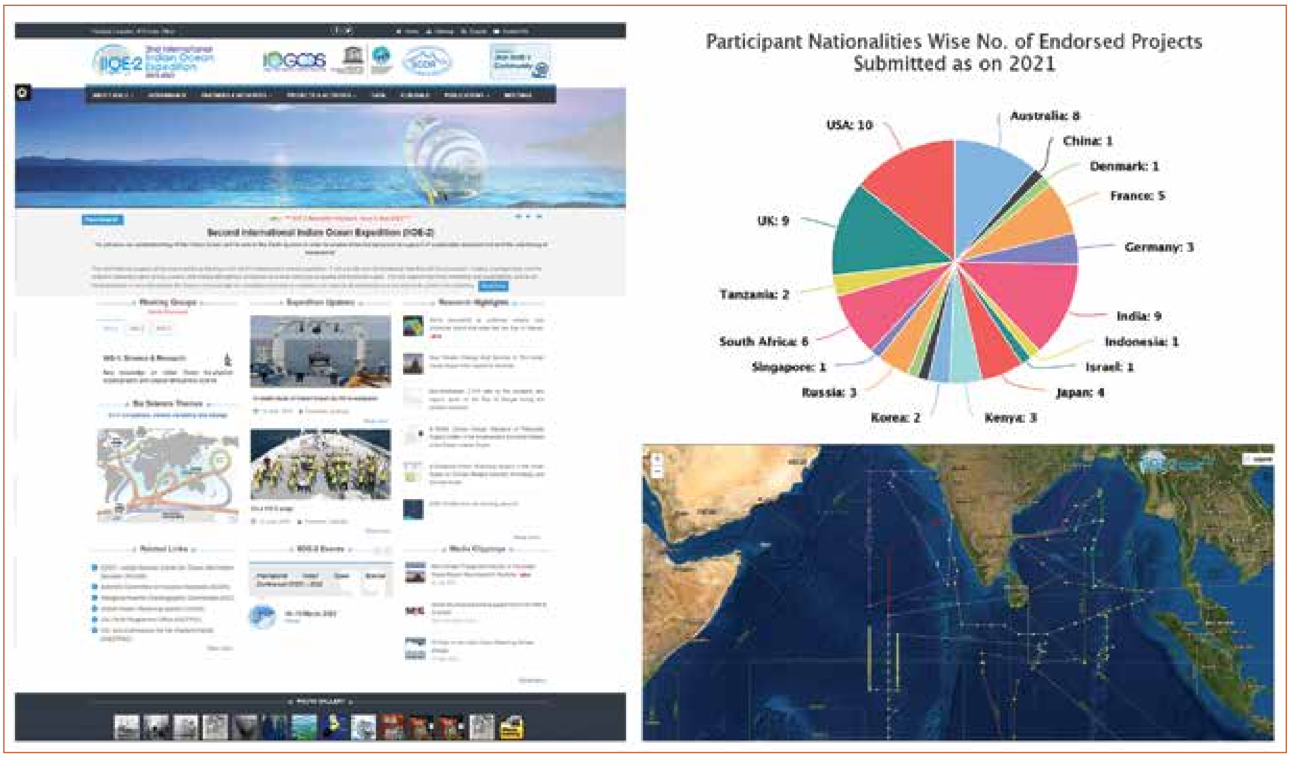


Fig. 4.31 IIOE2 Website; Participants from different countries; WebGIS Portal

4.4.2.7. Decision Support System for Storm Surge Service

A decision support system (DSS) for Storm Surge service is maintained in-house. During the reporting period, DSS handled seven events (5–cyclones & 3-Deep Depression events) and provided timely advisories to India Meteorological Department (IMD) for further dissemination to stakeholders.

Enhanced the decision support tool with the following capabilities:

- Developed the capability of issuing Storm Surge advisories to Oman, Iran, Bangladesh, and Myanmar countries. This led to issuance of advisory/graphic products to international countries during the Cyclone Shaheen (Arabian Sea region) and Deep Depression in March 2022 (Bay of Bengal region).
- Added the new GRID to cover Andaman & Nicobar Islands and issued advisories during the Deep Depression over AN islands in March 2022.

4.4.2.8. INCOIS Dashboard

INCOIS developed an "easy to visualise" dashboard for the calendar year 2021 with appropriate visualisation of graphs/ infographics giving the "state of INCOIS" that summarises the centre's performance during the calendar year. The summary includes quantitative information on advisories issued, users served, observing systems deployed, cruises participated, computing infrastructure, budget, publications, training programmers, etc.

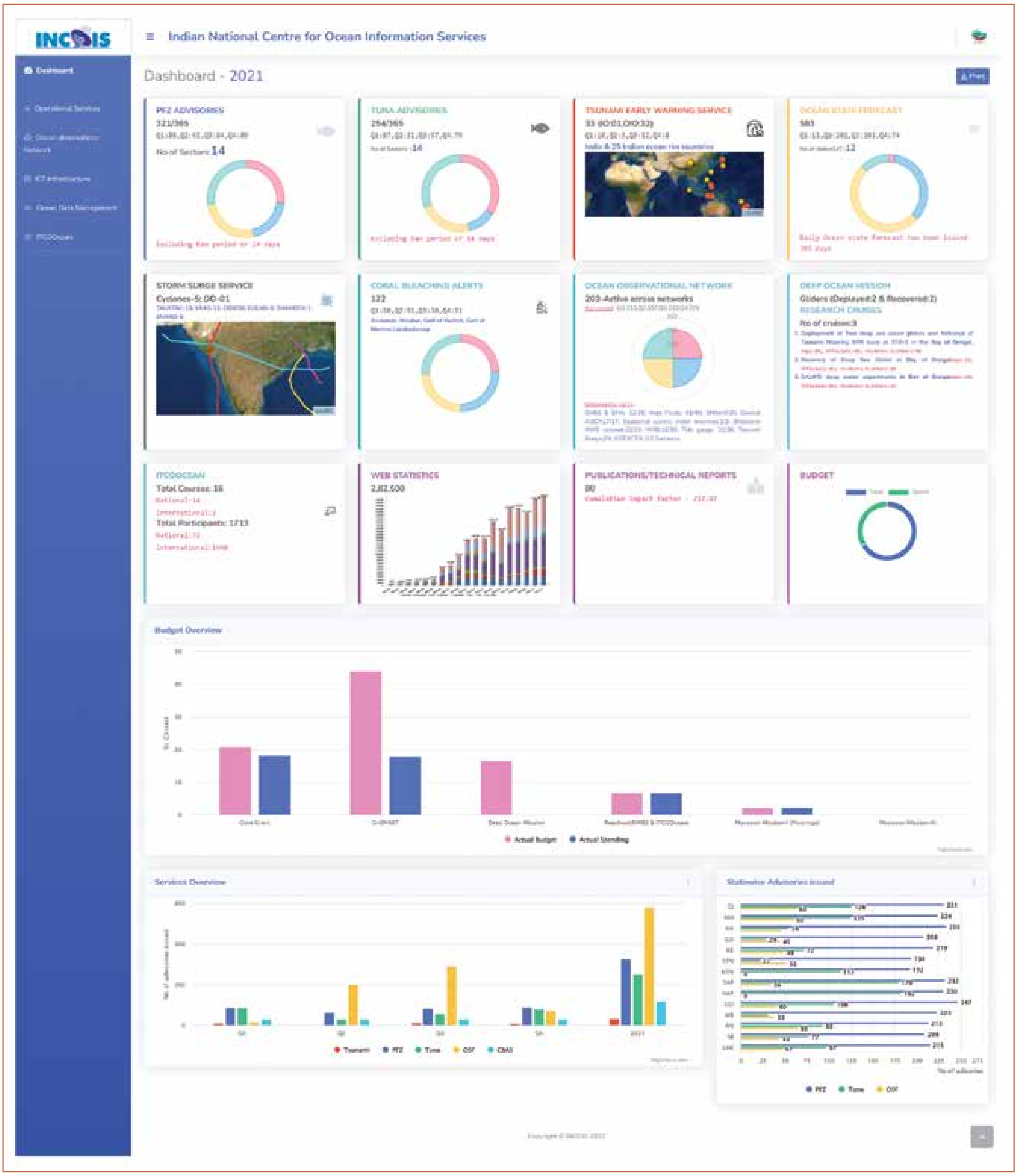


Fig. 4.32 INCOIS Dashboard

4.4.3. Communication Facilities

- Maintained the communication/network facilities such as the state-of-the-art satellite and VSAT communication hub to receive continuous data from Tide gauge network, AWS, Wave rider buoy network and other observational platforms used by INCOIS services. These communication channels include INSAT (MSS & DRT) Hub Stations, VSAT aided Emergency Communication System (VECS) network for the State Emergency Operational Centres (07 EOCs), Service Data Adaptation Protocols (SDAP), NPP and Oceansat-2 ground stations.

- ICT team continued to maintain a network of 36 tide gauges installed along the Indian mainland and islands coast to monitor the sea level with an uptime of 98%.
- Maintained the 100 Nos of Digital Display Systems (DDS) and contributed to the dissemination of INCOIS services such as PFZ, OSF and Tsunami Advisories.

4.4.3.1. Establishment of INSAT Communication with Autonomous Coastal Observatory System

INCOIS successfully integrated, tested, and established the INSAT-UHF & GPRS Communication for the coastal buoy deployed at Kochi. The necessary configurations were made at INCOIS DRT Hub to receive real-time data.

Fig. 4.33 Coastal Buoy Installation, testing of Communication channels (INSAT & GPRS)

4.4.3.2. Upgradation of Oceansat ground station

INCOIS, in collaboration with ISRO, successfully upgraded the existing Oceansat-2 ground station to receive the upcoming Oceansat-3/3A satellite data. Oceansat-3 is expected to be launched in 2022 by ISRO and will provide continuity to operators of Ocean Colour Monitor (OCM) and enhanced ability in applications by way of simultaneous Sea Surface Temperature (SST) measurements.

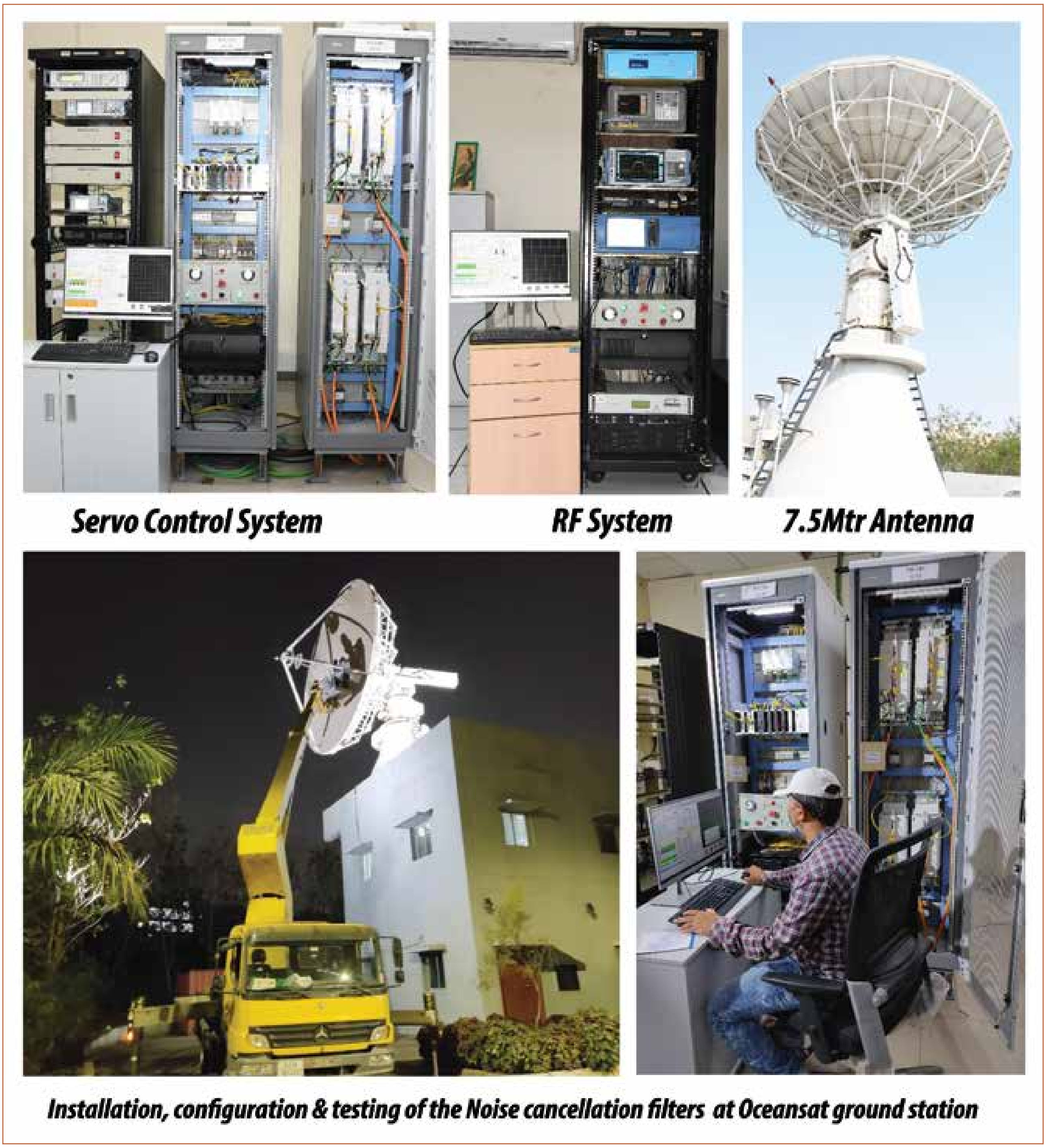


Fig. 4.34 Installation, Configuration and Testing of Oceansat-3 communication at Ground station.

4.4.3.3. Upgradation of VSAT's in SMA & GNSS Andaman & Nicobar Network

INCOIS successfully upgraded 42 VSATs at Strong Motion Accelerometer (SMA) & Global Navigation Satellite System (GNSS) observatories and 7 Emergency Operational Centers (EOCs) at Andaman & Nicobar Islands with new technology (DVB-S2). This ensures the real-time connectivity of the network to receive data to the Tsunami Early Warning Centre and connectivity of VSAT Aided Emergency communication (VoIP facility, Electronic Display Boards and Web Access) established for 7 EOCs at Andaman & Nicobar Islands.

Fig. 4.35 Observatory equipped with latest VSATs at Andaman & Nicobar SMA & GNSS Networks

5

APPLIED RESEARCH AND RESEARCH TO OPERATION

5 APPLIED RESEARCH AND RESEARCH TO OPERATION

5.1 Enhancement of Tsunami services

5.1.1 Tsunami Modelling: Towards "UNIFIED" Approach

For operational tsunami forecast in the Indian Ocean, the Indian Tsunami Early Warning Centre (ITEWC) currently utilizes pre-computed model results. Those results are computed for earthquake sources in the two well-known subduction zones in the Indian Ocean (Andaman-Sumatra and Makran) using TUNAMI-FF 2011 model, which is customized for the Indian ocean. For earthquakes occurring outside the Indian Ocean, the TUNAMI-2011 model is launched in real-time to model tsunami propagation. To model the inundation level in coastal regions, another model, TUNAMI-N2 is used. But, TUNAMI-N2 model is quite computation-intensive hence is not feasible to be used in real-time, which limits the operational capability of ITEWC to extend its services to regions other than the Indian Ocean and provide real-time coastal inundation for the Indian coast. To overcome these limitations, INCOIS decided to move towards a unified modeling approach of using a single model for operational forecast instead of multiple models. As a part of this, the ADvanced CIRCulation model (ADCIRC) for operation tsunami forecast has been ported to Mihir High-Performance Computing (HPC) environment, which can be used for both open-ocean tsunami propagation and coastal inundation and also can be launched in real-time based on available source parameters. The Finite Element Mesh (FEM) has been generated with a 5 km spatial resolution

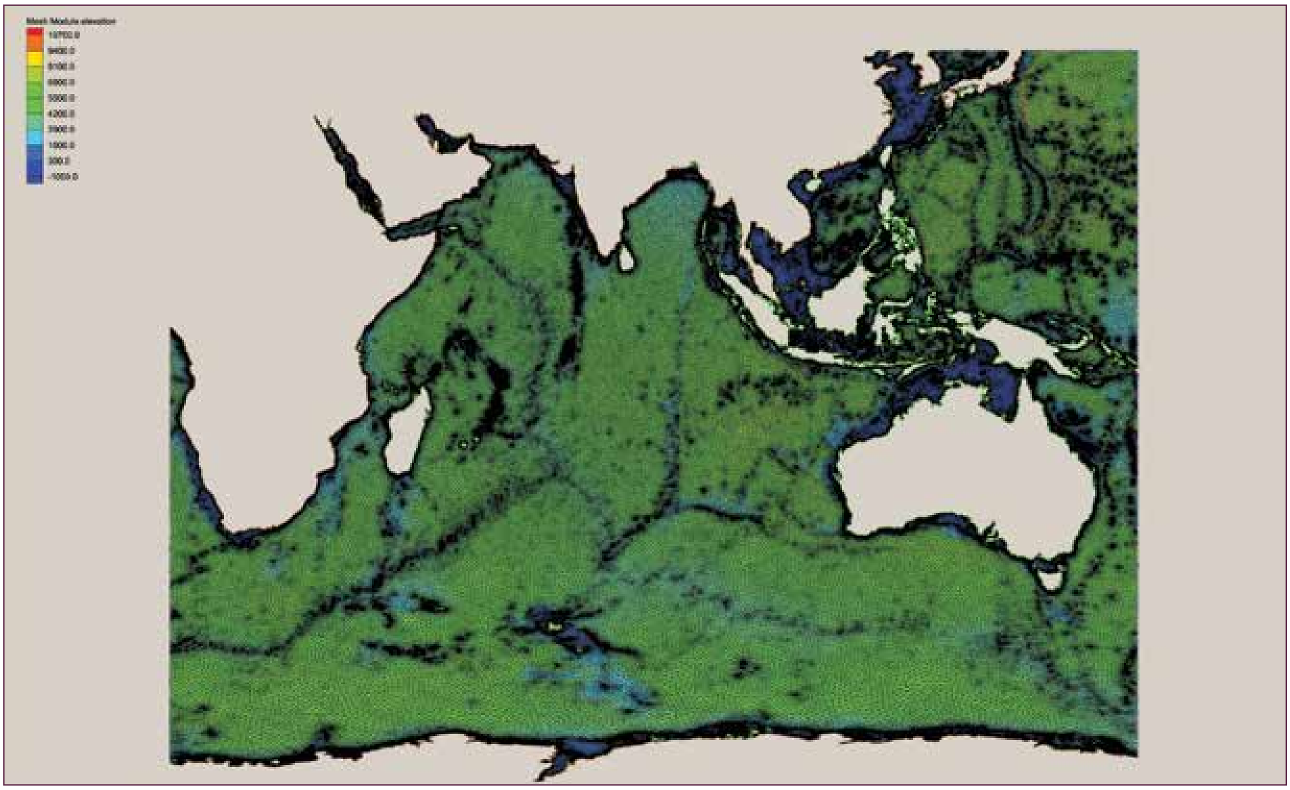


Fig. 5.1 Finite Element Mesh (FEM) with 5km resolution covering the entire Indian Ocean.

for the entire Indian Ocean modeling domain extending up to Antarctica, South-East Africa, and the South China Sea, as per operational requirements of India as a regional Tsunami Service Provider.

As part of Tsunami Hazard Assessment studies, the historical tsunamigenic earthquakes were simulated using ADCIRC for the test run of the model as listed in Table 5.1.

Table 5.1 Source parameters used for Historical Earthquakes in the Tsunami simulations using ADCRIC

Parameters	Sumatra 2004	Car Nicobar 1881	Andaman 1941	Arakan 1762	Worst-Case
Source	Sumatra	Car Nicobar	North Andaman	Arakan	Car Nicobar
Longitude	95.85°E	92.43°E	92.5°E	94.0°E	92.43°E
Latitude	3.32°N	8.52°N	12.1°N	19.0°N	8.52°N
Magnitude	9.3 Mw	7.9 Mw	7.7 Mw	8.8 Mw	9.3 Mw
Slip	15 m	5 m	5 m	10 m	15 m
Fault Length	1200 km	200 km	200 km	700 km	500 km
Fault Width	150 km	80 km	80 km	125 km	150 km
Strike Angle	345°	350°	20°	320°	345°
Dip Angle	15°	25°	20°	20°	15°
Rake Angle	90°	90º	90º	90°	90°
Focal Depth	20 km	15 km	30 km	10 km	20 km

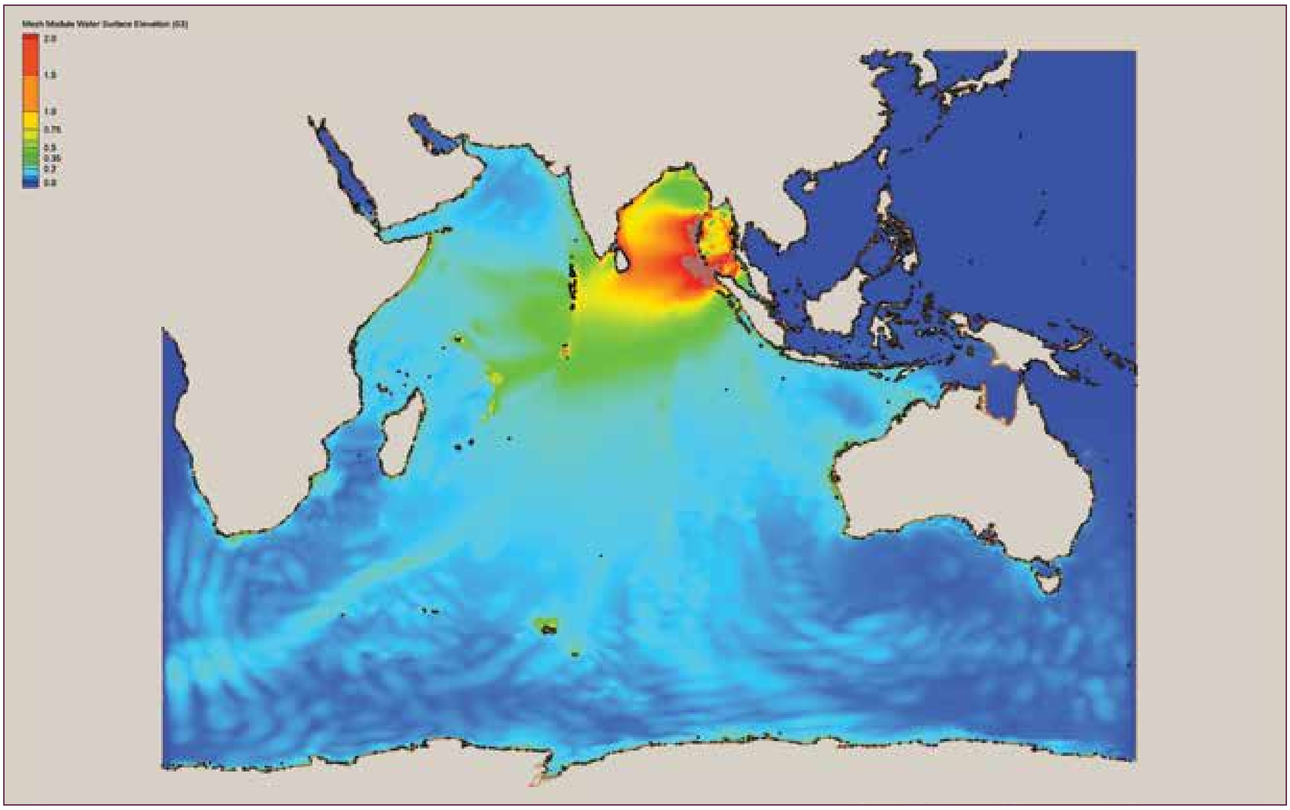


Fig. 5.2 Deepwater maximum wave amplitude map in the simulation of the December 26, 2004, Tsunami, using ADCIRC.

5 APPLIED RESEARCH AND RESEARCH TO OPERATION

5.1.2 Tsunami genesis and source characterization in the Indian Ocean

As a part of the Tsunami Ready Program, tsunami genesis and tsunami risk assessment studies have been taken up to enhance preparedness for tsunamis in the Indian Ocean region. A master catalogue for seismicity analysis and source zonation has been compiled from various sources comprising NCS, ISC, USGS, and Harvard CMT catalogues for the entire Indian Ocean covering Andaman-Sumatra and Makran subduction zone.

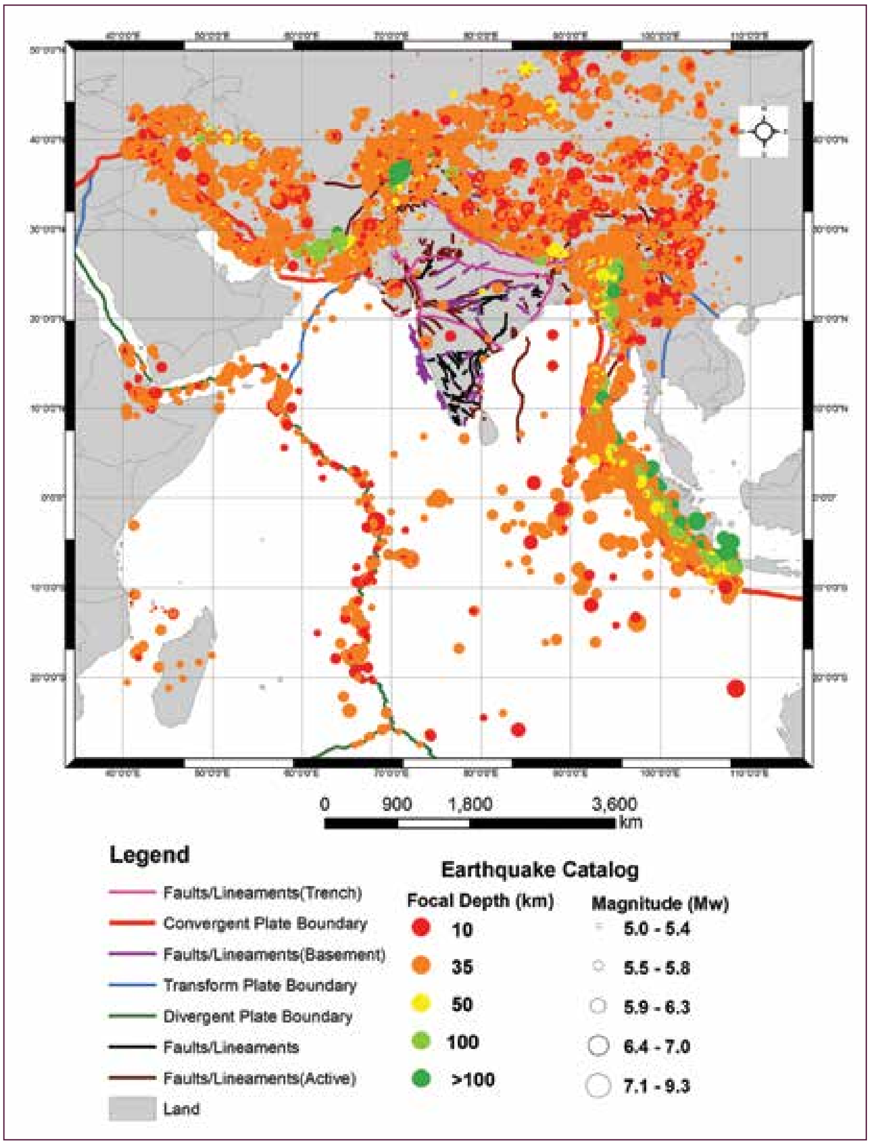


Fig. 5.3 Historical Seismicity and Fault/Liniments in the Indian Ocean (IO), including Andaman-Sumatra &Makran subduction zones

5.1.3 Tsunami shadow zone analysis for Andaman & Nicobar Islands

As per the INCOIS Research Advisory Council (RAC) suggestion to focus more on the near-field tsunami regions like Andaman and Nicobar islands, INCOIS is performing a tsunami hazard assessment in this region from the local tsunamis with available datasets. As a part of this effort, the tsunami shadow zone analysis for the Andaman and Nicobar Islands has been carried out using the Operational Open Ocean Propagation Scenario Database (OOPSDB) at INCOIS. Identifying shadow zones is vital for the tsunami hazard assessment of the region. The OOPSDB was generated with unit sources (equivalent to M 7.5 earthquake with 1 m slip) covering both known subduction zones in the Indian Ocean, viz., the Andaman-Sumatra-Java subduction zone and the Makran Subduction zone. Each unit source simulation is computed with all stages of a tsunami from the origin and the propagation in the deep ocean to the arrival at the coast and estimates of wave amplitudes at deep water (~ 30 m water depth). The tsunami wave amplitudes can be estimated at the beach (~1 m water depth) from these deep-water amplitudes by applying Greens' law.

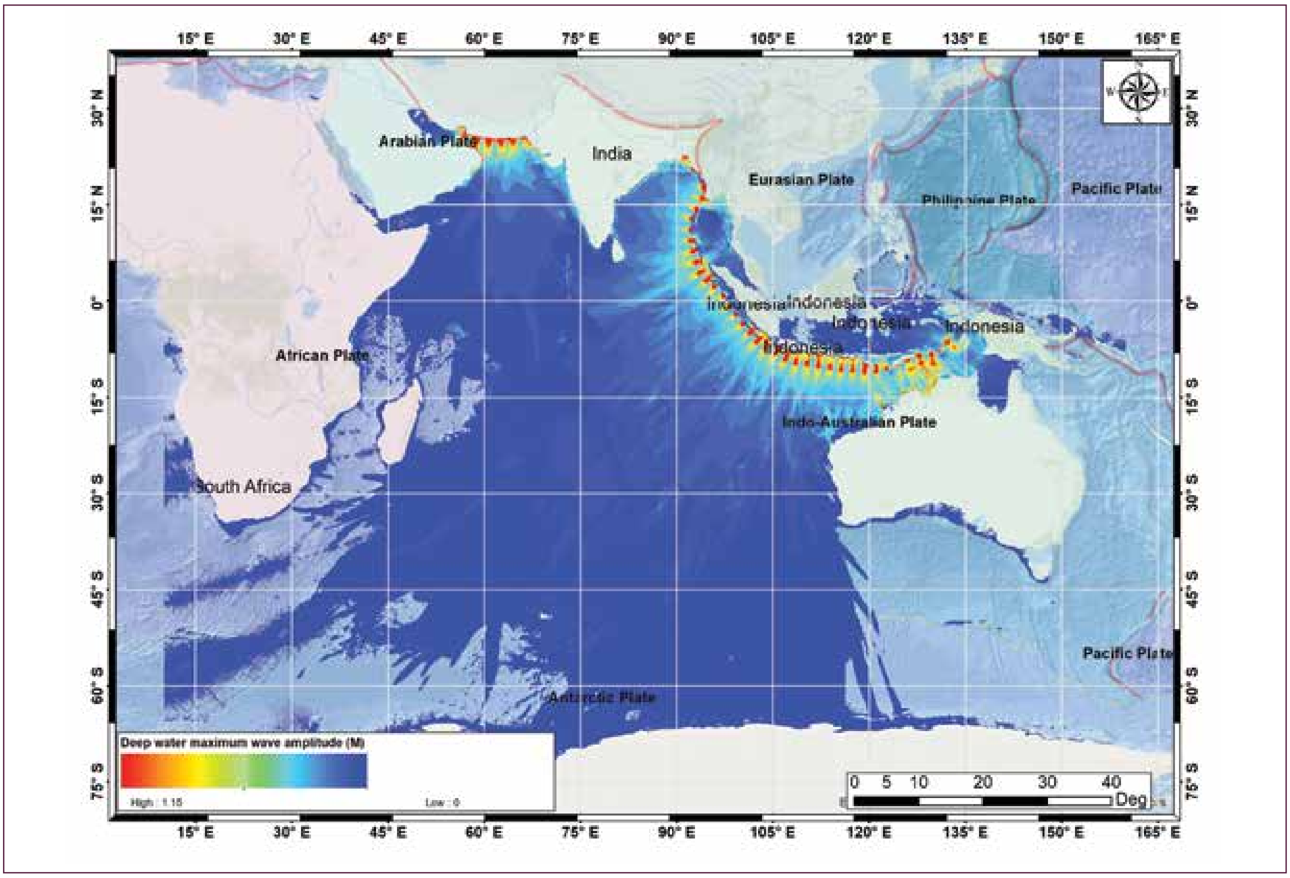


Fig. 5.4 Open Ocean Propagation Scenario Database (OOPSDB).

The model results at 30 m bathymetry from the OOPSDB were extracted to identify the Tsunami shadow zones at Andaman & Nicobar Islands. Deep Water Amplitude (DWA) zone with a magnitude less than 25 cm is considered as a TSZ.

5.1.4 Generation of blended high-resolution coastal topography and bathymetry for Andaman and Nicobar Islands and Tsunami inundation mapping

Andaman and Nicobar Islands are most vulnerable to tsunamis due to their proximity to the Andaman-Sumatra subduction zone. High-resolution topographic and bathymetry data for such a region are critical for inundation modeling and vulnerability mapping. However, the existing open-source data for the region are not useful for modeling the inundation level with sufficient accuracy and details. To overcome this limitation, hybrid topographic data

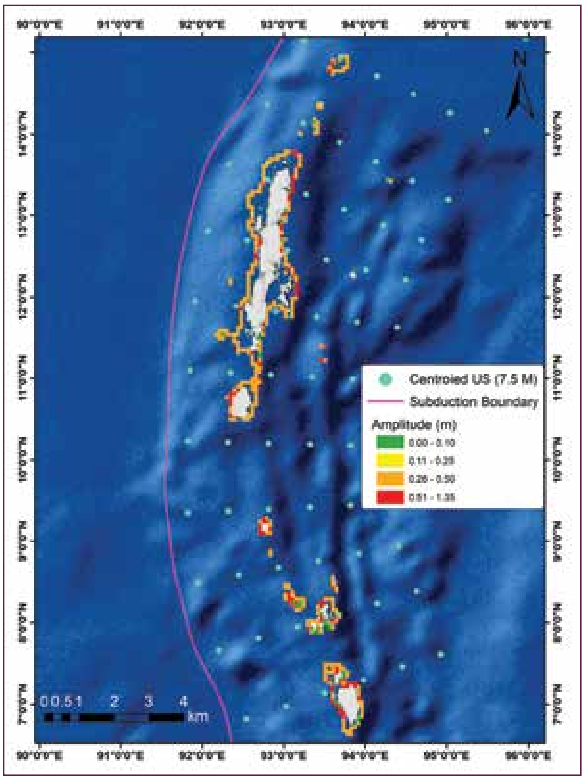


Fig. 5.5 Tsunami model results extracted at 30 m bathymetry from OOPSDB. Green (DWA < 10 cm), Yellow (DWA 10 cm to 25 cm), Orange (DWA 25 cm to 50 cm) and Red (DWA > 50 cm).

generated using Airborne Lidar Terrain Mapping (ALTM), Terrasar-X, and Carto-DTM data were obtained from the National Remote Sensing Centre (NRSC) and merged with available data from National Hydrographic Office (NHO) and National Institute Oceanography (NIO) to generate a high-resolution topography and bathymetry data of 200 m resolution. Fig. 5.6 depicts the merged data of Andaman and Nicobar. This merged data enhanced the accuracy of the inundation model results and the coastal vulnerability maps. Further, this blended data will be a vital input to other coastal circulation models.

The tsunami inundation map of Andaman for the 2004 Indian Ocean tsunami modeled using this high resolution topography and bathymetry data is presented in Fig. 5.7.

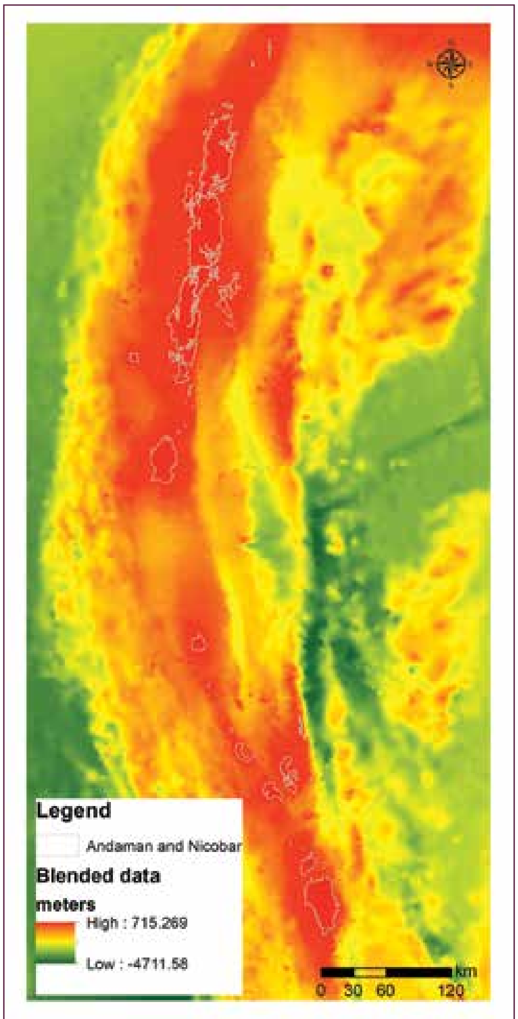


Fig. 5.6 The merged topography and bathymetry of the Andaman and Nicobar Islands.

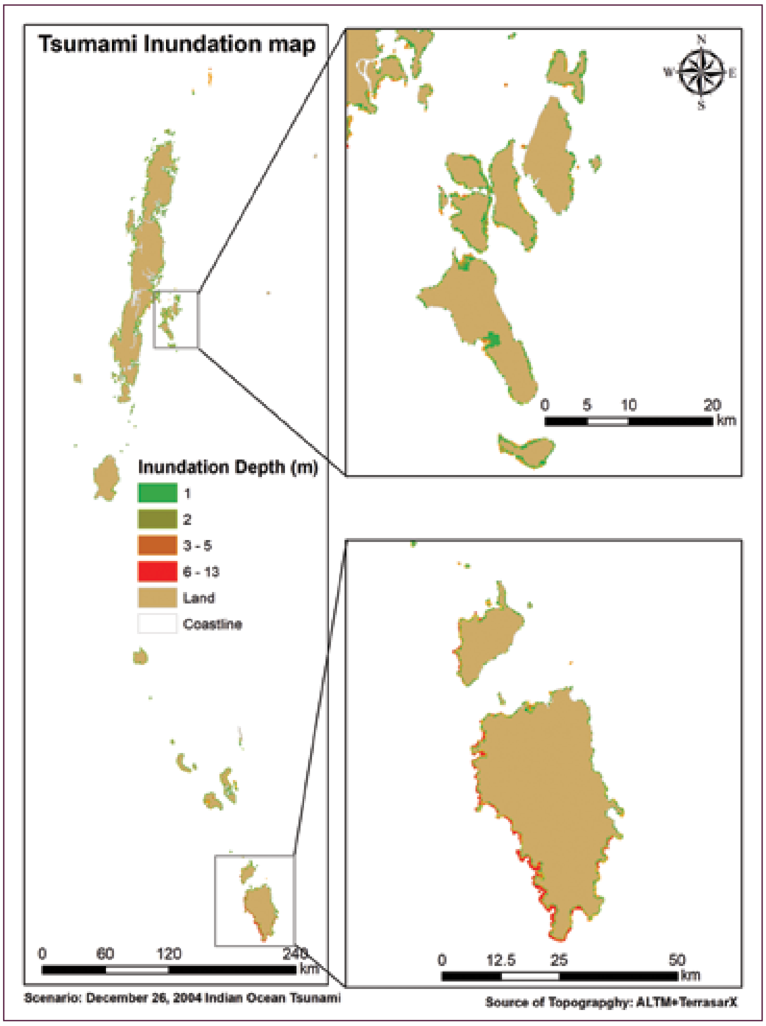


Fig. 5.7 Tsunami inundation map of Andaman and Nicobar Islands using new high resolution topography and bathymetry data.

5.1.5 Multi-Hazard Vulnerability Mapping of Andaman and Nicobar Islands

The Multi-Hazard Vulnerability Mapping (MHVM) for the entire Indian mainland coast was carried out earlier; now, with high-resolution topographic data availability, MHVM has been extended to the Andaman and Nicobar islands. MHVM for Andaman has been carried out using parameters such as the extreme water level return periods, sea-level change rate, shoreline change rate, and hybrid topographic data. A total of 119 maps pertaining to the Andaman and Nicobar Islands on a 1:25000 scale have been prepared. The MHVM map of Andaman and Nicobar is shown in Fig. 5.8. These MHVM maps represent the coastal zones exposed to oceanogenic inundation on 100-year recurrence. Hence, these are useful for coastal disaster management in planning and mitigation measures.

Fig. 5.8 1:25000 MHVM map of Andaman and Nicobar Islands.

5.1.6 Magnitude calculation without saturation using strong-motion data

Rapid and accurate earthquake magnitude estimation is the most critical aspect of an effective tsunami warning system. Recent improvements have been made in rapid magnitude estimation using P-wave scaling and the W-phase moment tensor method. Despite these improvements, magnitude estimation at local to regional distances remains a challenge, mainly due to the saturation of seismic broadband sensors for large earthquakes. Moreover, seismic instruments cannot reliably record long-period ground motions because ground tilts and rotations during heavy shaking contribute to baseline offsets, rendering integration to displacement unreliable. Due to these challenges, high-rate GNSS is identified as an alternative that records ground displacement, including co-seismic offset in a non-inertial frame. However, high-rate GNSS sensors are not as widely available as strong-motion sensors, and processing strong-motion data is straightforward and quick. Hence, a method is implemented which can be used to estimate magnitude quickly using near-field strong motion records not limited by the saturation issue.

This method is based on the fact that although baseline offsets present in strong motion records cannot be removed in real-time, their influence on the record can be minimized until at least the maximum displacement is observed through extremely long-period filtering. To identify the portion of the record where strong motion introduced by the earthquake is more significant than the error introduced by baseline offset, the JMA instrument intensity is calculated in real-time. The JMA intensity starts increasing at P wave arrival and continues to grow until the earthquake, and the resulting ground motion is still evolving. Only that time window of the strong motion record is used for magnitude calculation for which the JMA instrument intensity continues to grow. Beyond that, the baseline offset becomes a dominant feature in the recording and is not used for further analysis.

A python package (https://github.com/deep07004/MWS) was developed implementing this method and tested for a few historical events in Japan, Chile, and Alaska. Although peak ground displacement and hence magnitude estimated using this method are underestimated by 0.1 to 0.3, it provides a quick estimate mostly under 5 minutes of the origin time, which is far better than the estimate obtained from saturated broadband seismometer recordings.

5.1.7 Seismicity analysis of the North Andaman Island

The strong motion data from 17 stations in North Andaman has been analysed for the period of 2017 to July 2021 to determine the micro-seismicity of the region and to develop a local velocity model. The

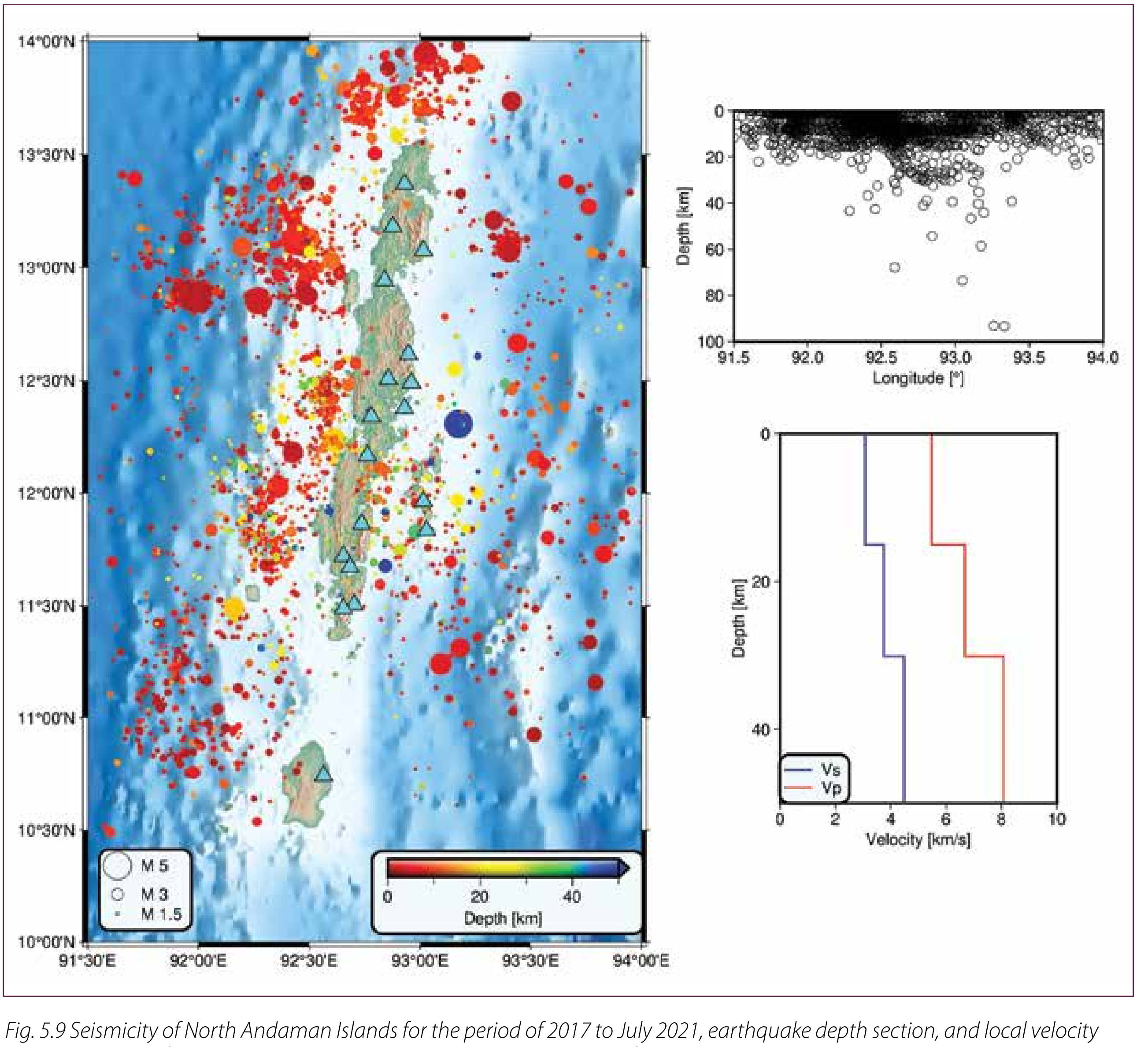


Fig. 5.9 Seismicity of North Andaman Islands for the period of 2017 to July 2021, earthquake depth section, and local velocity model developed for the region. Cyan triangles represent the location of the accelerometer network in the region. (Vp: P-wave velocity, Vs: Shear wave velocity).

initial phase picking and phase association were performed using a machine learning-based automated earthquake phase picker and then located using hypoinverse (https://www.usgs.gov/software/hypoinverse-earthquake-location). The initial locations have been further refined and a minimum local velocity model has been obtained using simultaneous inversion for hypocentres and velocity model. Using this procedure, 2446 events have been located with magnitudes ranging from M_L 1.5 to 5.2. The seismicity map of the region, longitudinal depth section of the earthquakes, and the minimum 1D velocity model for the region are presented in Fig. 5.9. The velocity model developed will be useful for precise location of earthquakes in the region.

5.2 Marine Fishery Advisory Service (MFAS)

5.2.1 Habitat suitability mapping of juvenile Hilsa

Seasonal habitat-suitability models are developed for the juvenile Hilsa at Hooghly estuary & adult fish at the north-western part of the Bay of Bengal. Characterization of habitat is done based on the relationship between three size classes of juveniles (3–5 cm, 5.1–10 cm, and 10.1–15 cm) and six biogeochemical parameters (water temperature, turbidity, salinity, chlorophyll-a, dissolved oxygen, and pH) in the lower part of the tidal riverine to the entire estuarine stretch of the Hooghly river.

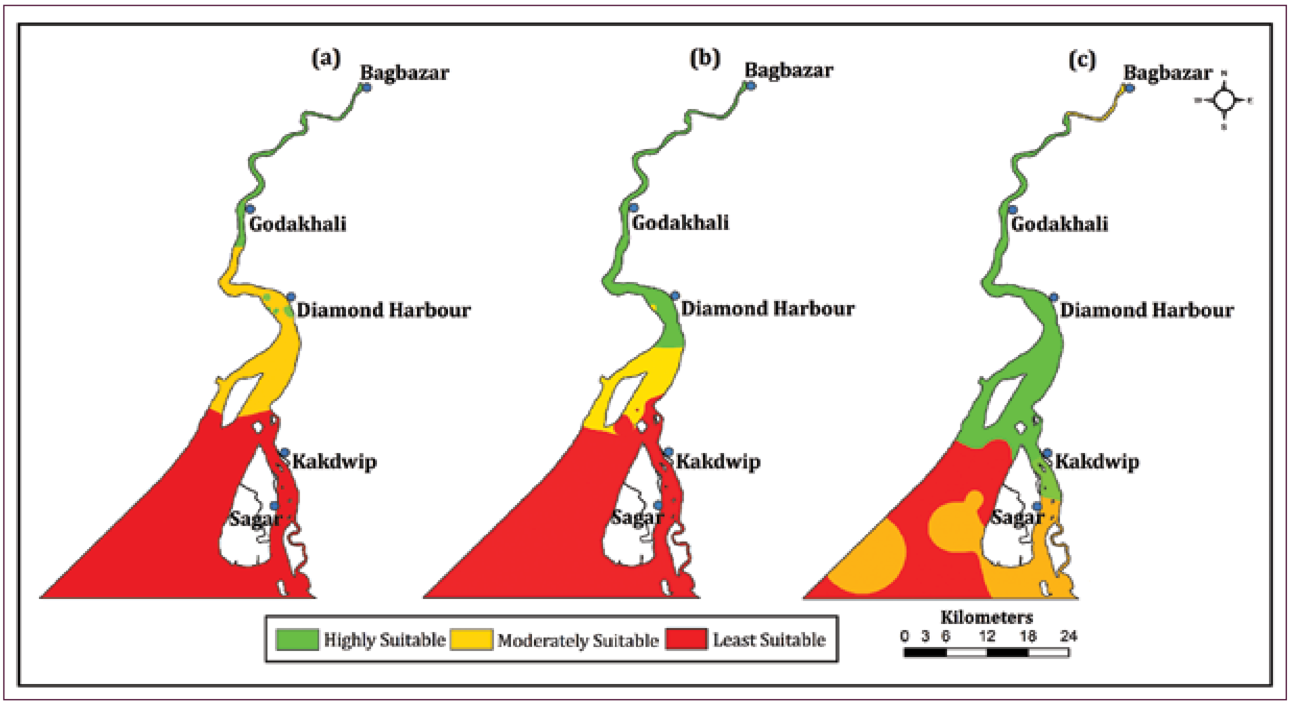


Fig. 5.10 Habitat suitability mapping of juvenile Hilsa

A similar seasonal (pre-monsoon, monsoon, and post-monsoon) habitat-suitability model for adult Hilsa has been developed for the coastal and near-coastal waters off Hooghly estuary, where ecological indicators are sea surface temperature, salinity, sea surface current and velocity. The veracity of the model is yet to be determined.

5.2.2 Machine learning approach for analyzing and forecasting monthly landings of Indian Oil Sardine

This study aims to develop an operational forecasting system for Indian Oil Sardine for the Kerala coast. The input parameter for this forecasting system is the monthly time series of Sardine landings during

2007-2013. In this study, coastal Kerala is divided into three zones: north, central, and south, and the time series of Sardine landings is analyzed at each zone by applying machine learning techniques. The dynamics of the Sardine catch are shown to be nonlinear in all three zones by reconstructing phase-space diagrams. However, the nature of nonlinearity of Sardine landings is not similar in these three zones. Sardine landings time-series do not show any periodicity in the southern zone, whereas it has periodic components in the north and central zones. Singular spectral analysis is able to predict Sardine landings in the north and central zones up to a 2-month time lead. It has been observed that the autoregression method can forecast Sardine catch in the southern zone as this time-series is autocorrelated with 1- and 2-months' time lag, probably because of the seasonality.

5.2.3 Indian Oil Sardine Predictive Capabilities

Under the MoES-NOAA technical cooperation for the development of predictive capabilities for fishery and Harmful Algal Blooms (HABs), scientists from MoES institutions (INCOIS and CMLRE) and NOAA, USA investigated environmental parameters that affect the Indian Oil Sardine (IOS, *Sardinella longiceps*) landings on the southwest coast of Indian mainland. Two environmental covariates improved prediction of the out-of-sample data points i.e. a subset of data points which were not used in training the model but for the validation of the prediction accuracy. The first parameter was the average regional SST 2.5-year prior

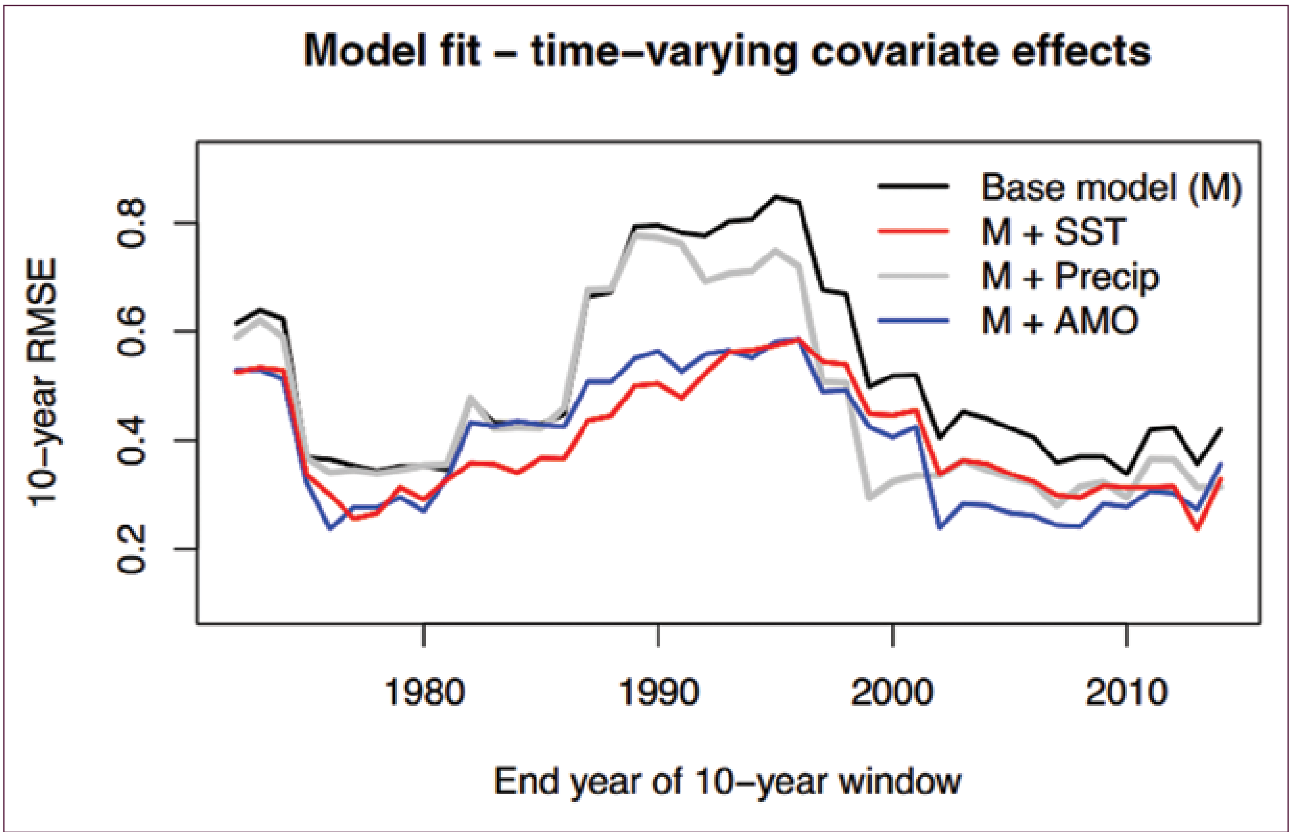


Fig. 5.11 The reduction in error (between predicted and observed landings) using base model and by adding covariates (important ones only shown here).

to the month of fish landing. Another parameter was precipitation over land (rain-gauge data from the coastal area, as a proxy to the rainfall along shore which triggers IOS migration) during June–July. The most significant improvement was with the SST covariate which improved the post-monsoon season landings prediction, with a 19%–22% reduction in mean-squared prediction error. Models with the second-best covariate, i.e. monsoon precipitation over land, provided a 4%–8% reduction in prediction error. Further, an index of the Atlantic Multidecadal Oscillation, also improved out-of-sample predictions similarly to the multiyear average regional SST.

5.2.4 Modelling Marine Primary Productivity

INCOIS provides several marine ecosystem services. Since, last couple of years, INCOIS is in process of studying Primary Productivity (PP) and Photosynthesis-Irradiance (P-I) parameters in the Indian waters which will aid in studying phytoplankton ecology, carbon dynamics, and possible improvement of marine fishery advisory services. The sample collected during February-March 2021 aboard research vessel ORV Sagar Nidhi (SN-162) in the Bay of Bengal was analysed for flowcytometry, and results revealed *Synechococcus* (a euryhaline cyanobacterium) group abundance in the range of 2.22E+05-3.48E+06 (median=1.19E+06) (Cells/mL). Together, *Synechcoccus* and *Prochlorococcus* are estimated to contribute 50% of marine carbon fixation (or productivity) globally every year, and thus, their regular observations are considered vital inputs for the modeling of ocean PP.

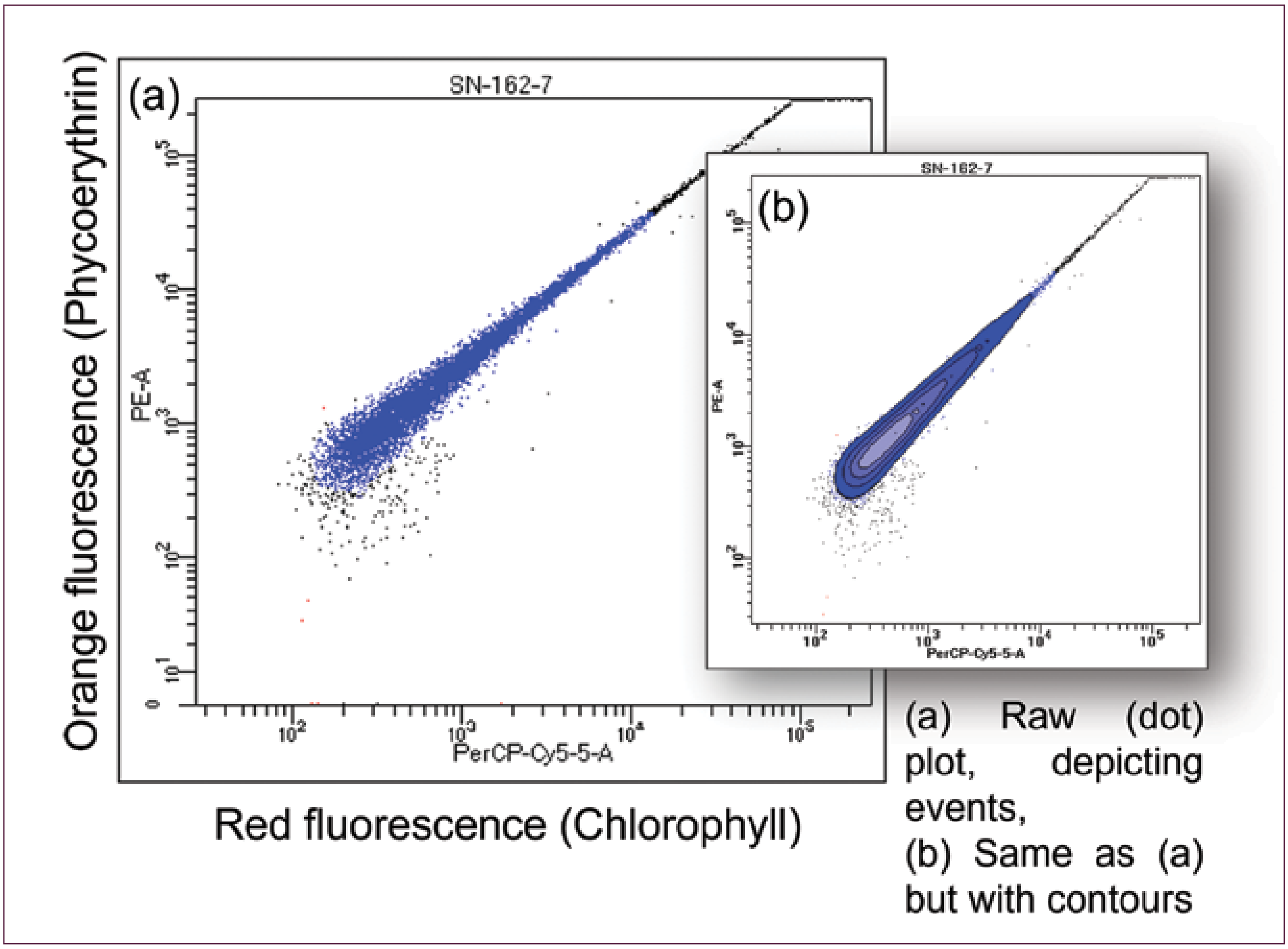


Fig. 5.12 An example plots of Synechococcus group cells characterization in flowcytometry.

5.3 Wave and Allied Services

5.3.1 Coastal erosion forecast system for RK Beach, Visakhapatnam

Identifying coastal stretches that are likely to erode under high wave conditions is essential to the coastal management community in addressing beach erosion-related issues. A wave-induced coastal erosion prediction has been carried out for the Rama Krishna (RK) beach, Visakhapatnam using a combination of WAVEWATCH III and Xbeach numerical models. The pre-monsoon beach topography surveyed using DGPS is used as the initial topographic condition in the morphological model. The model simulates subsequent beach erosion during the southwest monsoon season, which is forced by forecast waves. Beach erosion advisories that classify the beach as eroding, accreting and no change are disseminated with a lead period of 10 days. During the southwest monsoon period, we have monitored the beach using the dumpy level, and the beach topography during the post-monsoon is generated using DGPS surveyed profiles and issued for model validation. The beach area under erosion observed from the model result is homologous with the in-situ observations. The model shows cross-shore sediment transport to dominate during the SW monsoon, particularly in the central and northern sectors of RK beach. The model estimated shoreline position agrees with the DGPS observations, where the central sector has undergone maximum erosion. The comparison shows the model's ability to simulate beach morphodynamics like landward shifting of the berm crest under a high wave setup and oscillating water levels due to tides. The study highlights the importance of numerical modelling systems that decipher the beach response to the high monsoon waves.

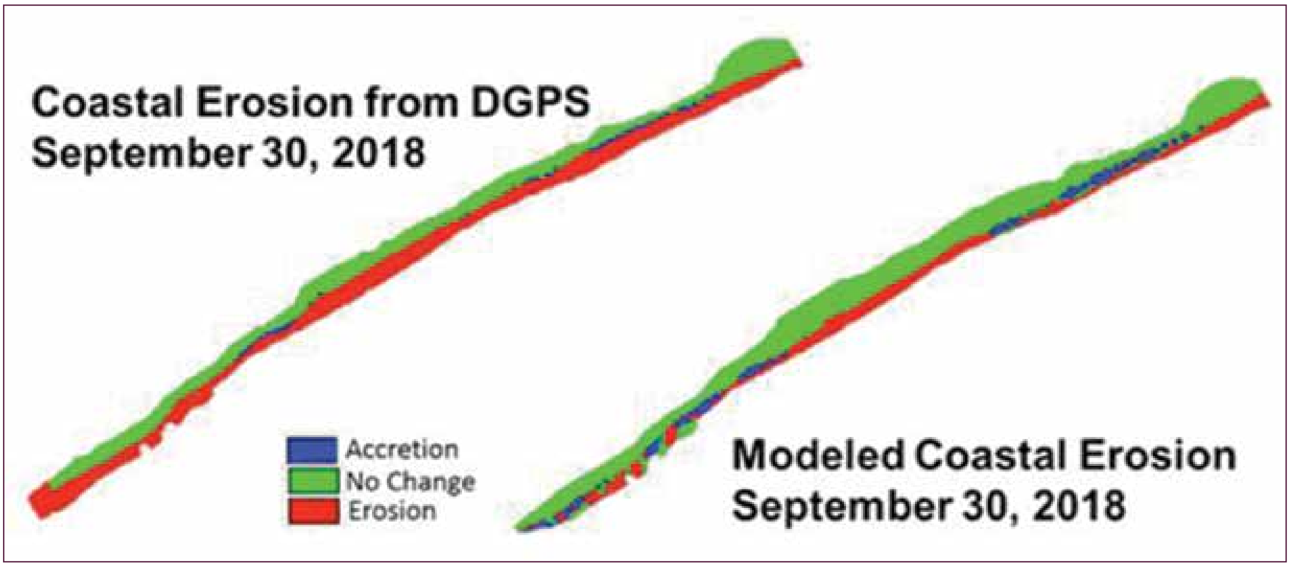


Fig. 5.13 Comparison of beach erosion prediction with in situ measurements.

5.3.2 Seasonal variation of wave power potential in the coastal areas of India

Wave-power generation could be a feasible solution to the huge power requirements of a country like India, having a long coastline. The study provides details of wave characteristics and wave power potential during different seasons along the Indian coast using wave rider buoy observations. The seasonal average of significant wave height (Hs) has been computed near the coastal areas of India from the measured data. Hs varied in the range 1.62–1.95 m and 1.38–1.39 m along the west and east coastal areas, respectively, during the summer monsoon. These high waves generate high wave power (>20 kW/m) along the east and west coastal areas of India. The seasonal average of wave power obtained was high (12–19 kW/m) off the west coast of India, suggesting that the west coastal areas are better-suited for power generation during the summer monsoon. The study highlights that the average wave power is high (12–19 kW/m) during summer monsoon along the west coast and insignificant (<2 kW/m) during non-monsoon. Thus, this study suggests employing a hybrid arrangement of power generation using solar and ocean wave energies to solve the problem of energy deficit near the coastal areas of India.

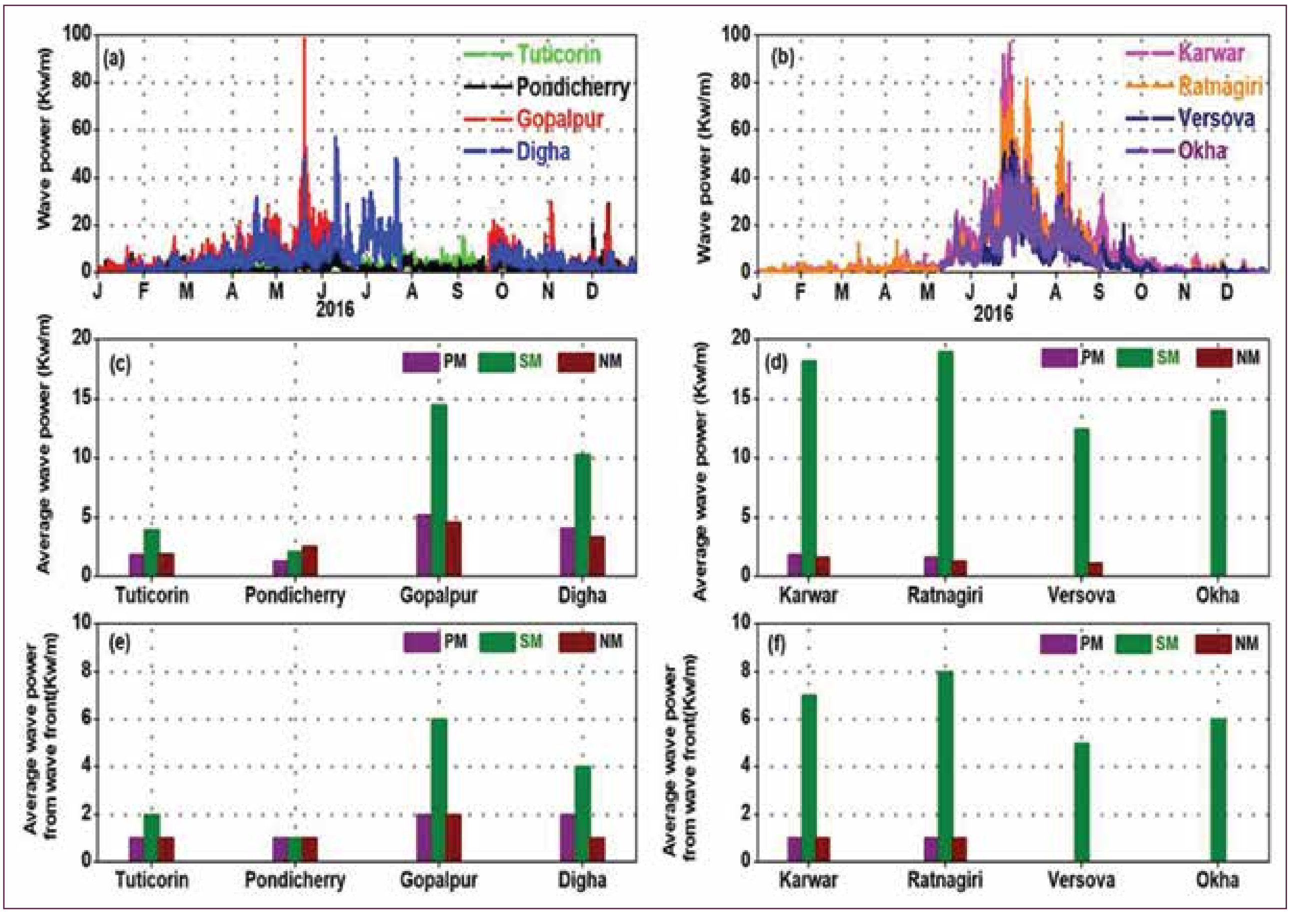


Fig. 5.14 Plots (a, b) refer to annual time series of wave power along the east and west coastal areas of India. Average wave power off east and west coastal areas are displayed in the figures (c, d) respectively. Plots (e, f) show average wave power from wave front of west and east coastal areas.

5.3.3 Implementation of data assimilation scheme in operational WAVEWATCHIII setup

INCOIS has implemented a data assimilation (DA) scheme in the wave forecasting system at INCOIS. Significant Wave Height (SWH) measurements from the SARAL/AltiKa, Jason-2, and Jason-3 altimeters have been assimilated using the Optimal Interpolation technique. The impact of altimeter DA towards improving the reliability of wave predictions in the Indian Ocean is evaluated by validating the forecasted wave parameters with buoy observations. The assimilation of altimeter data showed considerable improvement in the wave predictions. SWH forecast in the northern Indian Ocean region improved up to ~15 % in the first 24 h period. The improvement in forecasted wave parameters was due to the correction in the swell forecast, which persists throughout the forecast period. For the wind-sea forecast, the impact of DA was less visible (~4–6% improvement up to forecast lead time of 24 h), as it is primarily driven by local wind fields. The positive impact of DA on the swell forecast is further established considering a swell surge event named *Kallakkadal*. Recently the assimilation system has been upgraded to assimilate in-situ data along with satellite measurements, and the new system is operational now.

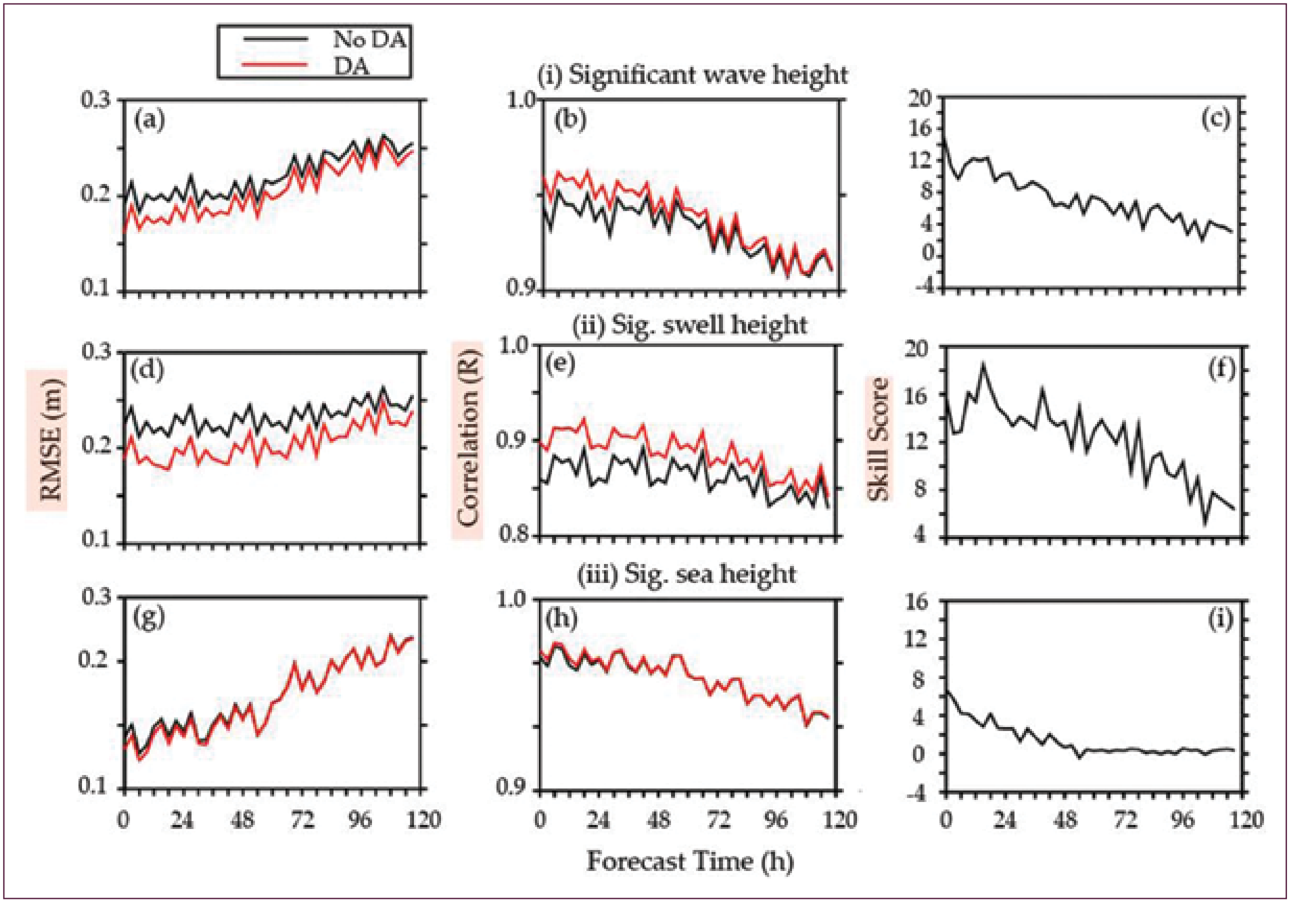


Fig. 5.15 Model error statistics for the moored buoy (BD08, BD11, BD14, AD06, AD07, and AD09) comparison of wave height as a function of forecast time.

5.4 Operational Oil Spill Advisory Service

INCOIS issues oil spill advisories in operational mode since 2015. Oil drift patterns were simulated using INCOIS oil spill trajectory prediction system, which is an integrated set up of oil spill trajectory model, general ocean circulation models, atmospheric models and Geographical Information System (GIS). During 2021-22, efforts were taken to reach a step ahead in this operational service/research in estimating the extent of affected coral reefs due to oil spillage and simulating the drift of plastic nurdles using the oil spill trajectory prediction system. Mauritius oil spill event during August 2020 and nurdles spill of MVX Press vessel during June 2021 were taken as case studies and the improvements made in the system are detailed detailed in the below sections.

5.4.1 Mauritius oil spill: Estimating the extent of affected coral reef environs due to oil spillage

MV Wakashio vessel spilled ~1000 tons of Fuel oil at 20°26'17.2"S 57°44'40.7"E off Mauritius on 06 August 2020. The spilled pollutant spread along the southeast coast of Mauritius. Simulated oil drift pattern agreed well with the oil slick signature obtained from Sentinel -1A data on 10 August 2020. Hence, the impact of oil spill over associated coral reef classes was estimated by superimposing the oil drift pattern over coral reef region. It was found that on 08 August 2020, the reef flats were highly affected.

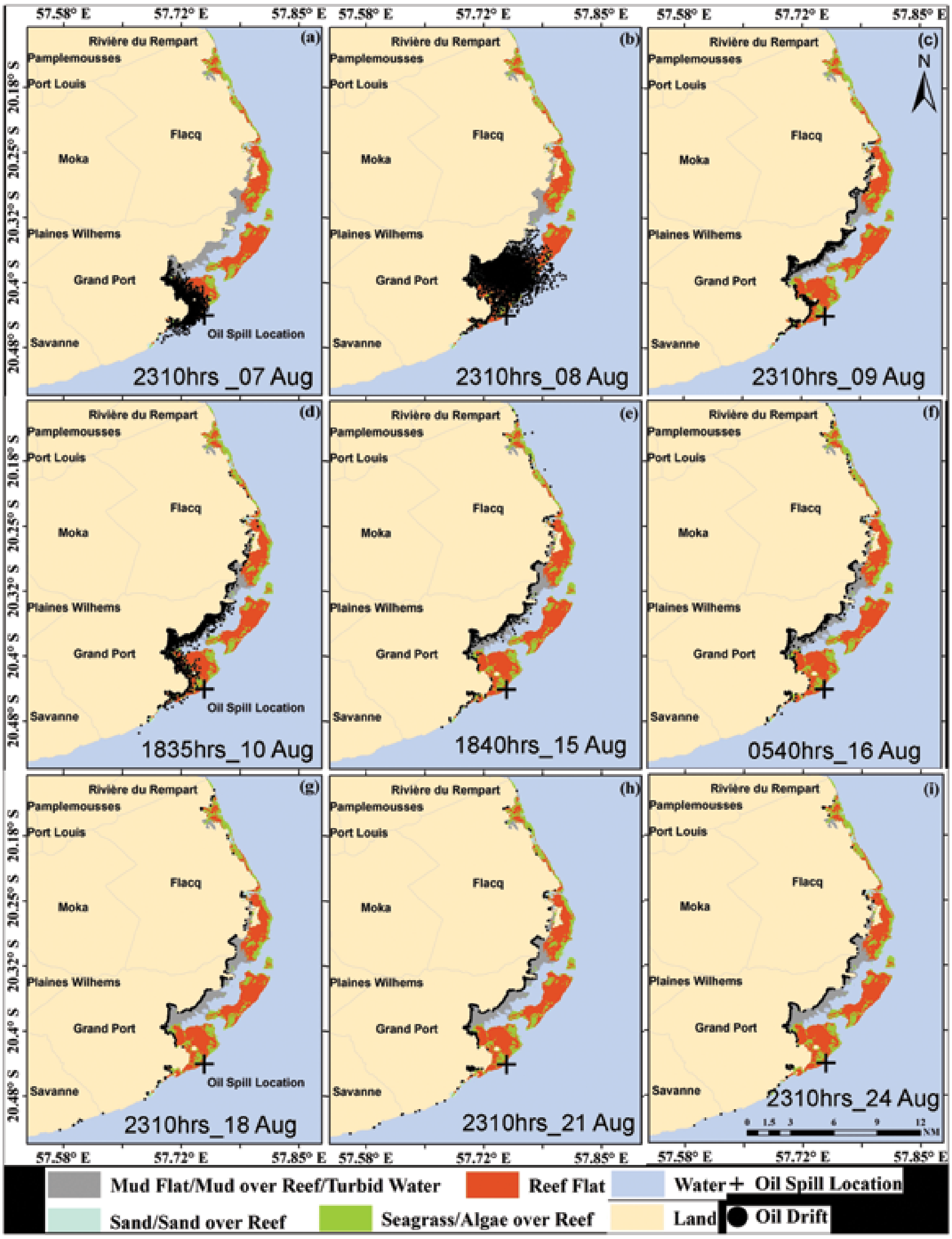


Fig. 5.16 Simulation results depicting the trajectory of spilled oil and its spatial extent of impact on reef flats.

5.4.2 Simulation and validation of nurdles spill drift from MVX-Press vessel

On 20 May 2021, MVX-Press spilled ~1680 tons of plastic nurdles off Sri Lanka. Oil Spill trajectory model GNOME was used to simulate the drift of nurdles, considering them as a non-weathering pollutant. The model was run from 20 May 2021 to 31 October 2021 forced by ECMWF winds and various ocean currents. Windage assigned varied from 0-3%, and the corresponding drifts obtained were compared with the location of the sighted nurdles along the Sri Lankan coast between 08 June and 07 July 2021. The drift pattern of nurdles was in good agreement with that of the observed, while GNOME was run with windage less than 0.5%, especially while using INCOIS-HYCOM model currents. The west coast of Sri Lanka got highly affected with the nurdles as per the simulation and observation.

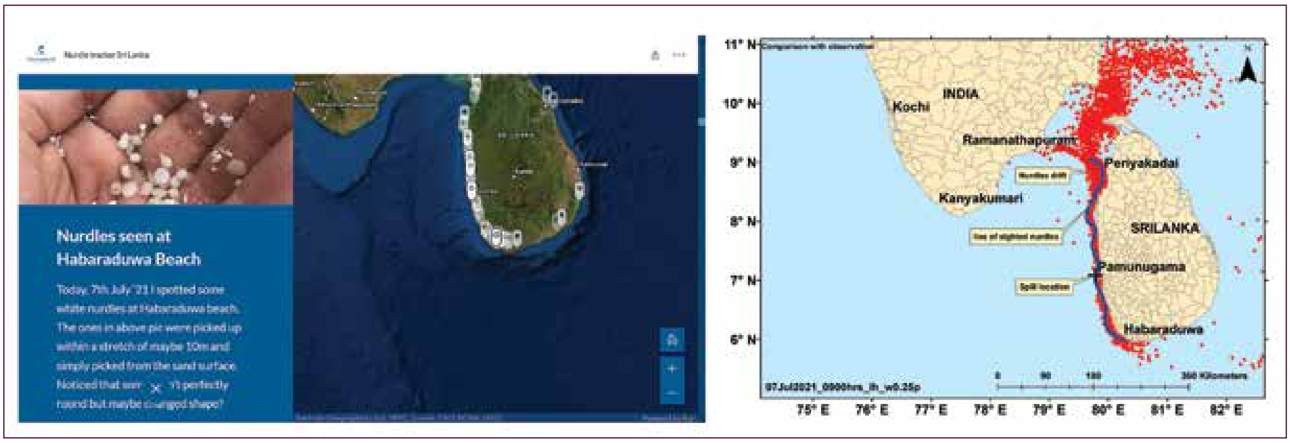


Fig. 5.17 Simulation results depicting the probable beaching location of the spilled nurdles

5.5 Water quality/coastal biogeochemistry

INCOIS has initiated the process of deploying autonomous physical-biogeochemical observatories at different strategic locations of the Indian coastal waters to provide real-time information on water quality/ecosystem health. The observatory recorded data will be displayed in a nowcast mode on the INCOIS website. The conceptual layout design for such a web portal was prepared, and a ready-to-operation webpage was finalized to disseminate the nowcast-mode data. In addition to the in-situ recorded data, INCOIS is also set to disseminate derived parameters (using the real-time in-situ data) which will be helpful to the stakeholders. The finalization of a set of such parameters for marine water quality services is completed. In addition, an initial performance assessment of physical-biogeochemical-optical sensors of the afore-mentioned autonomous water quality observatory were carried out during the test deployment in the coastal waters of Kochi.

INCOIS has a state-of-the-art laboratory facility for water sample analysis, including spectrophotometers, high-performance liquid chromatography setup, continuous flow nutrient analyzer, isotope-ratio mass spectrometer, etc. Instruments were operated with internal standards and assessed for stability.

Fig. 5.18 A screenshot from the water quality nowcasting web portal (under development).

Phytoplankton samples collected during INCOIS coastal cruises and field campaigns were analyzed, and data was added to INCOIS biogeochemical database.

5.6 Algal Bloom Information Services (ABIS)

INCOIS-ABIS is presently using MODIS-Aqua retrieved remote sensing reflectance to generate algal bloom-related products. However, considering the age of the MODIS-Aqua sensor, INCOIS has planned to shift the ABIS to a newer operational sensor. Assessment of different newer in-orbit ocean colour sensors and research towards shifting ADPC and ABIS to such a sensor is under process. Different algal bloom causative species have different optical/spectral signatures and require special spectral bands available in the sensor to detect them. It has been observed that even if VIIRS-SNPP is relatively newer, operationally available, and already incorporated in INCOIS automatic data processing chain, it lacks few bands which are required for the detection of algal bloom causative species for ABIS applications. OLCI sensor onboard Sentinel-3 is a prospective alternative and research toward determining the capability of OLCI in detecting various phytoplankton species is under process.

Time-to-time validation exercises are conducted to assess the performance of ABIS. In this context, a massive bloom that occurred in the coastal waters of Kerala in December 2021 was evaluated. This bloom

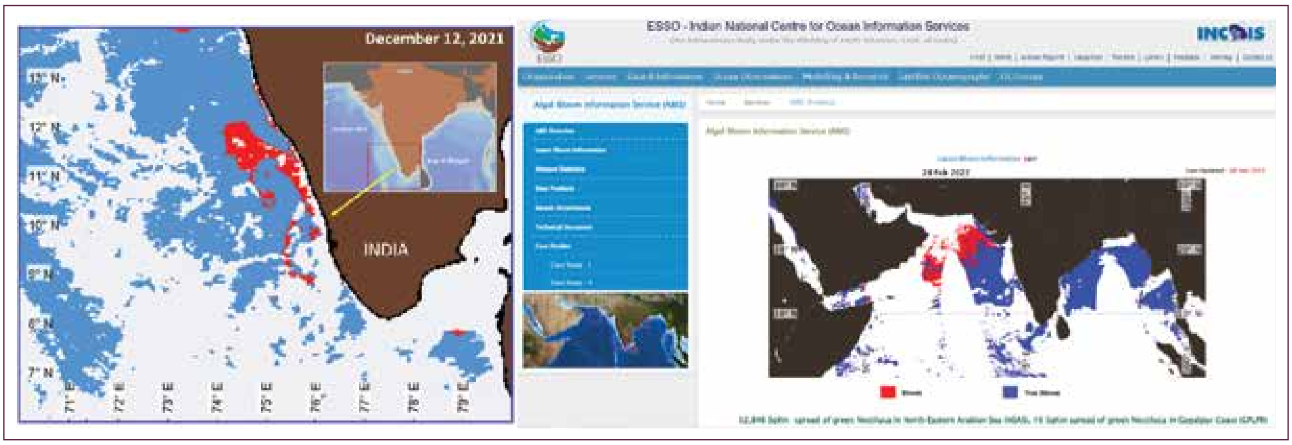


Fig. 5.19 (Left) Successful detection of recent algal bloom event in Kerala coastal water on 12 December 2022. The red patch is the algal bloom caused by green Noctiluca scintillans. (Right) Screenshot from INCOIS-ABIS web page on 28 February 2022 detecting massive algal bloom in the north-easter Arabian Sea.

was caused by green Noctiluca scintillans leading to fish mass mortality. INCOIS-ABIS outputs were used to monitor the temporal and spatial extent of the bloom. The consequences of the event and monitoring need to understand the pre-conditioning conditions are emphasized in the study.

In addition to four existing hotspots, ABIS was updated for two new extents (Kochi & Visakhapatnam) to provide algal bloom information in the upcoming Water Quality Nowcasting System (WQNS). Linking of ABIS-generated information towards satellite retrieved NRT component of WQNS was completed.

5.7 Integrated User Engagements and Feedback for improving and expanding the entire services of INCOIS

As a new extensive step, MS online Feedback cum survey forms have been designed and made separately for 14 services/user categories. These forms have been circulated among the concerned users/user categories and subsequently collected. The 14 services/user categories are Business/commercial agencies, OSF, PFZ, PFZ-Tuna, Tsunami, Coral Bleach Alert, Marine Algal Bloom services, SARAT, OOSA, Forecast along ship-routes, Navy & Coast Guard, Water quality services, Coastal vulnerability services, Renewable energy sector, and Coastal tourism services.

An integrated user interaction workshop, viz., “INCOIS Integrated User Interaction Workshop 22 (I-UIW-22)” was organised in an online mode on 02 February 2022 as part of commemorating the INCOIS foundation day. The workshop was conducted with an Inaugural session, followed by 3 sessions, namely, (1) Fisheries and ecosystem services and advisories, (2) Ocean warning and alert services, and (3) Value-added, user-customized & commercial products and services.

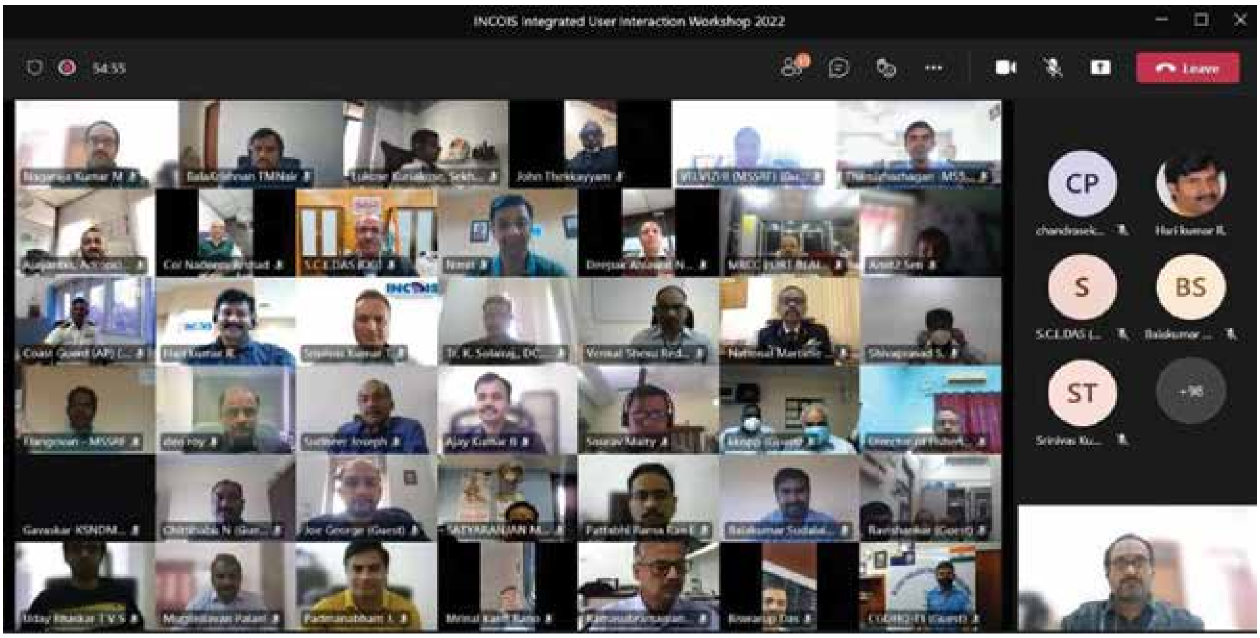


Fig. 5.20 Participants and dignitaries of the Integrated user interaction workshop-22.

A technical report is made with all the details on the Integrated User Interaction Workshop 2022, and also the feedback and further requirements received last one were analysed, interpreted, and distilled in a consolidated manner aiming at communicating to the concerned and to improve the entire INCOIS services.

5.8 Consultancy Projects

Ocean Forecast and Information related consultancy projects have been carried out/continued for M/s. ONGC Kakinada, M/s. Afcons House, COWI India PVT LTD. An MOU has been signed with DG HC for serving the general forecasts and warnings to various Oil & Natural gas offshore E&P companies. Project proposal with a budget (of 85 crores) for three years projects for providing improved customized forecasts and warnings to various Oil & Natural gas offshore E&P companies have been submitted and are under process of approval and work order. Syllabus and budget have been prepared for 2-day, and 5-day training to be imparted to Oil & Natural gas offshore E&P companies and have been finalized through a collaborative committee of INCOIS, DG Hydro Carbon, and E&P companies and submitted.

Table 5.2 Details of the consultancy projects/ECF during 2021-22

Sl. No.	Industry/firm	Title	Amount earned	Remarks
1	M/S ONGC-KG Basin Kakinada	Forecast and climatological trend analysis for K-G basin development and operations	~ 20 Lakhs	Commenced in April 2018. 3+2 year project. (payment on 3-Monthly-basis). Daily operational forecasting for wells and 2-monthly trend analysis and delivery on request.
2	M/S AFCONS	Forecast for off Agalega Island, Mauritius for marinal operations	~24 Lakhs	Daily operationally pushed.
3	M/S COWI India (P) Ltd.	Wave and swell data off Gujarat	~25000	One time consultancy
4	Kalpasar Project (NCCR, Chennai)	Impact of Tsunami on Kalpasar Dam Assessment of Sea-level Rise due to Climate Change Sea-side Inundation in Gulf post-construction of Dam	39 Lakhs	In collaboration with IITM too.
5*	DG Hydrocarbon	Improved- customized forecasts and warnings to various Oil & Natural gas offshore E&P companies	85 Crore	Integrated INCOIS-IMD proposal. 3 year project (Under discussion and approval from DG HC)

6

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, a large number of observation platforms have been deployed and maintained in the Indian Ocean coastal, and open ocean waters by INCOIS through the MoES funded project Ocean Observation Network (OON). A few of the ocean observation platforms under OON work in full coordination with the Indian Ocean Observing System (IndOOS) and its other components were designed and implemented to support Tsunami early warning and ocean state forecast services. Various restrictions and lack of ship-time opportunities caused by the COVID-19 pandemic during 2021-22 forced INCOIS to focus only to sustain the existing observation platforms. Here, it is to be noted that some of the platforms under these networks were maintained to contribute to IndOOS, and others are maintained to support INCOIS's day-to-day operational requirements. The details are summarized below.

6.1 Open Ocean Network

6.1.1 The Argo Program

The Indian Argo program is part of the international Argo program, where more than 30 countries collaborate to collect high-quality hydrographic observations from the ocean. The data from the Argo network is processed and made freely available to the researchers for research and development. INCOIS, representing India, actively participates in this international program by regularly deploying Argo floats in the Indian Ocean and processing the data following global standards. During the 2021-22 period, INCOIS maintained a network of 75 Argo floats in the Indian Ocean, while India's total contribution to the network is 494 floats. The present Indian active floats include 48 core Argo floats (CTD sensor only) and 27 BGC floats (CTD sensor plus biogeochemical sensors). In addition, there are 631 Argo floats deployed in the Indian Ocean by other countries and are presently active (Fig. 6.1). 7782 temperature and salinity profiles of the Indian Ocean were received at INCOIS and processed during the 2021-22 period.

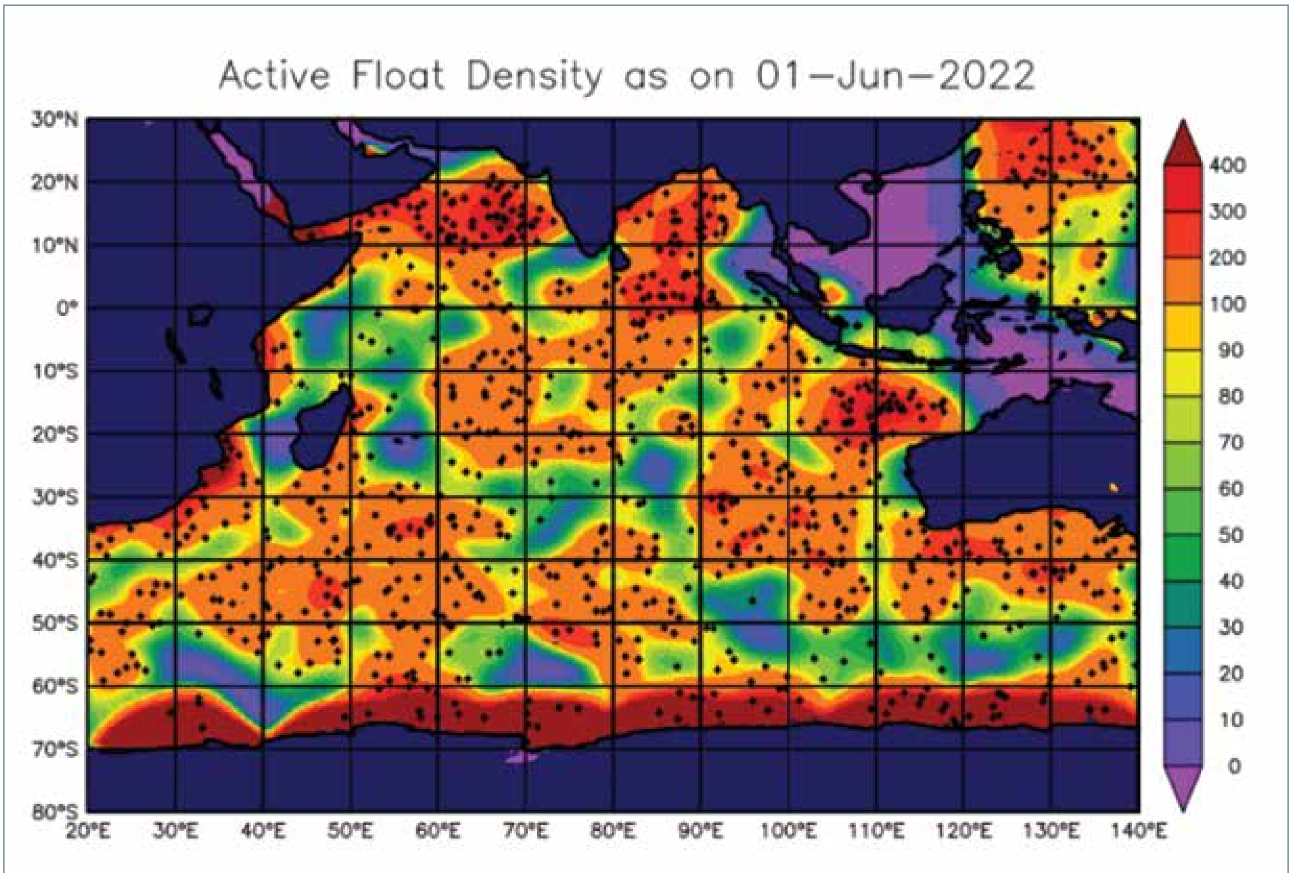


Fig. 6.1 Argo density map showing the percentage of Argo floats in each 3°x3° grid box in the Indian Ocean (color), and its location (black dots) as of 31 March 2022. If one (two) Argo float is available in a 3°x3° grid box, it is represented as 100% (200%).

6 OCEAN OBSERVATION NETWORK

6.1.2 Drifter

As a contribution to the Global Drifter Program (GDP), 15 satellite-tracked surface drifters were deployed in the north Indian Ocean. Three drifters were deployed in the southwestern Bay of Bengal directly by the INCOIS scientists whereas three drifters were deployed in collaboration with the Directorate of Fisheries (DoF) in the southeastern Arabian Sea, and six (three) drifters were deployed in the northeastern Arabian Sea (the western equatorial Indian Ocean) with the support of vessel management cell team of the National Centre for Polar and Ocean Research (NCPOR) (Fig. 6.2 and 6.3). The drifting buoys measure sea surface

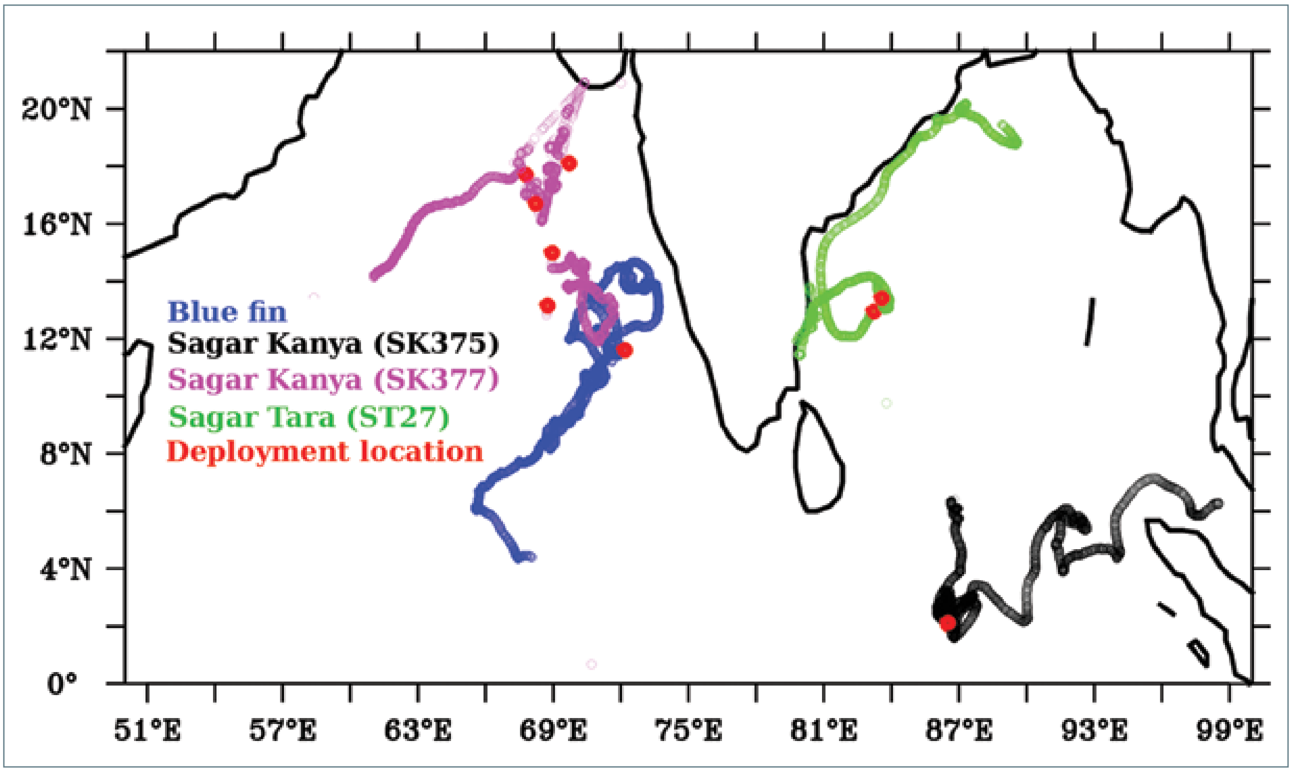


Fig. 6.2 The deployment locations (red dot) and trajectories of drifters deployed in the north Indian Ocean during the reporting period.

Fig. 6.3 The deployment of drifters by NCPOR personnel (left panel) and DoF personnel (right panel) in the north Indian Ocean.

temperature and barometric pressure every hour and transmit the data via satellite in real-time. Besides these measurements, the accurate information of the float position facilitates in deriving near-surface current velocity (Fig. 6.4). The data from these floats are used to improve the accuracy of atmospheric and ocean models.

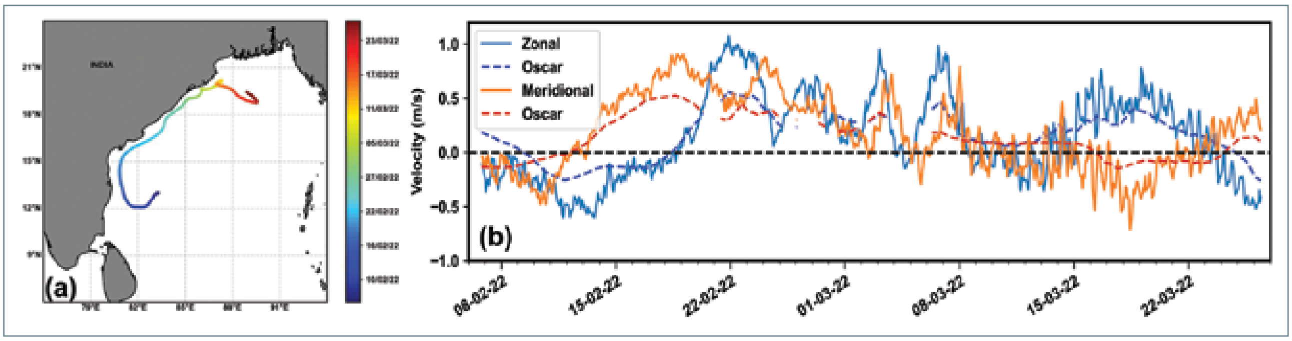


Fig. 6.4(a) Trajectory of a drifter with WMOID 220828 in the western Bay of Bengal between February 2022 and March 2022 and (b) zonal and meridional current (ms^{-1}) derived from a drifter (220828; blue), when northward-flowing east India coastal current prevails in the western Bay of Bengal. In panel (b), zonal and meridional current from Ocean Surface Current Analysis Real-time (OSCAR) is plotted as an orange line.

6.1.3 Tsunami buoy with Bottom Pressure Recorder

The network of Tsunami Buoys with Bottom Pressure Recorder (BPR), deployed close to the tsunamigenic source regions in the Bay of Bengal and the Arabian Sea, has been maintained during the reporting period (Fig. 6.5). The data from these buoys are transmitted in real-time to the ITEWC at INCOIS via satellites.

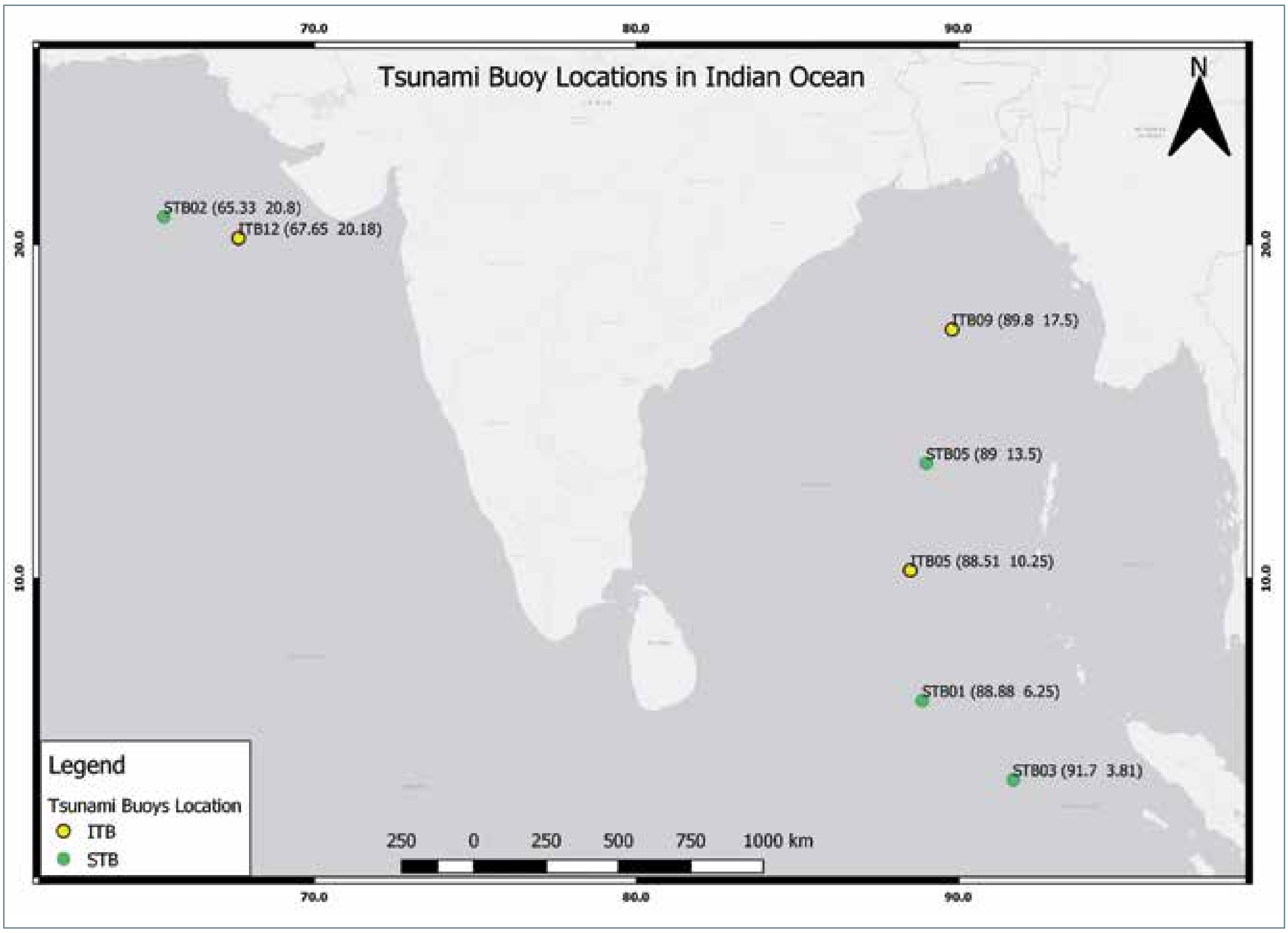


Fig. 6.5 The present status of the deployed Tsunami buoys with BPR network in the north Indian Ocean. The buoys maintained by INCOIS and NIOT are marked with yellow and green closed circles, respectively.

6 OCEAN OBSERVATION NETWORK

The planned service of the Tsunami Buoys could not be carried out due to the prevailing COVID-19 pandemic situation. The commercial purchase agreement was signed between INCOIS and Science Applications International Corporation (SAIC). The maintenance and repair of STB01 and STB05 buoys in the Bay of Bengal and STB02 buoys in the Arabian Sea are being scheduled in February 2023. At present, two buoys in the Arabian Sea and one buoy in the Bay of Bengal are active and provide data in real-time (Fig. 6.6).

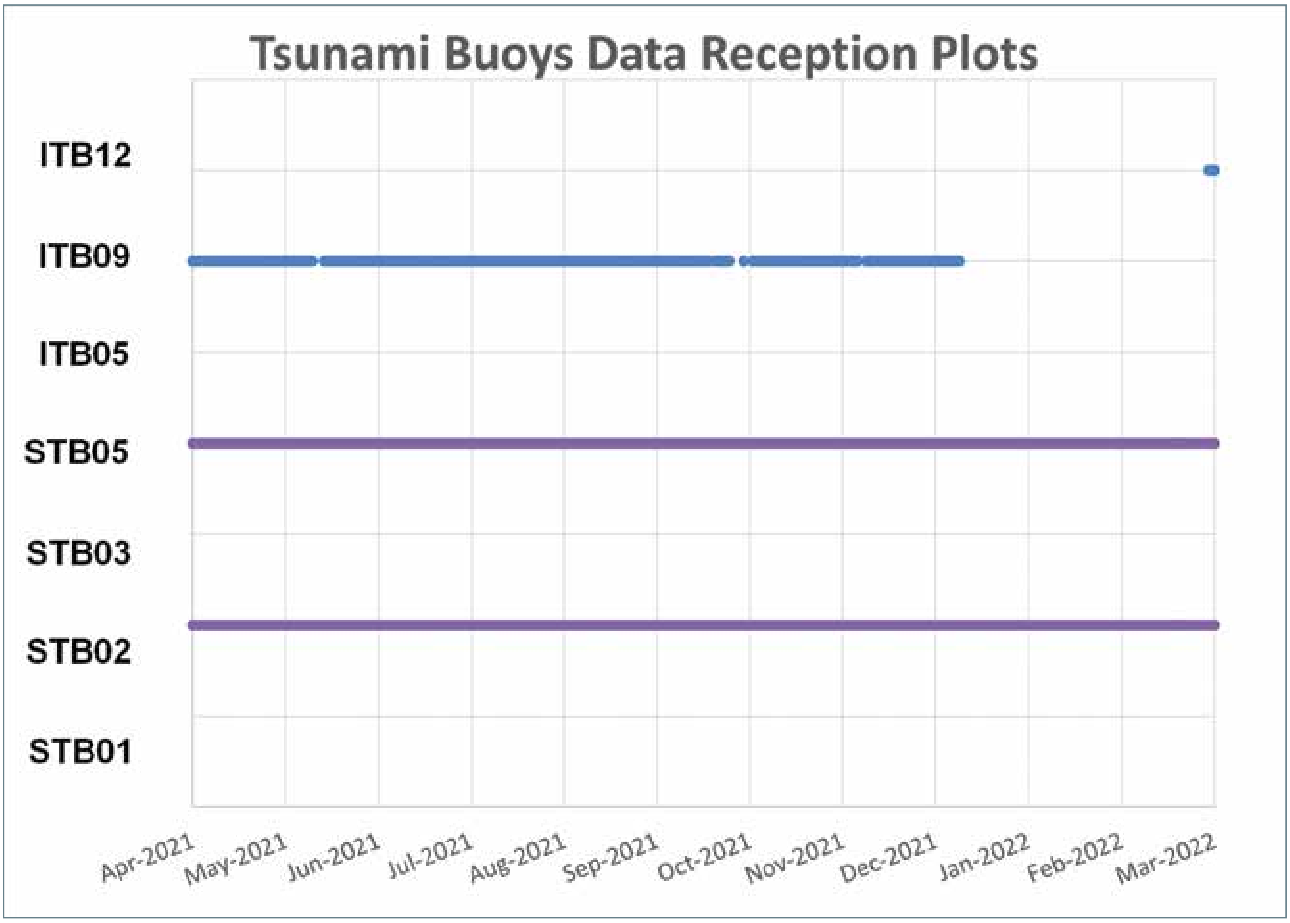


Fig. 6.6 The availability of data from the BPR network during the reporting period.

6.1.4 Equatorial current meter moorings

The equatorial current meter moorings have been maintained in collaboration with CSIR-NIO, Goa. These moorings were designed to record currents at selected depths to get information in the entire water column (Fig. 6.7). The depths were chosen such that information on current is available from the upper thermocline, main thermocline, intermediate, deep, and near-bottom depths. Presently, three moorings are operational and were serviced during the scientific cruise onboard ORV Sindhu Sadhana (SSD-082) between 06 August 2021 and 26 August 2021.

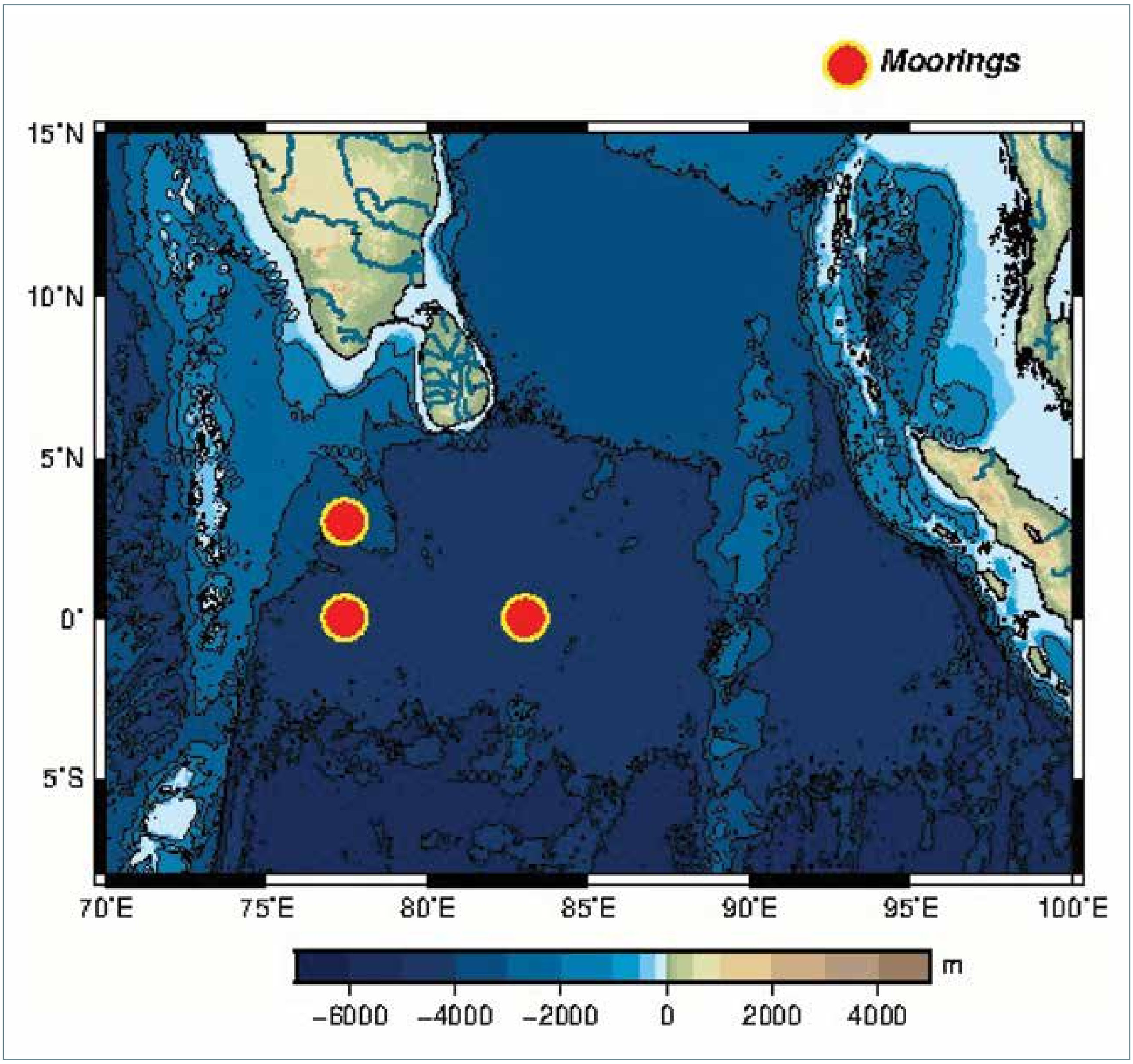


Fig. 6.7 The Schematic shows the locations of active deep-sea moorings in the equatorial Indian Ocean.

6.1.5 Automatic Weather Stations (AWS)

INCOIS maintains a network of 34 Automatic Weather Stations (AWS) in ships and offshore platforms to measure wind speed and direction, air temperature, humidity, downwelling longwave radiation, downwelling shortwave radiation, rainfall, sea surface temperature, and barometric pressure in the Indian Ocean in collaboration with different national agencies (Fig. 6.8). The real-time data from these systems are transmitted to INCOIS via INSAT. Three AWS systems were decommissioned from the vessels CRV Sagar Purvi, MV Nicobar, and MV Nancowry during 2021-22 as these vessels were scheduled for dismantling. INCOIS has received the necessary permissions to install the AWS system onboard "SCI Sindhu" and "INS Investigator". A site survey has been conducted on these two vessels. Soon, AWS will be installed on the above-mentioned two vessels.

6 OCEAN OBSERVATION NETWORK

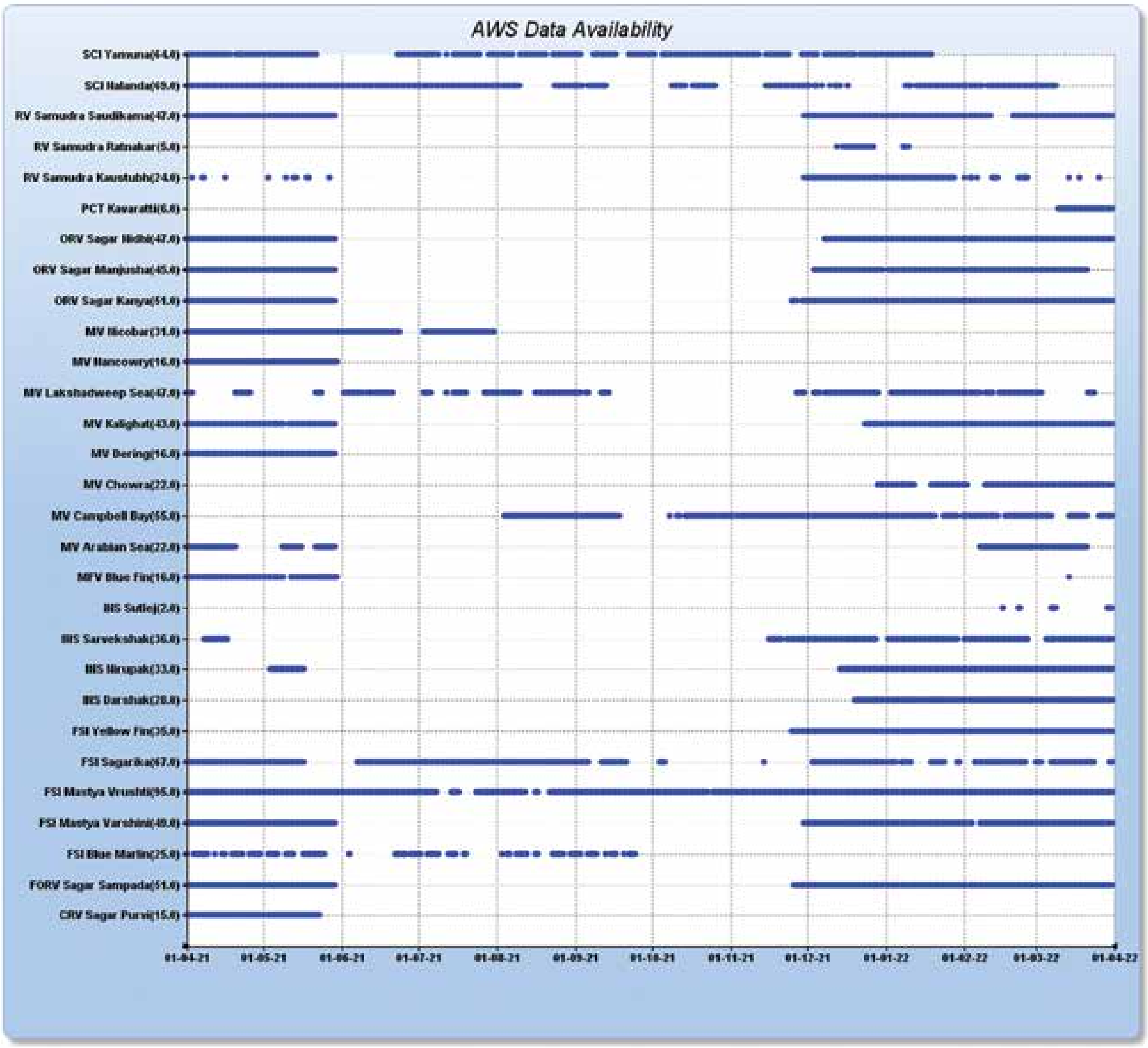


Fig. 6.8 Availability of real-time AWS data during the year 2021-22.

Further, INCOIS has received the necessary permissions from the Department of Port, Shipping, and Aviation of Lakshadweep to install an AWS in Port Control Tower, Kavaratti, which was decommissioned in 2021-22 (Fig. 6.9). The installation work has been successfully completed. Annual maintenance and calibration of AWS systems are being carried out at regular intervals.

Fig. 6.9 Newly installed AWS in Port Control Tower, Kavaratti.

6.2 Coastal Ocean Network

6.2.1 Wave Rider Buoy (WRB)

To monitor the ocean wave characteristics along the Indian coastal waters and propagation of southern ocean swells to the north Indian Ocean in near-real-time, INCOIS has maintained a network of 16 WRB during the reporting period (Fig. 6.10 and 6.11). The data from these networks have been used to validate the ocean state forecast products and assimilation of wave parameters in wave models. Regular calibration of the systems in recommended intervals has been performed to ensure the quality of data from these networks. The indigenously developed INSAT tracking mechanism for buoys helped to retrieve 14 drifted buoys. These buoys were later redeployed to their respective locations. A total of eight maintenance, 22 re-deployments, and two rescues on communication failure were carried out on WRB systems to ensure continuous availability of quality data from these observatories during the reporting period.

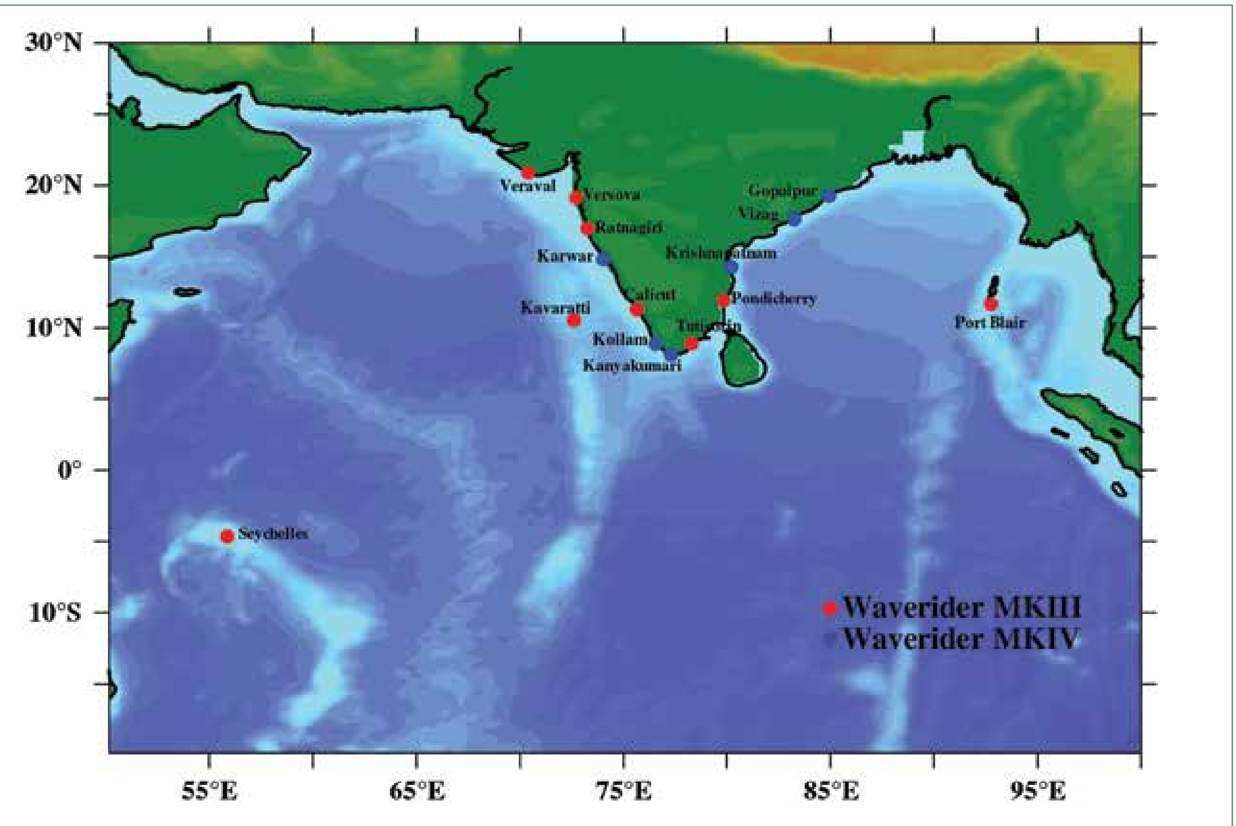


Fig. 6.10. The present status of WRB network. The red circle represents MKIII buoys (which can measure only wave parameters), and the blue dots represent MKIV buoys (which can measure both near-surface current and wave parameters).

Fig. 6.11 Real-time WRB data availability during 2021-22.

6.2.2 Tide Gauge Network

The tide gauge network, consisting of 36 stations (21 stations established in 2010-11 and 15 stations

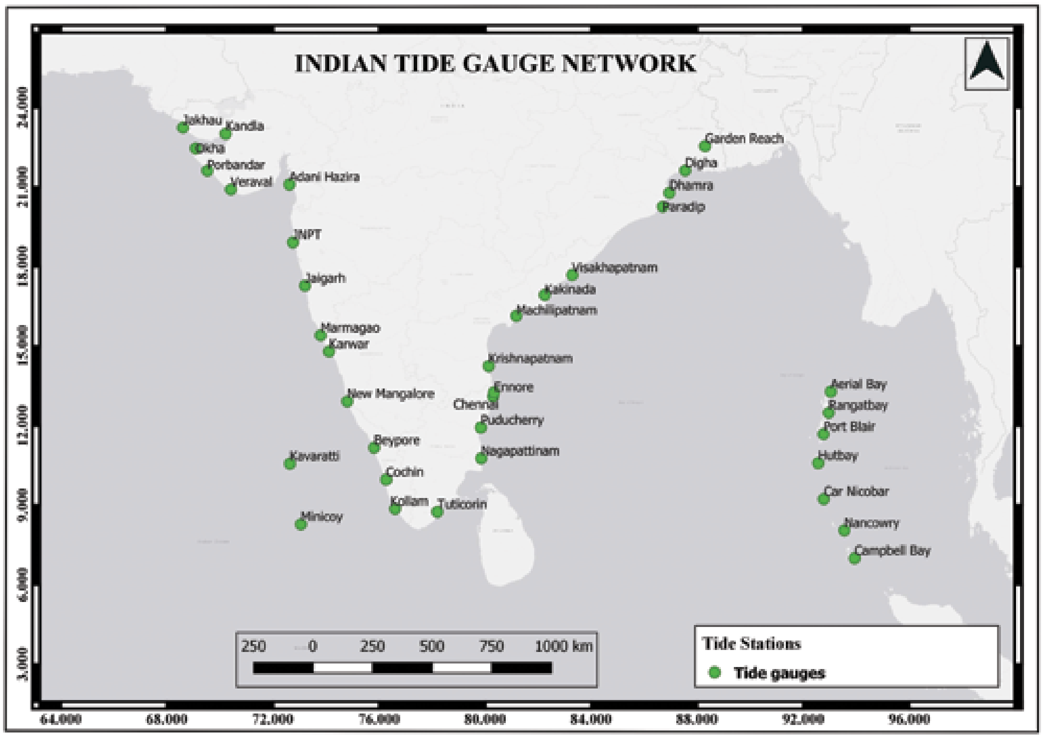


Fig. 6.12 Present status of the Sea level Gauges along the Indian coasts and islands.

established in 2015-16) established along the coasts of the Indian mainland and islands to monitor the sea level, has been maintained (Fig. 6.12). The real-time data from 36 tide gauges were received at ITWEC through INSAT and GPRS modes of communications. In addition, INCOIS also received near-real-time data from tide gauges installed and maintained by other countries. The real-time data from eight tide gauges (Chennai, Kochi, Nancowry, Port Blair, Visakhapatnam, Minicoy, Marmagao, and Veraval) have been shared with IOC Sea Level Monitoring Facility. A total of 59 regular maintenance visits and 22 breakdown visits were carried out to ensure the availability of quality data during the reporting period. Installation of Radar Tide gauge system at Gopalpur port with GPRS communication been successfully accomplished (Fig. 6.13).

Fig. 6.13 Newly installed Radar Tide gauge system at Gopalpur port

6.2.3 eXpendable Bathy Thermographs (XBT) / eXpendable Conductivity, Temperature and Depth (XCTD) Programme

There were no cruises conducted from April 2021 to March 2022 due to the non-availability of a ship of opportunity. However, the water sample collection for sea surface salinity at ten stations along the east coast of India (Paradeep, Vizag, Penupalem, Suryalanka, Chennai, Nagapattinam, Tirnuchendur, Rameswaram, Kolachal, and Arambol) with an interval of five days has been carried out.

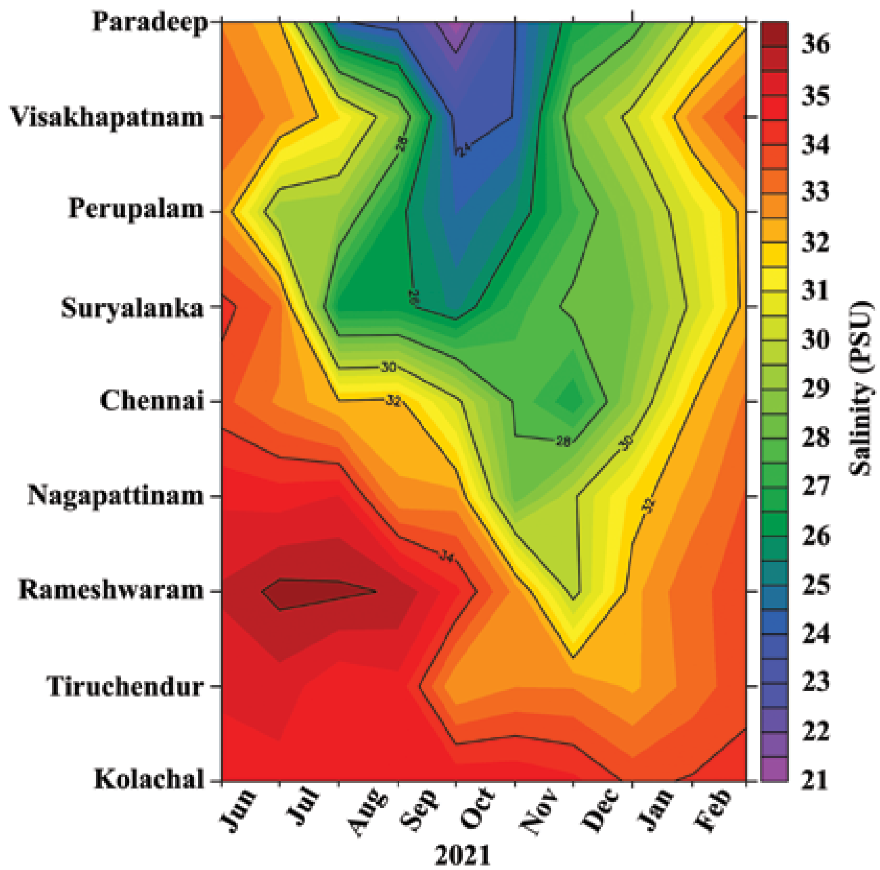


Fig. 6.14 Temporal evolution of sea surface salinity along the east coast of India from June 2021 to February 2022.

6.3 Coastal Current Meter Network

The Acoustic Doppler Current Meter Profiler (ADCP) network in Indian coastal waters has been maintained in collaboration with CSIR–NIO. The service of seven ADCP moorings deployed on the continental slope along the west coast of India has been carried out onboard RV Sindhu Sankalp (SSK-140) from 02 March 2022 to 18 March 2022 (Fig. 6.15). Currently, 17 ADCP moorings (13 slope moorings and four shelf moorings) are active along the entire Indian coast (Fig. 6.16).

Fig. 6.15 Re-deployment of an ADCP mooring (after service) on the continental slope along the west coast of India during RV Sindhu Sankalp (SSK-140) cruise.

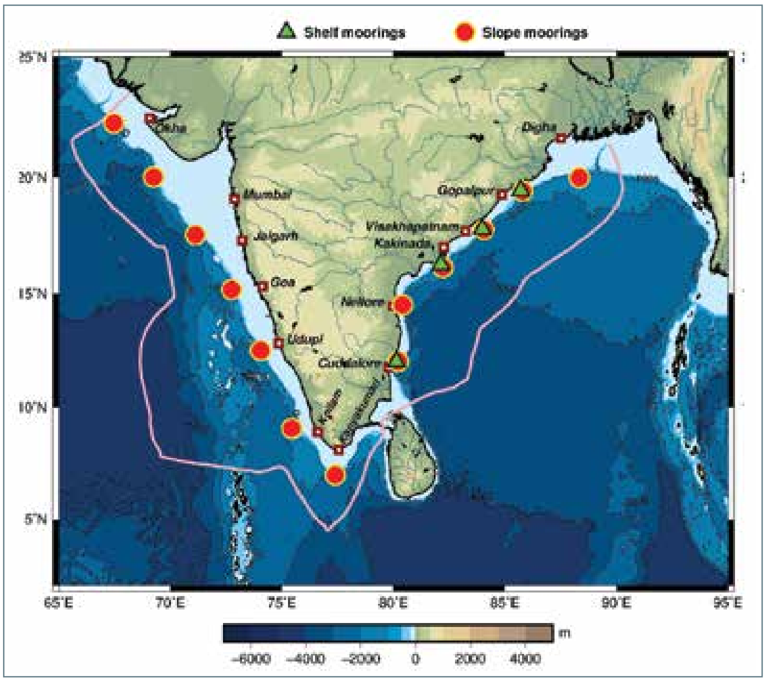


Fig. 6.16 Schematic showing the locations of ADCP moorings in slope (red filled circles) and shelf (green filled triangles) regions of the Indian coastal waters. The pink line marks the Indian EEZ.

Further, the back scatter data from the ADCPs have been analyzed and documented. The available data from the continental slope in the eastern Arabian Sea have been used to show that the seasonal cycle of zooplankton standing stock varies in the eastern Arabian Sea (Fig. 6.17). The seasonal variation is weak in the southeastern Arabian Sea, but it is stronger farther north. The standing stock varies seasonally in the northeastern and central-eastern Arabian Sea and is maximum (minimum) during the winter (summer) monsoon. This seasonal variation of standing stock is in contrast to that of satellite-derived chlorophyll-*a*, which peaks in the eastern Arabian Sea (EAS) during the summer monsoon.

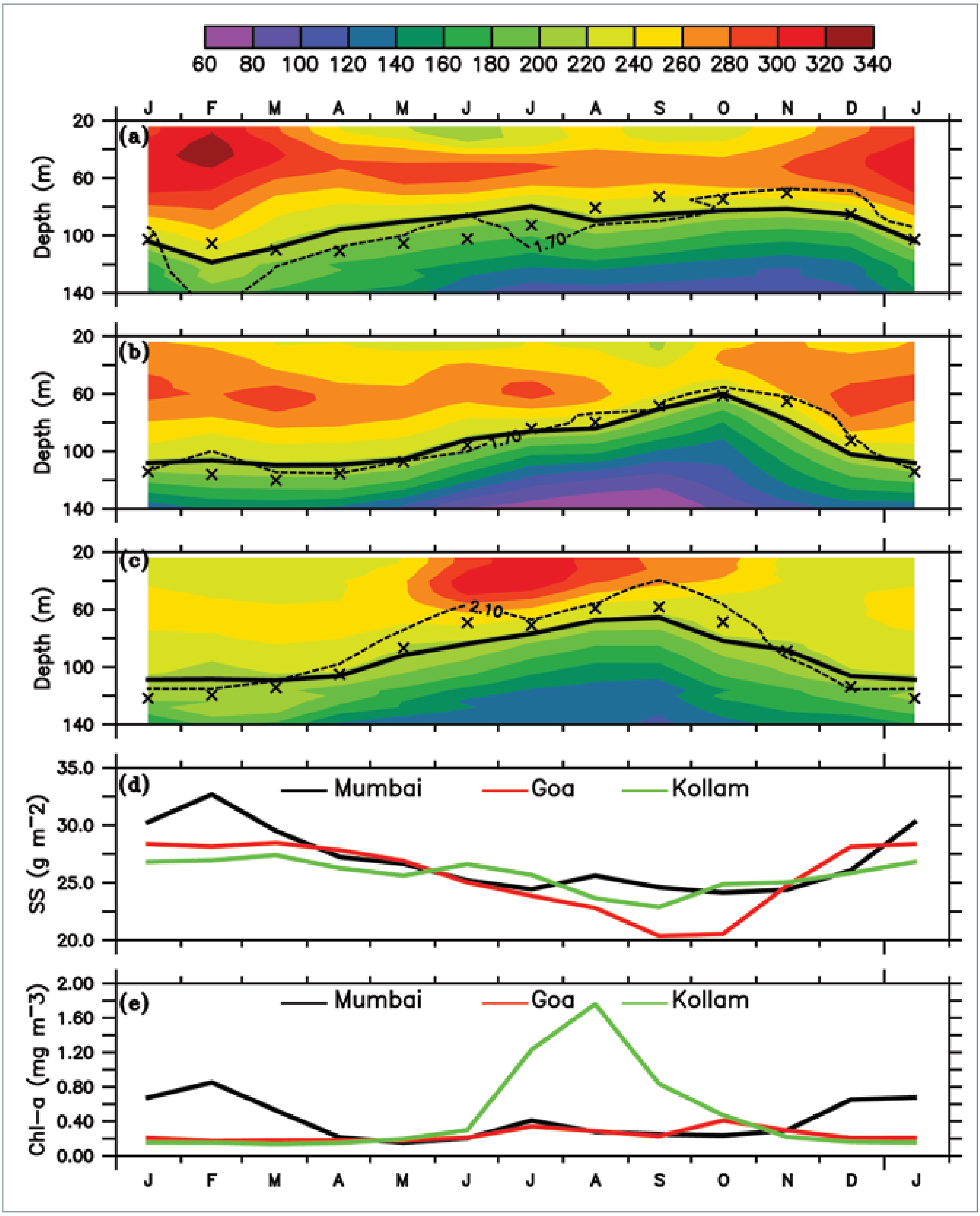


Fig. 6 .17 The seasonal variation of the monthly climatology of biomass (mg/m³), standing stock (wet weight g/m⁻²), and chlorophyll-a (mg m⁻³), showing the climatological seasonal cycle. The monthly climatology was estimated by averaging all the available values for the given month. (a) The monthly climatological seasonal cycle of zooplankton biomass off Mumbai; the solid black curve is the depth of 215 mg m⁻³ biomass contour, the crosses mark is the depth of the 23°C isotherms, and the dashed curve marks the oxycline, which is denoted by the 1.7 ml/l (2.1 ml/l) contour for Mumbai and Goa (Kollam). D23 is plotted instead of 20 because they are roughly parallel, and the latter exceeds 140 m during the winter monsoon. The value for January is repeated at the end of the abscissa. (b) As in (a), but off Goa. (c) As in (a), but off Kollam. (d) The monthly climatological seasonal cycle of standing stock off Mumbai (black), Goa (red), and Kollam (green). (e) As in (d), but for chlorophyll-a.

6.4 Coastal Water Quality Monitoring Buoy

As a part of the "Coastal Monitoring Programme" under the Umbrella Scheme "Ocean Services, Modelling, Application, Resources and Technology (O-SMART)" implemented by MoES, Govt. of India, INCOIS is in the process of establishing "Coastal Observatories" along the Indian coast. The program's main aim is to monitor the Indian coastal water, understand its long-term impacts, and provide short-term forecasts on the water quality along the Indian coast. Real-time information and short-term forecast on the coastal water quality will benefit the coastal population, help minimize coastal hazards such as those related to food poisoning arising out of the ocean and boost coastal tourism and recreational activities. The coastal observatories will be in the form of moored buoys housing multiple sensors for physical (temperature, salinity, depth, surface current) and water quality (dissolved oxygen, nutrients, chlorophyll, turbidity, pH, pCO_2) parameters (Fig. 6.18). The buoy will be deployed at approximately 30 m water depth (~6-8 km from the coast) and will have the capability to withstand harsh sea conditions. Two buoys were delivered to off Kochi and Visakhapatnam, and sensor validation with in-situ measurements of the various parameters has been carried out. Water quality sampling at the proposed location is initiated in collaboration with CSIR institutes CSMCRI, NIO-Goa, NIO-RC, Kochi, and NIO-RC, Visakhapatnam. Test deployment of the buoy in

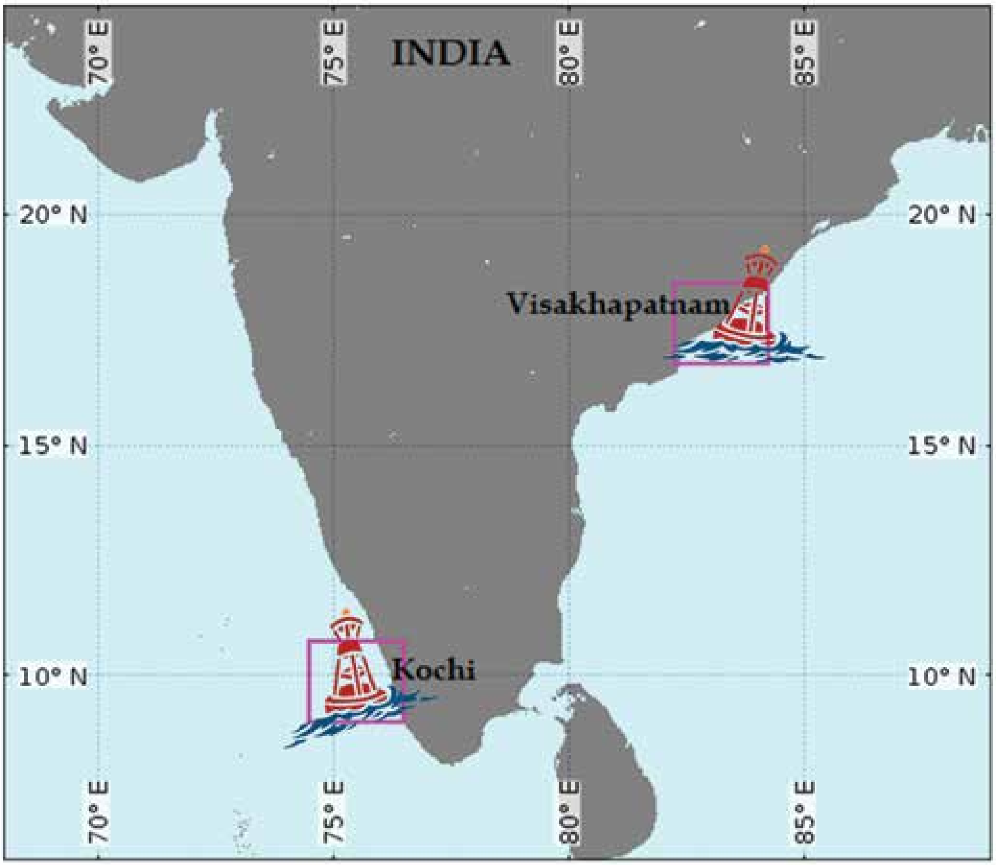


Fig. 6.18 First Phase deployment locations of Coastal water quality buoy off Kochi and Visakhapatnam. The chlorophyll-a (mg m^{-3}) during January 2003.

the estuarine region was conducted on 03 March 2022, and the first phase of buoy deployment at off Kochi is planned in May 2022 (Fig. 6.19).

Fig. 6.19 Test deployment of the water quality monitoring buoy in the estuarine region off Kochi on 03 March 2022.

6.5 GNSS and Strong Motion Accelerometer (SMA) Network at Andaman & Nicobar Islands

INCOIS has planned to establish GNSS and SMA network in Andaman and Nicobar Islands at 35 locations (Fig. 6.20). During the reporting period, the construction of the recording room at the Wandoor location has been completed, and SMA sensors are installed, and it is functional now (Fig. 6.21). Half-yearly maintenance of SMA sensors has been performed at 31 locations during the reporting period. Presently, the construction of the recording room has been completed at 32 stations, and GNSS and SMA sensors have been installed at 31 and 32 stations, respectively, with co-located SMA, GPS, and meteorological sensors with real-time VSAT connectivity. The construction of the observatories in the three remaining locations is in progress.

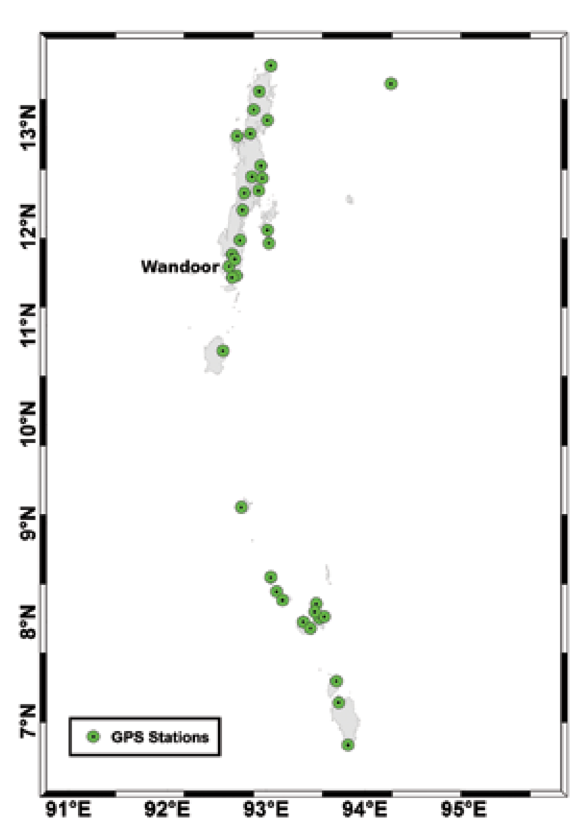


Fig. 6.20 GNSS and SMA network at Andaman and Nicobar Islands. The newly constructed recording room at Wandoor is highlighted.

6.6 INCOIS scientific cruises

INCOIS conducted a cruise in the Bay of Bengal during 04-08 February 2022 onboard CRV Sagar Tara. The main objective of this cruise was to collect high-quality eddy covariance flux observations and air-sea bulk meteorological data from the Bay of Bengal

Fig. 6.21 The newly constructed GNSS and SMA recording room at Wandoor. The inset map at the bottom shows the SMA sensor.

(Fig. 6.22). One advantage of Eddy covariance fluxes from the ship-borne system compared to that from the mooring is that the ship-based eddy covariance fluxes are from a height above the wave boundary layer and hence uncontaminated by waves. Detailed quality checks and data processing have been carried

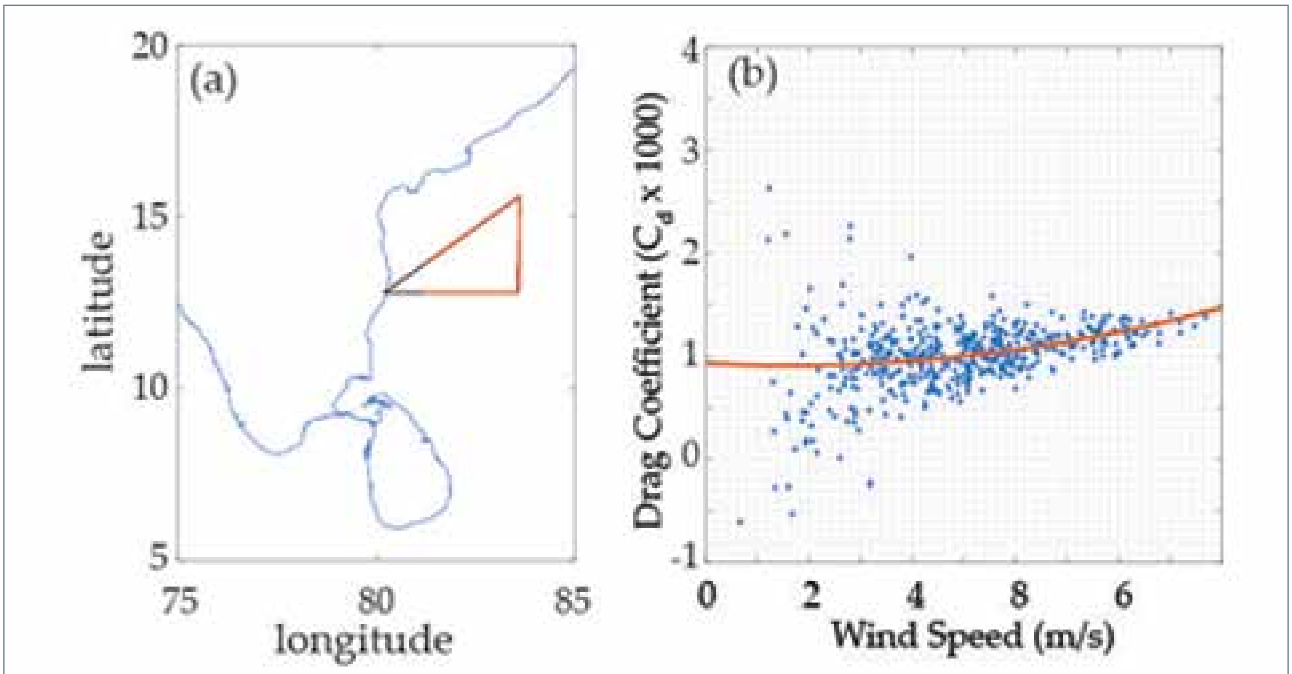


Fig. 6.22 (a) Cruise track of CRV Sagar Tara during 04-08 February 2022 in the Bay of Bengal. Eddy Covariance data was collected from the red highlighted track. (b) Variation of drag coefficient as a function of mean wind speed. The red curve is the best fit curve of the data.

out with the raw eddy covariance flux data to estimate high-quality air-sea turbulent fluxes. Preliminary analysis suggests a large scatter of drag coefficient in the low wind speed regime, while there is a convergence of values in the higher wind regimes. This observation indicates that other processes, like swell waves, may modify the sea surface's roughness and drag coefficient, thus impacting the turbulent fluxes. Detailed data processing and analysis are presently underway.

6.7 Progress of Flux Mooring Data Analysis

The quality control of near-surface meteorological, sub-surface temperature, salinity, and current measurements from the flux mooring has been accomplished, and data analysis is being initiated to meet the proposed scientific objectives during the reporting period. At present, the research is being carried out in two directions. First, the micro-meteorological aspects of the Bay of Bengal are being studied using the available Eddy Covariance flux and bulk meteorological data. A significant amount of time has been dedicated for developing the flux processing algorithm to process high-frequency eddy covariance data. Eddy Covariance fluxes have been successfully estimated. Secondly, the upper ocean variability and the water mass modifications resulting from the freshwater influx are studied using the hydrographic data collected from the mooring. A brief account of the preliminary results obtained from the data processing is provided here.

6.7.1 Micro-meteorological conditions of the Bay of Bengal

A major focus of INCOIS scientists working with the eddy covariance fluxes is to check the validity of widely used bulk flux algorithms during the monsoon period in the Bay of Bengal. Initial results indicate large variations (20-25%) in the drag coefficient which is a function of rain flux in the near-neutral boundary layer conditions (Fig. 6.23). In such situations, the non-dimensional shear estimation from widely used bulk flux algorithms differs significantly compared to eddy covariance data from the Bay of Bengal. Initial analysis suggests that correcting the non-dimensional shear estimation will improve the transfer coefficients and hence the bulk flux estimation in the Bay of Bengal, especially during the monsoon months. Detailed analysis is under process.

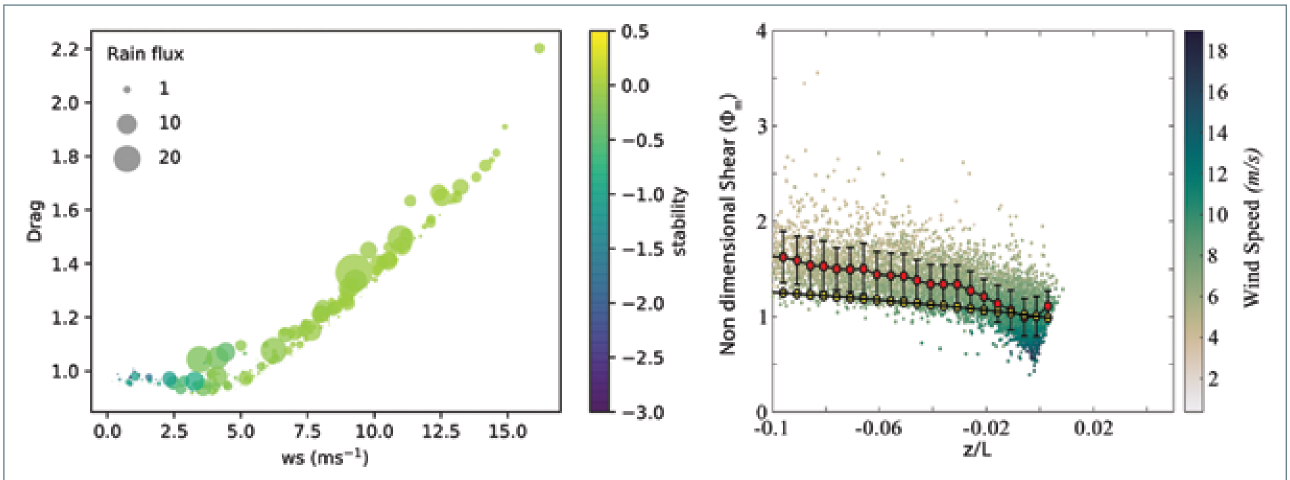


Fig. 6.23 (a) Drag Coefficient vs. wind speed as a function of rain flux and stability (z/L) during June. (b) Non-dimensional shear vs. boundary layer stability (z/L) as a function of mean wind speed during June. Here black circles indicate the estimation from the coare 3.5 bulk flux algorithm, and red circles indicate the estimate from the INCOIS Eddy Covariance Flux system. Error bar indicates one standard deviation.

6.7.2 Statistical estimation of flux events in the Bay of Bengal from ECFS data

Another research problem that includes ECFS data, is to study the existence of a series of organized motions in the boundary layer turbulent flow, called coherent structures, that produce, modify, and dissipate the boundary layer turbulence. These coherent structures play an essential role in the turbulent transport of heat and momentum across the boundary layer (Fig. 6.24). A reasonable understanding of these coherent structures is critical in developing some predictive ability of boundary layer turbulence. The preliminary findings suggest that sweeps and ejection processes (both transfer momentum flux from air to the ocean) significantly increase the total momentum flux. In contrast, outward interactions (ocean transfer momentum flux to the atmosphere) reduce the total momentum flux. At the flux mooring location, it is found that the above observation is mainly related to the mean wind speed. The outward interaction processes are comparable to sweeps and ejections in low winds, whereas sweeps and ejections are dominant in high winds. Detailed analysis is presently under process.

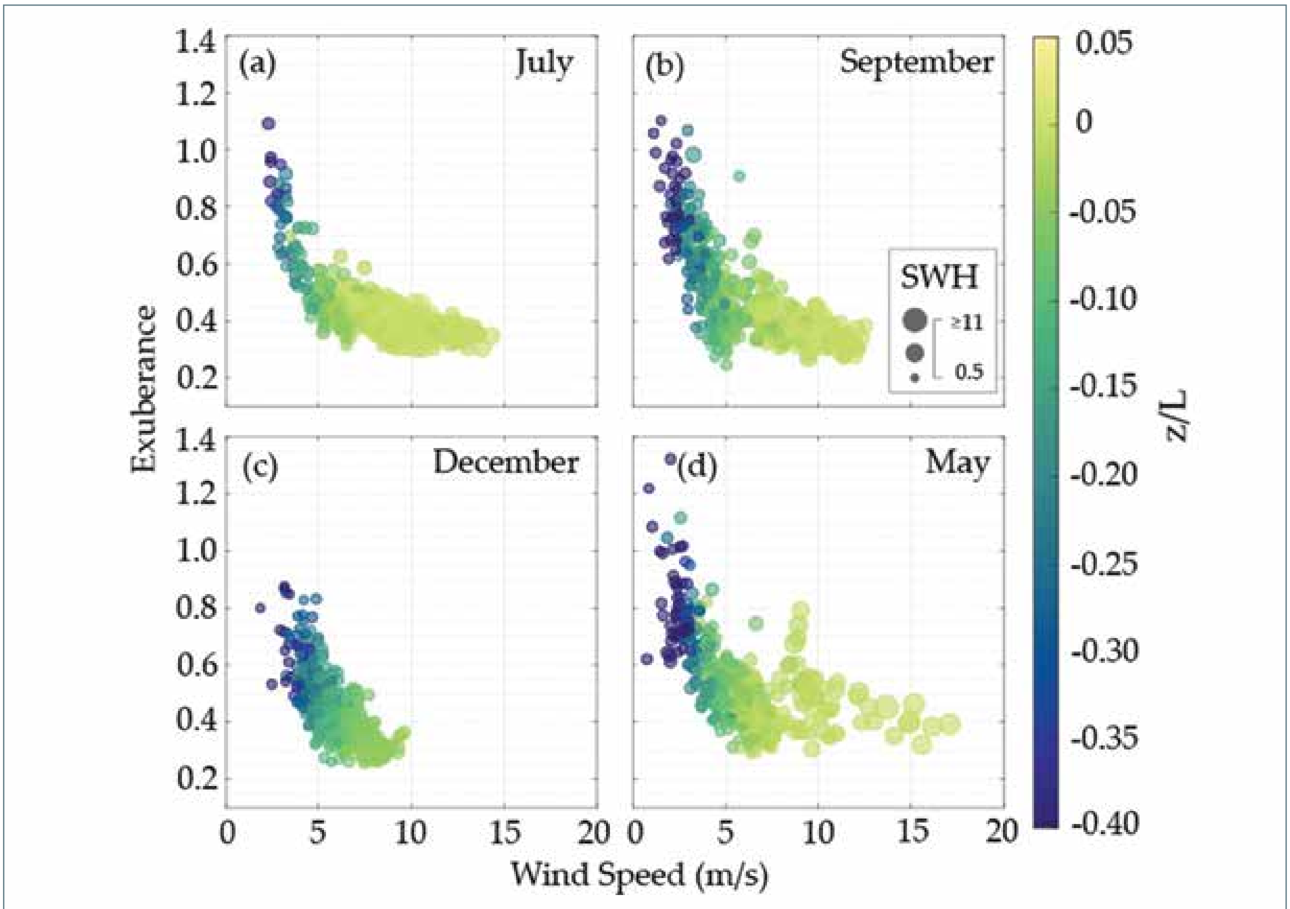


Fig. 6.24 Exuberance (E) which is the ratio of the sum of outward interactions to the sum of sweeps and ejection process as a function of mean wind speed, stability, and significant wave height. E values closer to 1 indicate a comparable contribution from outward interaction and sweep plus ejection processes. In contrast, smaller E values indicate a substantial contribution from the sweep and ejection processes to the total momentum flux.

6.7.3 The seasonality of spiciness in the near-surface layer in the Bay of Bengal

The hydrographic observations from the flux mooring at the Bay of Bengal, one of the freshest basins globally, provide an unprecedented opportunity to look into the water mass modifications due to the freshwater influx (Fig. 6.25). To describe such isopycnal variations of temperature and salinity in the Bay of Bengal, Diapycnal Spiciness Curvature (DSC) is estimated. The absolute values of DSC indicate vertical interfaces between dissimilar water masses, characteristic of interleaving or local water mass modification. Detailed analysis to understand the processes of water mass modification due to the freshwater influx is presently under process.

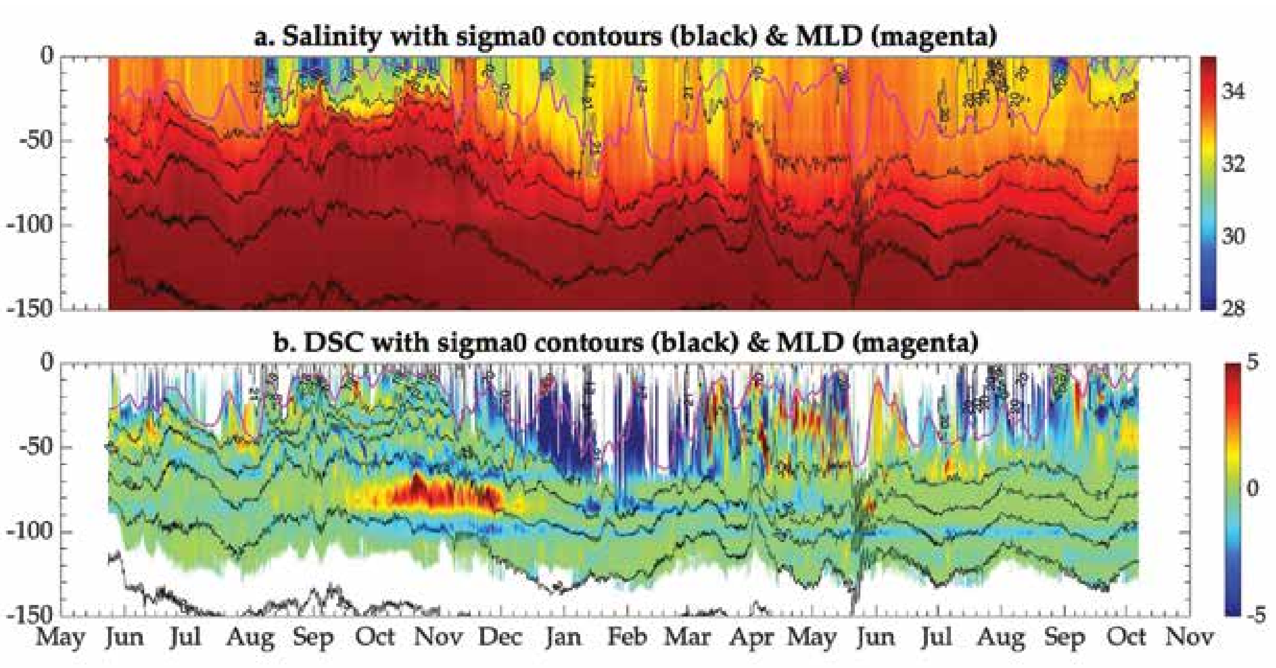


Fig. 6.25 Depth time section of (a) Salinity and (b) Diapycnal Spiciness Curvature (DSC) with sigma-θ contours (kg/m^3; black) and mixed layer depth (MLD) derived from INCOIS flux mooring. DSC indicates vertical interfaces between dissimilar water masses, characteristic of interleaving or local water mass modification.

6.8 Deep Ocean Mission: Glider operation in the Bay of Bengal

To implement the objectives of the observations component of the Deep Ocean Mission program, INCOIS procured and deployed two Slocum Gliders (SG) in the Bay of Bengal to monitor the physical and biogeochemical variables in the upper 1000m of the water column in the northern Indian Ocean. Both gliders (SG890 and SG891) were deployed on 05 March 2021 onboard ORV Sagar Nidhi (SN-162) at the central Bay of Bengal. The measurements from these two gliders have been used to understand

Fig. 6.26 Recovery of a glider on 20 May 2021.

the temporal and spatial variability of the physical and biogeochemical variables in the northern Indian Ocean. The gliders covered a northern (SG890; between 11.50°N, 88.79°E - 17.50°N, 88.79°E) and southern transect (SG891; between 11.50°N, 88.79°E - 4.50°N, 88.79°E) within two and half months and covered a total distance of ~5000 km. Both gliders were successfully recovered between 18 and 20 May 2021 onboard ORV *Sagar Kanya* (SK-370) (Fig. 6.26 and 6.27). Data processing and analysis of the measurements from these gliders are in progress.

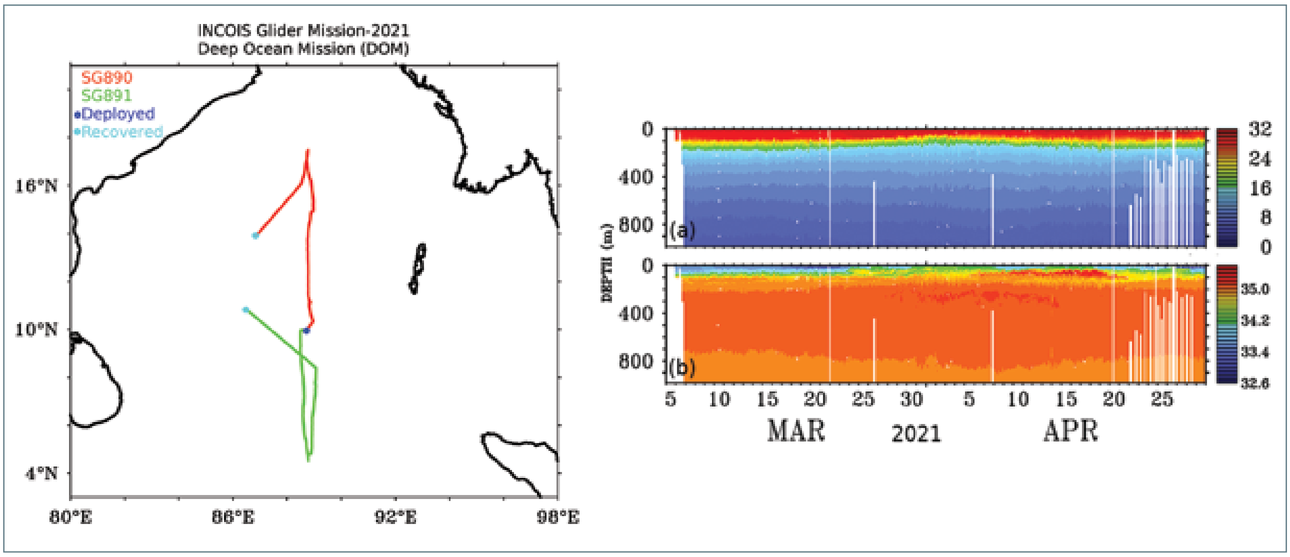


Fig. 6.27 (left panel) Northern and southern transects of the gliders, (right panel) temperature (°C), and salinity from gliders during testing phase.

7

OCEAN MODELING & DATA ASSIMILATION

7 OCEAN MODELING & DATA ASSIMILATION

7.1 Numerical Ocean Modeling and Data Assimilation for Operational Services

INCOIS has been spearheading the research in numerical ocean modeling and data assimilation in India for the past several years while taking the responsibility to provide ocean analysis, reanalysis, and forecasts in and around the Indian Ocean. This has led to the successful implementation of the High-resolution Operational Ocean Forecast and reanalysis System (HOOFS). The system consists of a suite of models configured using the Regional Ocean Modeling System (ROMS) coupled with marine ecosystem models and integrated with the data assimilation scheme, known as the Local Ensemble Transform Kalman Filter (LETKF), to model the regional and coastal ocean processes.

7.1.1 High-resolution Operational Ocean Forecast and reanalysis System (HOOFS)

The high-resolution operational model, NIO-HOOFS, with a nominal resolution of ~ 2.8 km over the north Indian Ocean encompassing the Indian coastline lacked assimilation of any observations. The data assimilation team of INCOIS succeeded in developing an assimilation scheme based on LETKF coupled offline to the ocean general circulation model ROMS wherein the temperature and salinity profiles from various observation network are assimilated along with the satellite track data of sea-surface temperature (SST) from the Group for High Resolution Sea Surface Temperature (GHRSST). The assimilation significantly improves the SST estimation of the model and the coastal currents (Fig. 7.1). This assimilation system will be made operational soon.

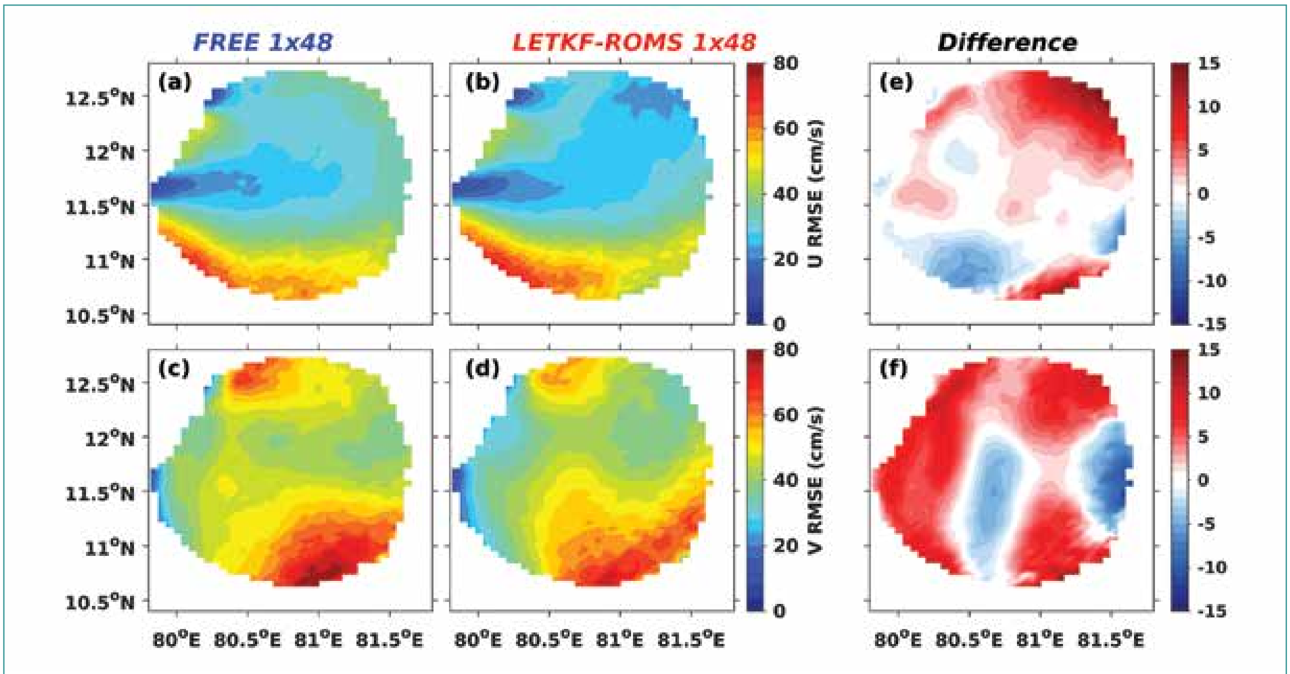


Fig. 7.1 Improvements in Currents with SST assimilation in NIO-HOOFS. (a-b) Spatial RMSE of Zonal current estimates from FREE and LETKF-ROMS with respect to Tamil Nadu HF radar observations. (c-d) Spatial RMSE of Meridional current estimates from FREE and LETKF-ROMS with respect to Tamil Nadu HF radar observations. (e-f) RMSE difference is shaded. Red (Blue) indicates an improvement (degradation).

The basin-wide Indian Ocean data assimilation system, known as the Regional Analysis of the Indian Ocean (RAIN), provides the initial condition to the basin-wide operational model (~ 9 km horizontal resolution) used to forecast ocean states every five days. RAIN assimilates temperature and salinity profiles from various observation networks along with satellite track data of SST from GHRSST (Fig. 7.2). The data assimilation team successfully developed the assimilation of absolute dynamic topography over the existing RAIN using a novel methodology. The assimilation takes place sequentially. Once the assimilation of physical tracer variables is over, the system estimates the steric height from the analysis at each model grid point. This steric height is deducted from the satellite observations to bring it at par with the model output since ROMS does not include steric height in its sea level anomaly output. The resultant observations are thereafter assimilated with the previously estimated analysis (derived from assimilating tracers) to get a new analysis. This new-found analysis is the initial condition for the next assimilation cycle and the process is repeated. This process significantly improves ocean analysis. The assimilation of absolute dynamic topography will be a new addition to the existing RAIN shortly.

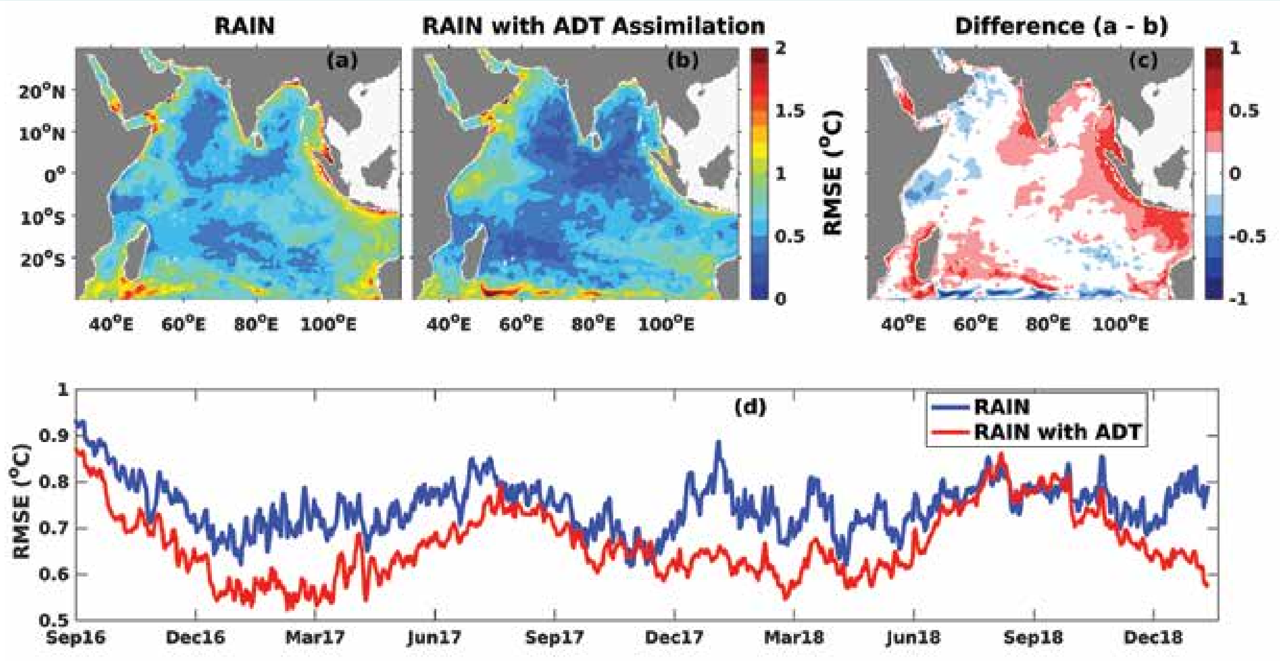


Fig. 7.2 Improvements in SST with ADT assimilation in RAIN. (a-b) Spatial RMSE of SST estimates derived from RAIN and RAIN with ADT assimilation with respect to AVHRR observations. (c) RMSE difference is shaded. Red (Blue) indicates an improvement (degradation). (d) Temporal RMSE of SST estimates derived from RAIN and RAIN with ADT assimilation with respect to AVHRR observations.

7.1.2 Biogeochemical State of the Indian Ocean (BIO)

The international carbon cycle research community is currently coordinating the largest and the most comprehensive assessment it has ever undertaken: the REgional Carbon Cycle Assessment and Processes Phase 2 (RECCAP-2). RECCAP-2 is coordinated by the Global Carbon Project and collects and synthesizes regional data for 14 large regions of the globe with a requirement of harmonization sufficient to be able to scale these budgets to the globe and to compare different regions. Within the ocean-specific part of RECCAP-2, a global consortium of partners aims to better quantify and understand the CO_2 fluxes into and out of the ocean, the associated changes in ocean carbon storage beneath the sea surface, as well as the role of the ocean's biological pump. The international community has submitted global and regional models' simulated surface ocean pCO_2 levels and air-sea CO_2 fluxes along with surface and interior ocean properties of a list of ocean state variables to the FTP Server hosted at MPI Jena, Germany under RECCAP-2. The evaluation of surface ocean pCO_2 levels and air-sea CO_2 fluxes is being carried out against available observations by the RECCAP-2 Indian Ocean chapter to identify the best models reproducing the real scenarios in the Indian Ocean basin.

7

OCEAN MODELING & DATA ASSIMILATION

A regional coupled ocean-ecosystem model (known as INCOIS-BIO-ROMS) for the extended Indian Ocean region has been configured following the 'RECCAP-2: Ocean Modeling Protocol' for the regional oceans to participate in the above-mentioned assessment process. The model simulated data for a period from 1980 to 2019 (Fig. 7.3) has been submitted to the MPI-BGC data server. The evaluation process has been initiated by the Indian Ocean chapter and it is under process.

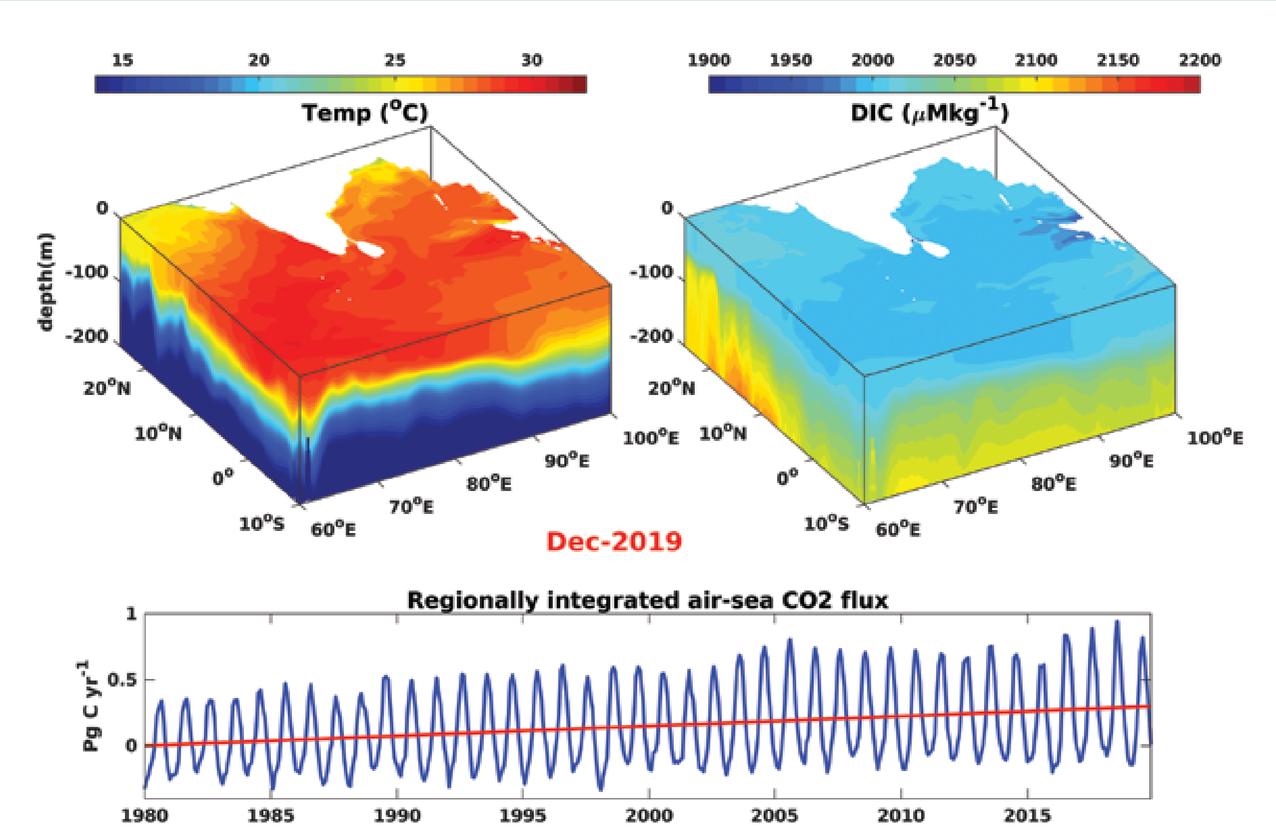


Fig. 7.3 Model simulated upper ocean structure of temperature (°C) and dissolved inorganic carbon (μM/kg) in Dec 2019 (top panels). Time series evolution of the regionally integrated air-sea CO_2 flux for the Indian Ocean from 1980 to 2019 (bottom panel).

7.1.3 INCOIS- Global Ocean Data Assimilation System (GODAS)

The global ocean analysis provided by INCOIS is based on the Global Ocean Data Assimilation System (INCOIS-GODAS), a modified version of the NCEP-GODAS. The model is based on Modular Ocean Model (version 4.0) with a tripolar global grid. Its horizontal resolution is 0.5° (~55 km) in zonal and varying meridional resolution (0.25° within 10°S-10°N) which gradually increases to 1° at the poles. The model uses a Three-Dimensional Variational (3DVAR) data assimilation system to assimilate observed T/S profiles (Fig. 7.4) obtained through the Global Telecommunication System (GTS). The model simulation is used to provide lateral boundary conditions for IO-HOOFS. INCOIS-GODAS also provides oceanic initial conditions for the seasonal and extended range prediction of the Indian monsoon using the Climate Forecast System (v2) issued by the India Meteorological Department (IMD). This system also provides climate outlooks for El-Nino and IOD indices.

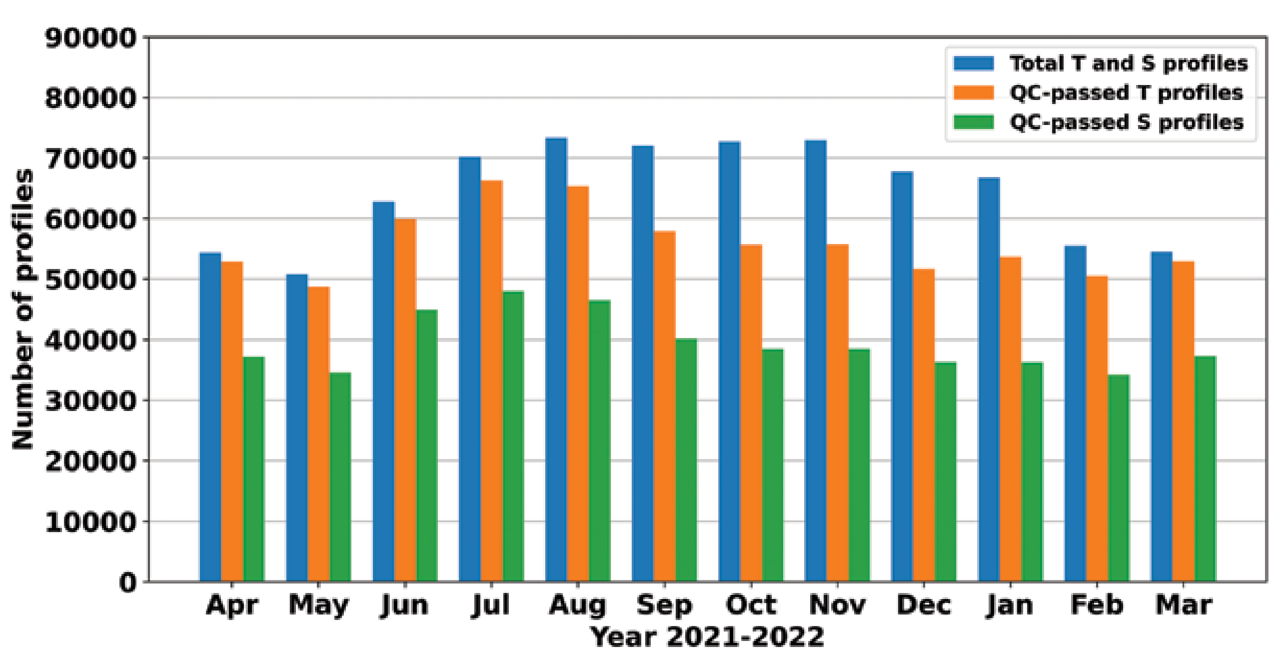


Fig. 7.4. Monthly data inventory (total no. of T/S profiles received and the number of profiles assimilated after quality-control module developed at INCOIS) from Apr 2021 to Mar 2022.

7.2 Ocean Modeling Mission - Development of a Unified Operational Ocean Forecast System

INCOIS is the nodal agency for the operational ocean forecasts and therefore, INCOIS relies on the extensive integrated development of numerical modeling frameworks such as ocean circulation, tsunami, storm surge, waves, and regional coupled ocean-atmosphere model. To optimize the model resources used for operational ocean model development, INCOIS has taken up a unified ocean modeling system framework under its Modelling Mission. Global and regional ocean analyses are some of the most critical products that INCOIS generates for the initialization of short/medium/extended range and seasonal forecast models of the Indian summer monsoon, short-term ocean state forecasts as well as the datasets used for preparing climate indices. These datasets are extensively used for ocean process studies as well. The Ocean Modeling Mission of INCOIS envisages that the global to regional level ocean circulation model will be configured based on Modular Ocean Model version 6 (MOM6). Integration of marine ecosystem models in the regional and global configurations will follow the configuration of the respective physical model configurations. The Carbon, Ocean, Biogeochemistry and Lower Trophic (COBALT) ecosystem model will be used to model the biogeochemical and planktonic food web response. A large number of users of INCOIS services request information/forecasts/advisories for the coastal waters around the country. This includes the forecasts on coastal currents, waves, tides, etc. Further, the critical operational services such as tsunami and storm surge predictions also have significant implications on the life and livelihood of millions living along the coastal regions. Hence, it has been decided that while Tsunami and Storm Surge predictions will be carried out based on the ADCIRC model coupled with SWAN (to incorporate the effects of waves, wherever it is important), the wave forecasts will be based on WAVEWATCH III and for the prediction of water quality in the coastal/shelf sea/estuaries, coupled ocean-ecosystem models will be configured based on Finite Volume Community Ocean Model (FVCOM).

7.2.1 Development of global/regional models for ocean analysis/reanalysis

MOM6 is a numerical ocean model that can be applied to simulate ocean circulation from the regional scale to the planetary scale. It is based on a horizontal C-grid stencil and uses vertical Lagrangian remapping (a variant of the Arbitrary Lagrangian-Eulerian (ALE) algorithm) to enable choices of either sigma or isopycnal or geopotential or Z or a hybrid vertical coordinate system.

The goal is to replace the existing operational regional Indian Ocean ROMS model with a very high resolution MOM6 model. MOM6 is a complex ocean general circulation model compared to its predecessors. Therefore, a bottom-up approach starting with a simpler configuration to gradually enhance the complexity has been adopted. The model is initially tested with a very coarse (1° X 1°) spatial resolution. For the vertical layers, various possibilities with a simple Z-star to complex hybrid coordinates are tested. Experiments are also conducted with a different number of hybrid vertical layers to test the optimum number of layers needed for simulating Indian Ocean physical processes. At present, an eddy-permitting Indian Ocean model of uniform 0.25° X 0.25° (~25 km) horizontal resolution is being configured. For the open southern and eastern boundaries of the model, various open boundary conditions such as closed, sponge, and existing radiation boundary conditions are tested. The model simulation has been completed for 25 climatological years. The initial model simulated climatological surface temperature and salinity compared well with the World Ocean Atlas 2013 (Fig. 7.5).

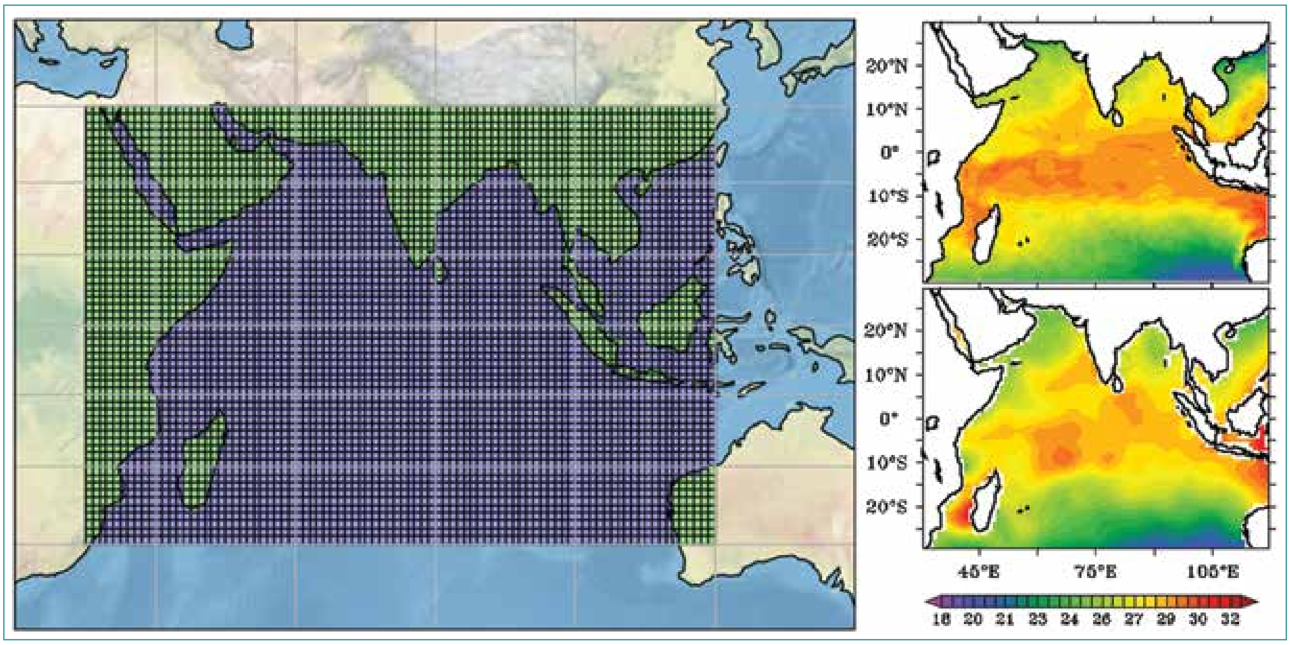


Fig. 7.5 Domain of the Indian Ocean grid for uniform 0.25°X0.25° horizontal resolution (left panel). Comparison of climatological SST for December from MOM6 (left) and World Ocean Atlas 2013 (right panel).

7.2.2 Development of coastal/shelf sea/estuary models for coastal applications

7.2.2.1 Coastal General Circulation Modeling

Most of the users of INCOIS services require information/forecasts of the ocean state near the coasts, including shelf sea and continental margins. Hence, the numerical ocean models used for the operational services must be fine-tuned to simulate the near-shore processes with better accuracy. Improving the representation of coastal and shelf seas in global models is a great challenge to the ocean modeling community. Accurate forecasts of the near-shore ocean state require a high-resolution finite element modeling approach that can better delineate the coastlines and shallow regions and improve the representation of physical and biological processes. In this context, a finite element mesh (varying resolution between 2.5 km and 500 m) has been created for the Cochin region (Fig. 7.6) using INCOIS-GEBCO blended bathymetry (500 m resolution). A hydrodynamic model has been configured using FVCOM for the coastal waters off Cochin as a pilot study. A compatible version of the physical system has been successfully installed in Mihir-HPC. Several test case experiments were conducted to test the stability and performance of the physical model. Extensive scripts have been developed to prepare initial condition and hourly boundary conditions of the physical state variables in FVCOM from the operational NIO-HOOFS (1/48 degree) model outputs of INCOIS. The physical model simulations have been carried out for a year, using 45 vertical layers, hybrid coordinates, and nested boundary conditions. The results were compared with available observations of temperature, salinity, and sea level anomaly. The model could reproduce the diurnal variability and the seasonal cycle of physical state variables. Sensitivity experiments are being conducted to fine-tune the physical model to further improve the accuracy of the simulations.

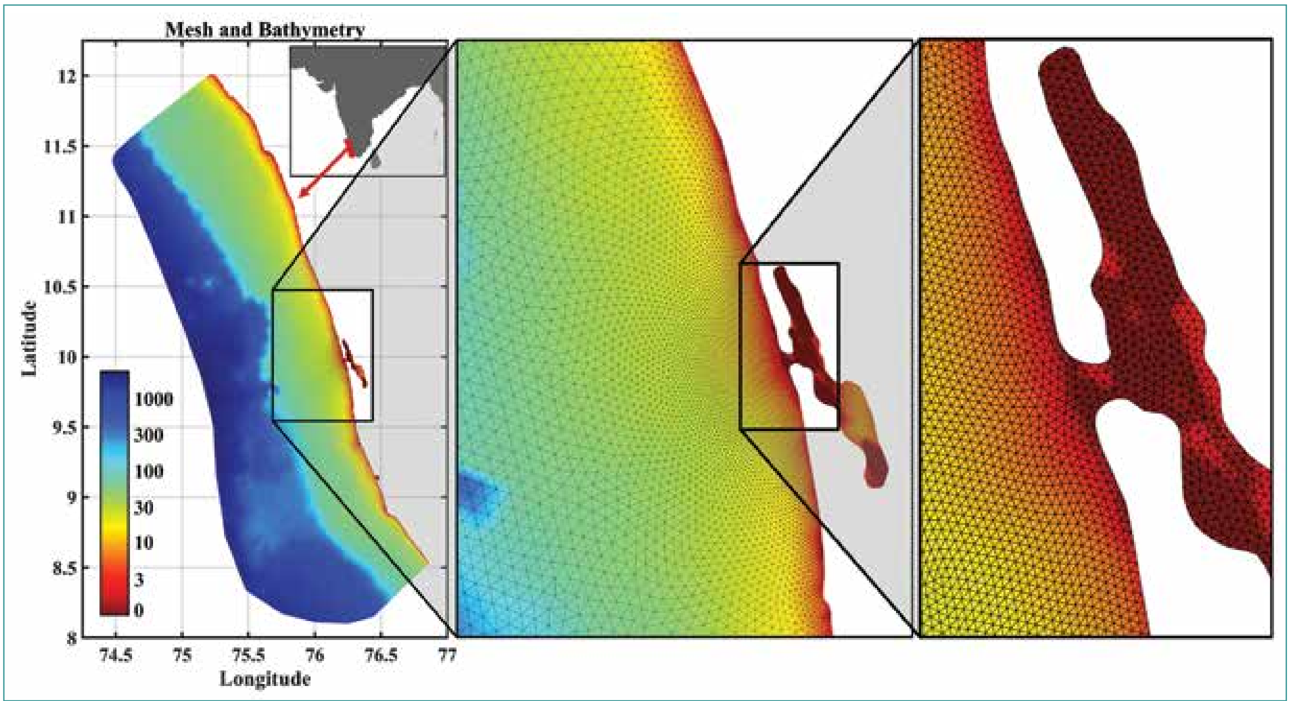


Fig. 7.6 Flexible mesh grid of the physical model configured using FVCOM for the coastal waters off Cochin. The resolution varies from 250 m in the estuary and near coastal waters to 2.5 km in the open ocean. The background colour is the INCOIS-GEBCO merged bathymetry.

7.2.2.2 Coastal Wave Modeling

Information about ocean waves is in high demand among the users of Ocean State Forecast, provided by INCOIS. The coastal community, including the fisherfolk and the owners of small vessels, need this information at high resolutions, while the industry such as shipping and ONGC need the information at moderate resolutions. Due to the varying demands on resolution and accuracy, the best option is to go for a wave model which has a very fine resolution near the coast and moderate resolution elsewhere. The wave model WAVEWATCH III 6.07 (WWIII) has the capability of having fine resolution unstructured mesh near-shore and coarse/medium resolution structured meshes in the open ocean, and hence suits the purpose. Therefore, it has been planned to configure a coastal WWIII model with unstructured mesh, nested in a global WWIII with structured mesh. As a first step towards this goal, a high-resolution model has been configured for the Indian ocean using WWIII. This configuration would be beneficial for fine-tuning, and research involving wave-current interaction studies. The model has a grid resolution of 1/10° with a spatial extent of 15°E - 120°E & 70°S - 30°N. The model grid uses ETOPO1 bathymetry and GSHSS high resolution coastline. The wave parameters such as significant wave height, wave periods, wave directions, and wind speed were validated with available moored buoy observations in the Bay of Bengal and the Arabian sea. The results of validations were quite encouraging, with an average correlation coefficient of 0.96, average negative bias of 8 cm, average RMSE of 24 cm, and an average scatter index of 0.14 for all the moored buoy locations together (Fig. 7.7).

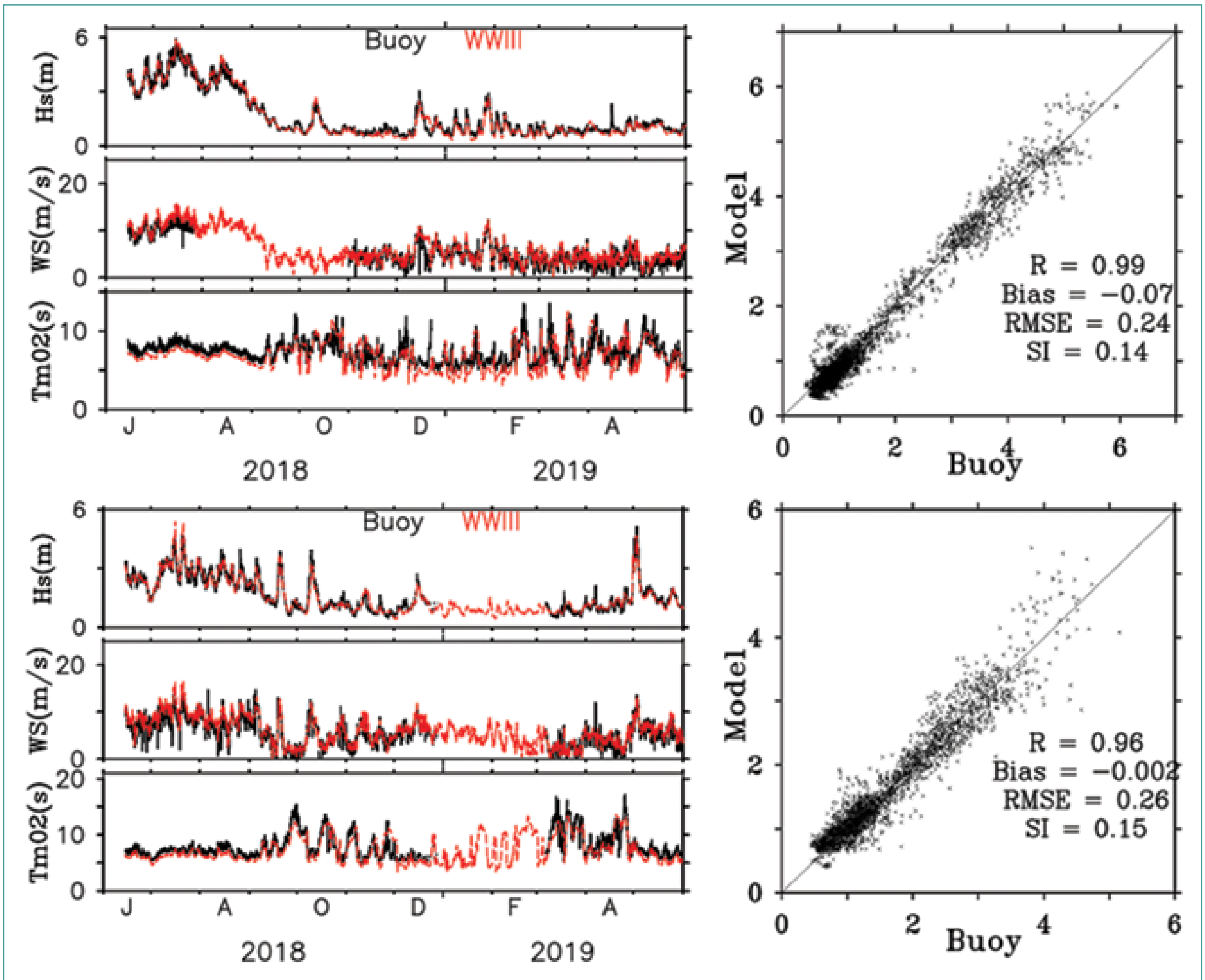


Fig. 7.7 The comparison of the temporal evolution of model simulated and observed significant wave height, wind speed, and mean wave period is shown on the left panel. The scatter plots on the right panel correspond to the significant wave height. The top panels correspond to a location in the Arabian Sea and the bottom panels correspond to a location in the Bay of Bengal.

7.2.2.3 Storm Surge Modeling

Storm surge early warning centers forecast storm surge threats to coastal inhabitants during tropical cyclones. Atmospheric numerical models forecast the cyclone track and intensity for three to four days with uncertainty. The storm surge warning centers mainly use the track and provide warnings in a deterministic way; such methodology has uncertainties and might lead to false warnings. To counter this issue and improve forecasting capabilities, a Probabilistic storm surge (P-surge) approach considering the uncertainties in track and intensities is introduced. P-surge is an ensemble-based storm surge computation where Monte Carlo storm surge simulations are performed with multiple tracks that landfall at different points with different intensities within the cone of uncertainty. The cyclone track is usually shifted by every 10 km on either side, considering uncertainty in the intensity of the deterministic track within the cone of uncertainty. The number of ensemble members and their spread depends on the cyclone track error associated with the atmospheric model. The storm surge residual is computed in each ensemble member, and the threat level is displayed using probability (Fig. 7.8). At present, P-surge is in experimental mode.

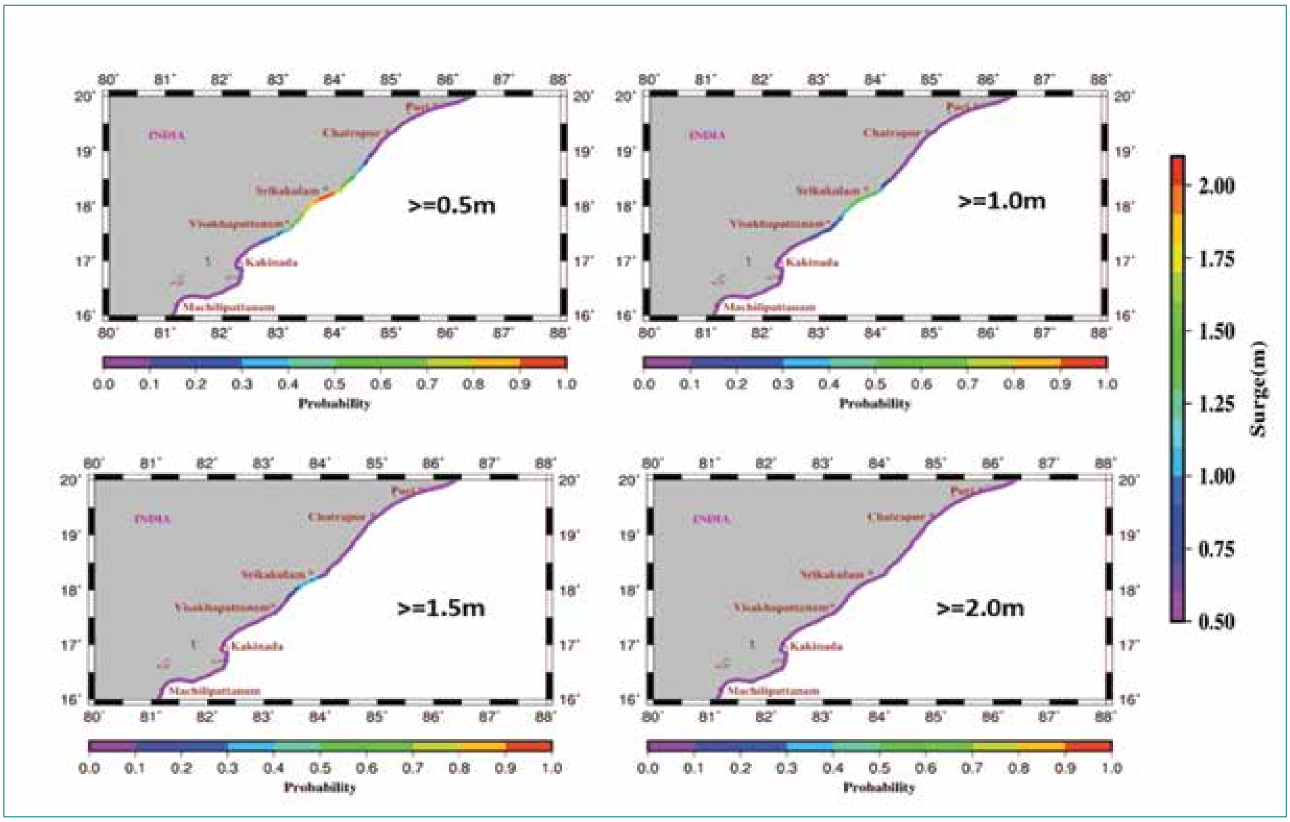


Fig. 7.8 Probabilistic approach of representing surge height

7.2.3 Development of marine ecosystem models for regional and coastal applications

The integration of the European Regional Seas Ecosystem Model (ERSEM), a generic and well-established lower-trophic level marine food web and biogeochemical cycling model, with the physical configuration of FVCOM for the coastal waters off Cochin has been successfully carried out as a pilot study for providing water quality forecasts and monitoring the health of coastal waters off Cochin. The integration of ERSEM with physical FVCOM configuration has been done by enabling their coupling via a universal generic coupler, Framework for Aquatic Biogeochemical Models (FABM) resulting in a high and flexible resolution, coupled, and nested modeling framework (FVCOM-FABM-ERSEM) (Fig. 7.9). The initial and boundary conditions for the ecosystem state variables have been taken from INCOIS-BIO-ROMS and GFDL-ESM 4.1. The results have been compared with available remote sensing and in-situ observations. It is observed that the coupled system reproduces the diurnal variability and the seasonal cycle of ecosystem state variables.

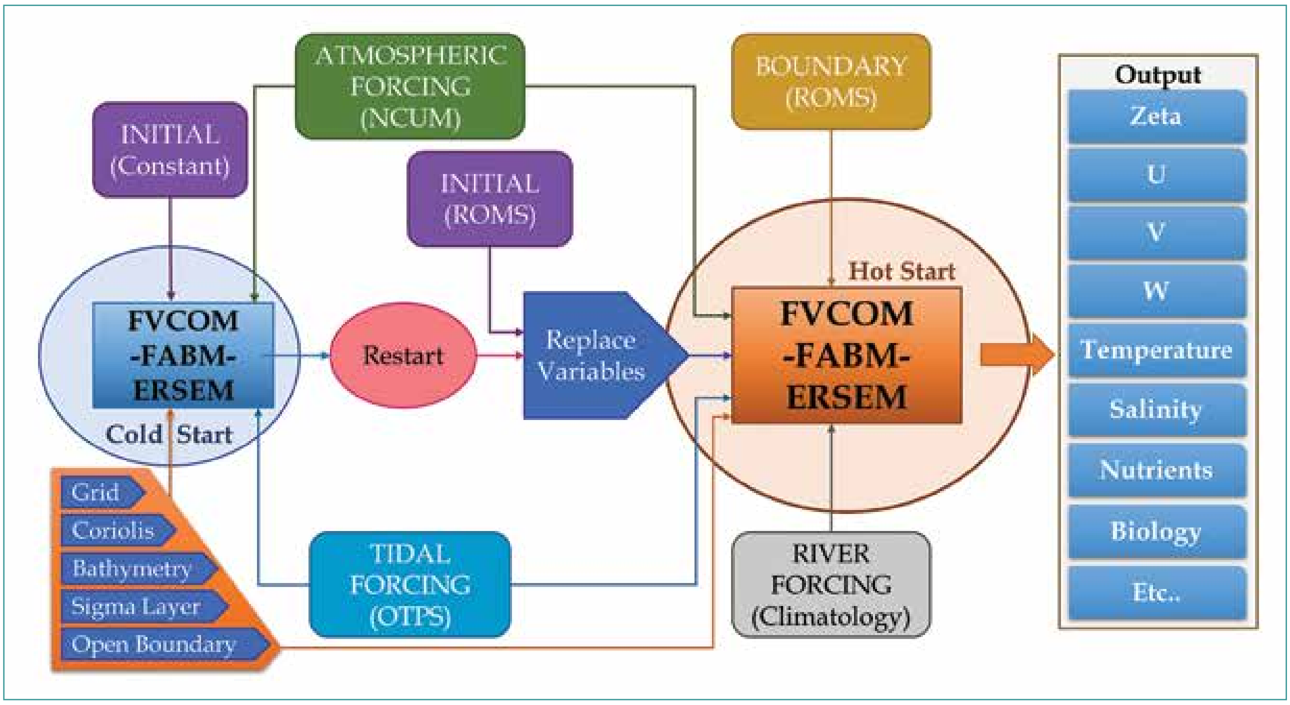


Fig. 7.9 Modeling framework for developing water quality forecasts system using FVCOM

7.2.4 Development of river forcing files for simulating the coastal marine ecosystem

The Indian coastal waters experience strong seasonality attributed to the reversing monsoon effect and river influx. Several perennial and seasonal rivers drain into the Bay of Bengal and the Arabian Sea. These rivers supply a substantial quantum of freshwater enriched with nutrients, suspended matter as well as anthropogenic pollutants into the adjoining coastal ecosystem. Therefore, it's very important to consider the effect of the river as well as the long-term dynamic range of biogeochemical state variables in the near coastal waters while setting up any forecasting/monitoring model. Undermining the dynamic water quality range, including the effect of river influx, the marine ecosystem models can't account for the extreme values and seasonal maxima/minima of biogeochemical state variables. Therefore, a comprehensive review is in the process for collecting a dynamic range of biogeochemical state variables along the Indian coastal waters (Fig. 7.10) from the available literature.

Fig. 7.10 Map shows the locations of stations for monitoring biogeochemical properties of the river runoff along the Indian coastal waters.

7.2.5 Downscaling of atmospheric forcing to force high-resolution models

The numerical models need wind fields as atmospheric forcing to simulate and forecast waves, surges, etc. An increase in the resolution of wind fields greatly benefits the forecast. However, data is frequently available at low resolution for several reasons. Numerical models reconstruct high-resolution data from low-resolution utilizing interpolation techniques. But interpolation techniques fail to capture the sub-grid scale information, resulting in missing original wind magnitudes, leading to inaccurate forecasts. Downscaling is a procedure of reconstructing high-resolution data from low resolution, capturing local effects and magnitudes. Considering the availability of a good amount of past data, Deep Learning (DL) techniques that solely depend on data can be trained to learn the mapping from low-resolution to high-resolution. A well-proven DL technique, super-resolution convolutional neural network (SRCNN), is explored for downscaling wind forcing. The SRCNN method is investigated with six years of the first day forecasted ECMWF wind fields of spatial resolution of 0.25° x 0.25° and temporal resolution of 3 hours for the East Coast of India. The input to DL is a lower-resolution matrix, and the output is an original higher-resolution matrix. The higher-resolution matrix is the original matrix and acts as ground truth; the lower-resolution input matrix is of resolution 1°×1° and is generated from ground truth using traditional interpolation methods. Few variations of SRCNN, a two-layered SRCNN (stacked) and stacked SRCNN with input data augmented along with dependent variables (deepSD), are also applied in the current study to explore the downscaling methodology. It is found that DL methods can reconstruct high-resolution winds from low-resolution wind fields better than the traditional interpolation techniques (Fig. 7.11). Further, we are in the process of investigating the use of DL techniques for downscaling atmospheric forcing. However, the success of applying DL methods is subjective to the availability of a very good length of past data.

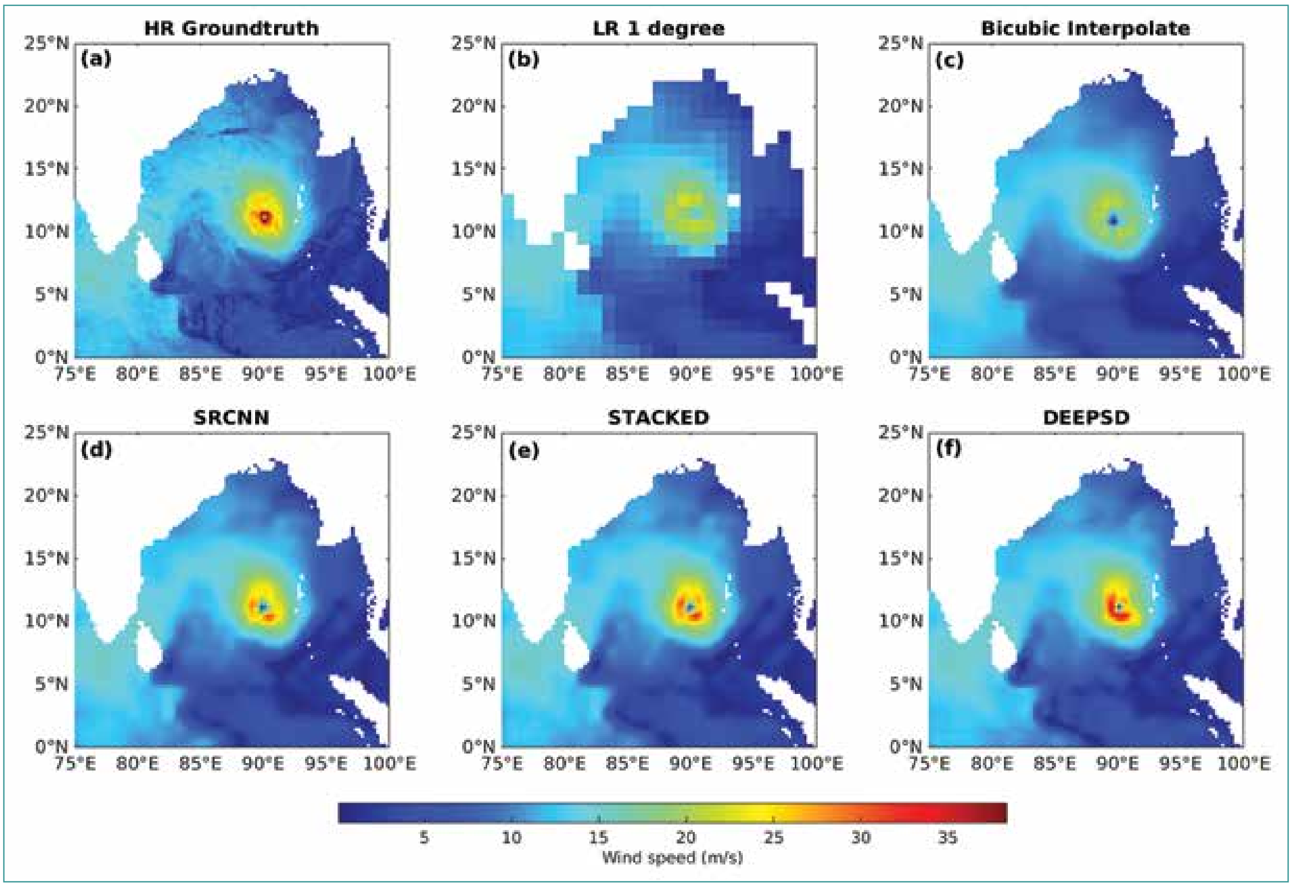


Fig. 7.11 Wind speed data on 19 May 2020 at 12:00:00 IST for Amphan cyclone(a) Ground truth (b)Low-resolution winds (c) Interpolated high-resolution winds (d-f) DL High-resolution winds.

7.3 Development of Ocean Climate Change Projections

Climate change is one of the major threats to the marine environment and the economy it supports, such as tourism, livelihood, and trade. Anthropogenic pressure is causing an ever-changing climate and it interacts with our day-to-day economic activities. To assess these climate change-driven impacts and improve our understanding of the sustainable use of marine resources, the Ministry of Earth Science (MoES) is in the process of implementing a mission mode project known as the 'Deep Ocean Mission' over the next five years. This project has six major objectives, and one of them is the 'Development of Ocean Climate Change Advisory Services (OCCAS)' led by the Indian National Centre for Ocean Information Services (INCOIS). The broad objective of OCCAS is to provide climate change advisory services for the societal and economic benefit of the Indian coastal regions.

OCCAS program aims to provide climate change assessment of various marine climate indicators that directly impact the coastal infrastructure, ecosystem, economy, and policy decisions in coastal zone management activities. The major thrust areas are assessing change in sea level, the intensity of cyclone, storm surge, and waves, and their impacts on associated coastal erosion and inundation in the projected climate.

Another major thrust area is to assess the impact of climate change on the coastal marine ecosystem and create advisories on the likelihood of intensity and spread of Harmful Algal Blooms that may impact the future potential migration of fishing zones and may adversely contribute to the marine-driven economy along the long coastline of India. The above-mentioned thrust areas are divided into five different modules for implementation with the help of well-designed observing and monitoring networks and a suite of modeling frameworks. Finally, the outcomes of all the modules in terms of climate assessments will be provided through interactive GIS-based mapping applications so that they can be effectively utilized for coastal zone management and policy decisions.

7.3.1 Sea Level Projections

INCOIS is developing a suite of ocean models for downscaling sea level, wave, and biogeochemical projections of the Indian Ocean. The modeling framework consists of a high-resolution global model based on MOM5 with LETKF assimilation system and a very high-resolution regional ocean model based on MOM6. The development of the LETKF assimilation system on the MOM5 global model is in the final stage. The development of the regional model based on MOM6 is being initiated and the present status has been reported under Section 7.2.1.

These models will be forced by selected atmospheric forcings from CMIP6 model simulations to generate the downscaled projections for the Indian coastal waters. To choose the best performing CMIP6 models for the Indian Ocean, an extensive analysis of 27 CMIP6 model-simulated sea level, wind stress, and wind stress curl was carried out (Fig. 7.12). A manuscript on the selection process to identify suitable CMIP6 forcing is presently under review in a peer-reviewed international journal.

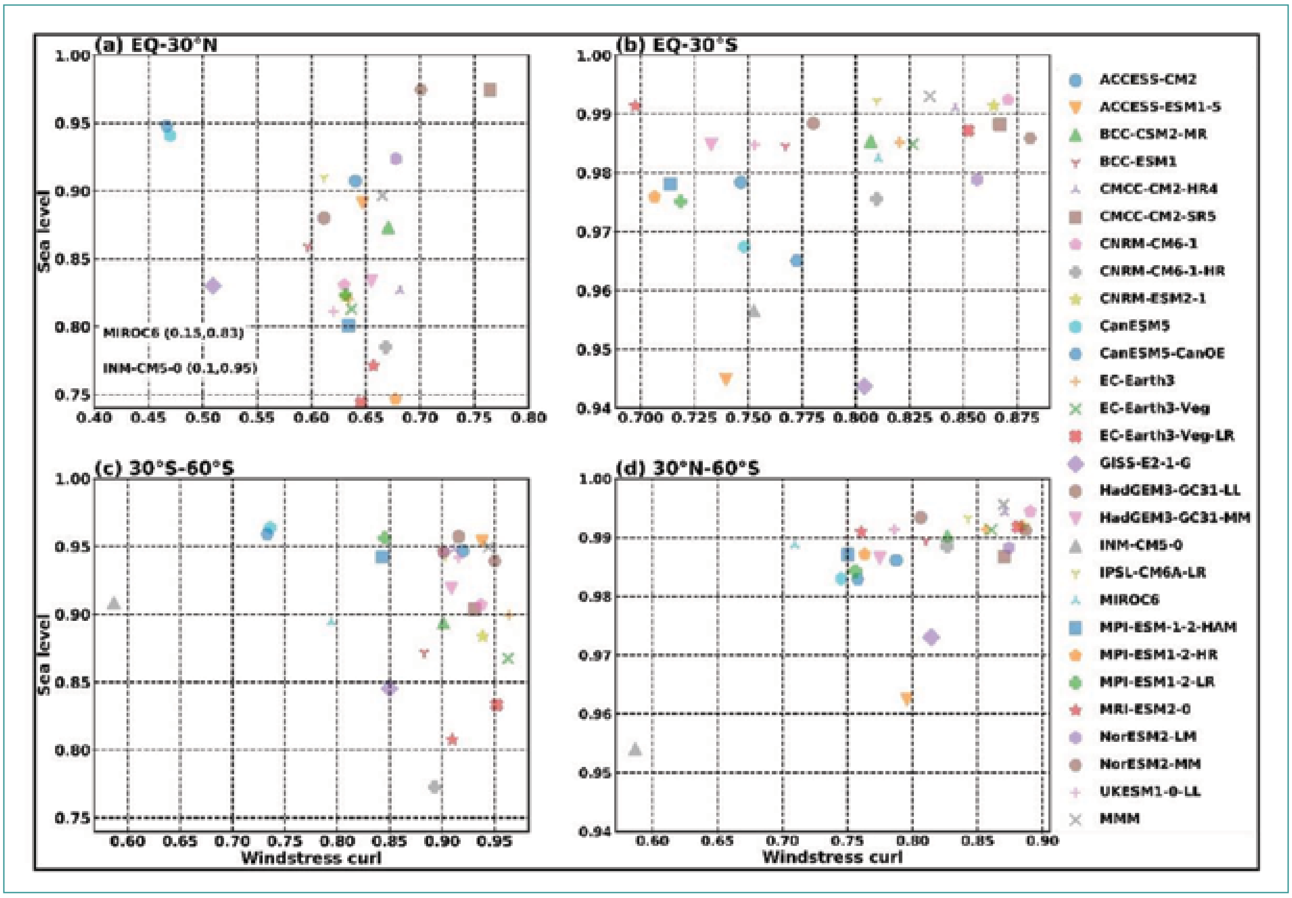


Fig. 7.12 Skill score of Individual CMIP6 models for the different latitudinal bands of the Indian Ocean. The skill scores are calculated based on the fidelity of each model's simulated mean and variability of sea level and wind stress curl.

To test the downscale simulation of sea level forced by the selected CMIP6 atmospheric forcing, the existing ROMS based Indian Ocean operational model with 1/12° uniform horizontal resolution is used. This exercise is carried out for the preparatory development of a methodology necessary for dynamical downscaling. This includes fixing of datum between observation and model, estimating steric effects (due to thermal and salt expansion/contraction) on a regional scale using volume conserving regional model and incorporating the impact of land ice melts, etc. Initially, the downscale simulation is carried out using four CMIP6 models (HadGEM3 GC31, ACCESS CM2, MPI ESM1, and MIROC6) (Fig.7.13). The analysis of downscaled simulations and the development of a regional downscaling methodology are in progress.

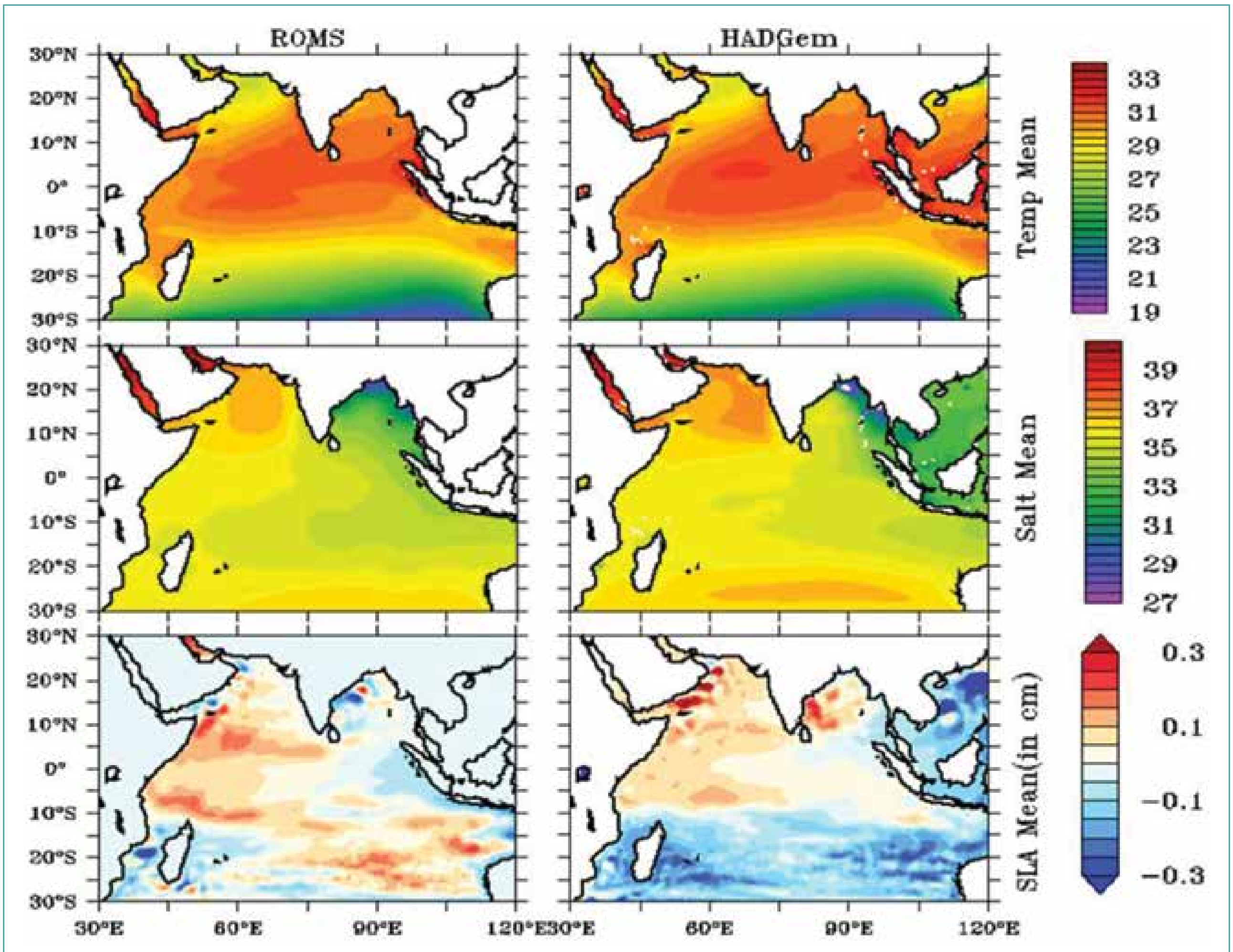


Fig. 7.13 Comparison of mean SST (Top Panel), SSS (Middle Panel) and SLA (Bottom Panel) for the period 2018-2100 between model (ROMS) and HADGem3 CMIP6 simulations.

7.3.2 Wave Climate Projections

For wave climate projections, a wave model based on WAVEWATCHIII (WWIII) - V6.0.7 for the Indian ocean has been configured. The same configuration has been used for carrying out a few sensitivity experiments. The objective of the sensitivity experiments is to investigate the impact of Southern Ocean (SO) sea ice on Indian Ocean Swells. The impact of the SO sea ice on the north Indian Ocean (NIO) wave fields through swells is analyzed using six years (2016-2021) of WWIII simulations. Two experimental runs of WWIII have been carried out - one with sea ice and winds as the forcing (W3with_ice) and the second run with no sea ice but only wind forcing (W3no_ice). Analysis shows that the impact of SO sea ice on swell waves propagating towards NIO peaks in September-November and coincides with the maximum sea ice extent in the Antarctic region of the Indian Ocean. The significant wave height and period simulated by both the experiments are compared with NIO mooring data (Fig. 7.14). In comparison, the significant wave height and period simulated by W3no_ice are found to have more bias, respectively, by ~60% and ~37% against W3with_ice. W3no_ice simulates low-frequency swells and travels fast towards NIO. Forecasts of the timing of high swell events along NIO coasts, like the Kallakkadal events, can be erroneous by ~12 hours if SO sea ice is not included in the model. The essence of this study is to highlight the importance of projected Southern Ocean sea-ice simulations (to be carried out as part of the global ocean general model for sea-level projections) for accurately projecting wave climate for the north Indian Ocean.

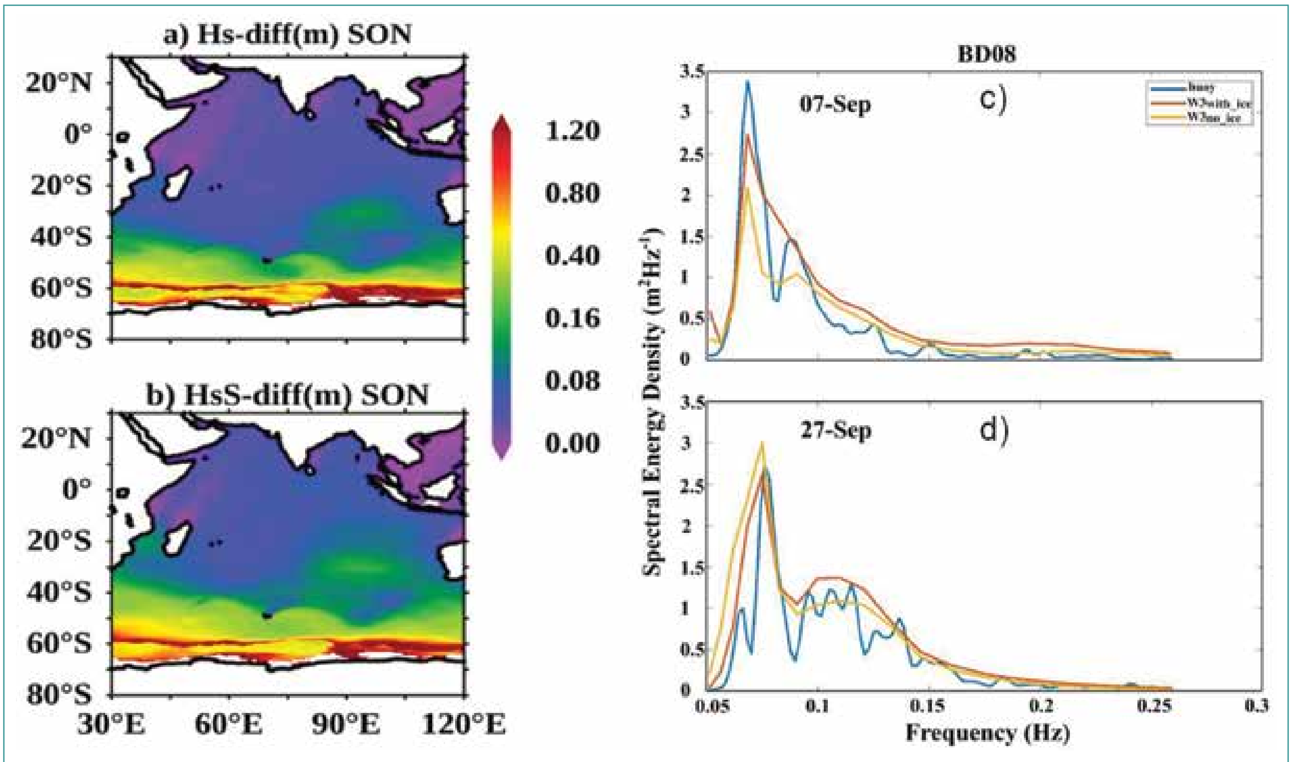


Fig. 7.14 Maps showing September to November averaged difference of W3no_ice and W3with_ice for (a) significant wave height (Hs) and (b) swell wave height (HsS). (c & d) Spectral energy density comparison of W3no_ice (orange) and W3with_ice (red) with BD08 data (blue) at 03 UTC on 07 September 2017 and 09 UTC on 27 September 2017.

8

OUTREACH AND CAPACITY BUILDING

8.1 International Training Centre for Operational Oceanography (ITCOocean)

During the reporting period, ITCOocean continued to impart trainings online owing to Covid-19. In total, 14 training courses (10 international and 4 national) and 2 webinars were conducted. In these courses, a total of **1514** persons were trained of which **851 (Male: 460, Female: 391)** are from India and **663 (Male: 432, Female: 231)** are from **61** other countries. Discussions on conducting of short-term courses to officers from Indian Navy was initiated.

The second Governing Board meeting of UNESCO Category-2 Center was held on 21 May 2022 online. The committee recommended the following activities:

- ITCOOcean to plan and synchronize training activities along with those conducted by MEA to reach to a bigger target audience and increase the reachability.
- Set up state of art e-learning system to facilitate online training programs keeping in view the prevailing pandemic situation.
- Develop strategy for Indian Ocean (IO) region for management of IO by well-trained specialist with available approaches and infrastructure. Engage in coherent activities for the region and have capacity of education and training by collaborating with RCOWA, Iran.
- ITCOOcean to act as nucleus for capacity building activities of UNDCC, IOCINDIO, IOTWS, IOGOOS, MEA etc.
- Collaborate with Category-2 Center in Iran and if possible, conduct training course of mutual interest.
- Possibility of practical and field measurement and sampling-based training involving oceanographic research cruises in the Indian Ocean spanning a period of 1–3 months to be pursued.
- Information about feedback, learning outcome of the courses to be included in presentation to the board.
- ITCOOcean to look at the short-term internship in place of short-term training.

List of the training courses conducted during the year and the brief details are given below:

- Training on **'Sea Glider instrumentation, testing, data acquisition, processing and analysis' [02 March 2022].** The focus was on handling the gliders and analyzing the data.
- Training on operational oceanography to International Seabed Authority (ISBA) trainees [21-22 February 2022]. This course demonstrated the operational services being rendered by INCOIS to all the stake holder in the Indian Ocean region.
- Training to Coastal Community Radio Operators [09 February 2022]. This training was devised, to familiarize the community radio operator in successful dissemination of alerts from INCOIS to coastal community.
- Training course for the students on 'Ocean Observation System and Ocean Data Utilization' [23-24 December 2021]. This was conducted targeting the students from IITs and other Universities to familiarize them with observations and data for use in their academic activities.
- Indian Tsunami Early Warning System (ITEWS) Training to Naval Officers [13 December 2021]. This training aimed at educating the Naval and International Liaison officers, regarding ocean state monitoring.
- IOCINDIO workshop on 'Methodologies and Approaches of coastal vulnerability and Advances in Operational Oceanography Science and Technology in the Indian Ocean' [13-17 December 2021]. The goal of the workshop was to prepare guidelines for coastal vulnerability index and early warning

systems for storm surges and provide these to all the countries in the region for becoming ready for the anticipated sea level rise.

- Workshop on 'Modelling for Ocean Forecasting and Process Studies' [06–10 December 2021]. The purpose of this course was to introduce the basic concepts of physical and dynamic oceanography and numerical modelling of the ocean general circulation, waves, tides, etc. to participants.
- Workshop on 'Biological Observations in the Indian Ocean (From Microbes to Megafauna)' [08–12 November 2021]. The workshop focussed primarily on biological essential ocean variables for functional groups, in particular microbes, phytoplankton, zooplankton and benthic invertebrates, including briefing on fish, turtles and marine mammals, as well as habitat states such as hard corals, mangroves and seagrasses.
- OTGA-INCOIS training course on 'Discovery and Use of Operational Ocean Data Products and Services' [25-29 October 2021]. The course demonstrated the data resources available from operational services of INCOIS with focus on operational activities, various data and data products, outputs from INCOIS services and methods to download and visualize them.
- Training program on 'Fundamentals of Ocean Modelling' [27 September-01 October 2021]. Considering the importance of the numerical ocean modelling in the field of oceanography, the course provided brief ideas on the fundamentals of ocean circulation modelling, data assimilation, biogeochemical modelling, waves/storm surge/tsunami modelling.
- Training program on 'Fundamental of Ocean Data Management' [23-27 August 2021]. This course provided a comprehensive introduction to a variety of oceanographic datasets and formats and the use of software for visualization and analysis of oceanographic data.
- Workshop on 'Operational Services Training to Naval Hydrography Officers' [18 August 2021]. The course provided exposure to various products and services developed by INCOIS for operational requirements to the Naval Hydrography officers.
- Training session on 'Principles of Ocean remote sensing & its applications' [26-30 July 2021]. This course provided details on acquiring remote sensing information/data and fundamental of ocean remote sensing.
- Webinar on 'An Observing System Simulation Experiment for Indian Ocean surface pCO_2 measurements' [07 July 2021].
- Webinar on 'Numerical modelling of the coastal circulation around India' [25 June 2021].
- Workshop on 'Fishery Oceanography for Future Professionals (Level: Basic, Batch-2)' [19-23 April 2021]. This course familiarized the young professionals of the Indian Ocean-Rim (IOR) countries with the latest developments in this field.

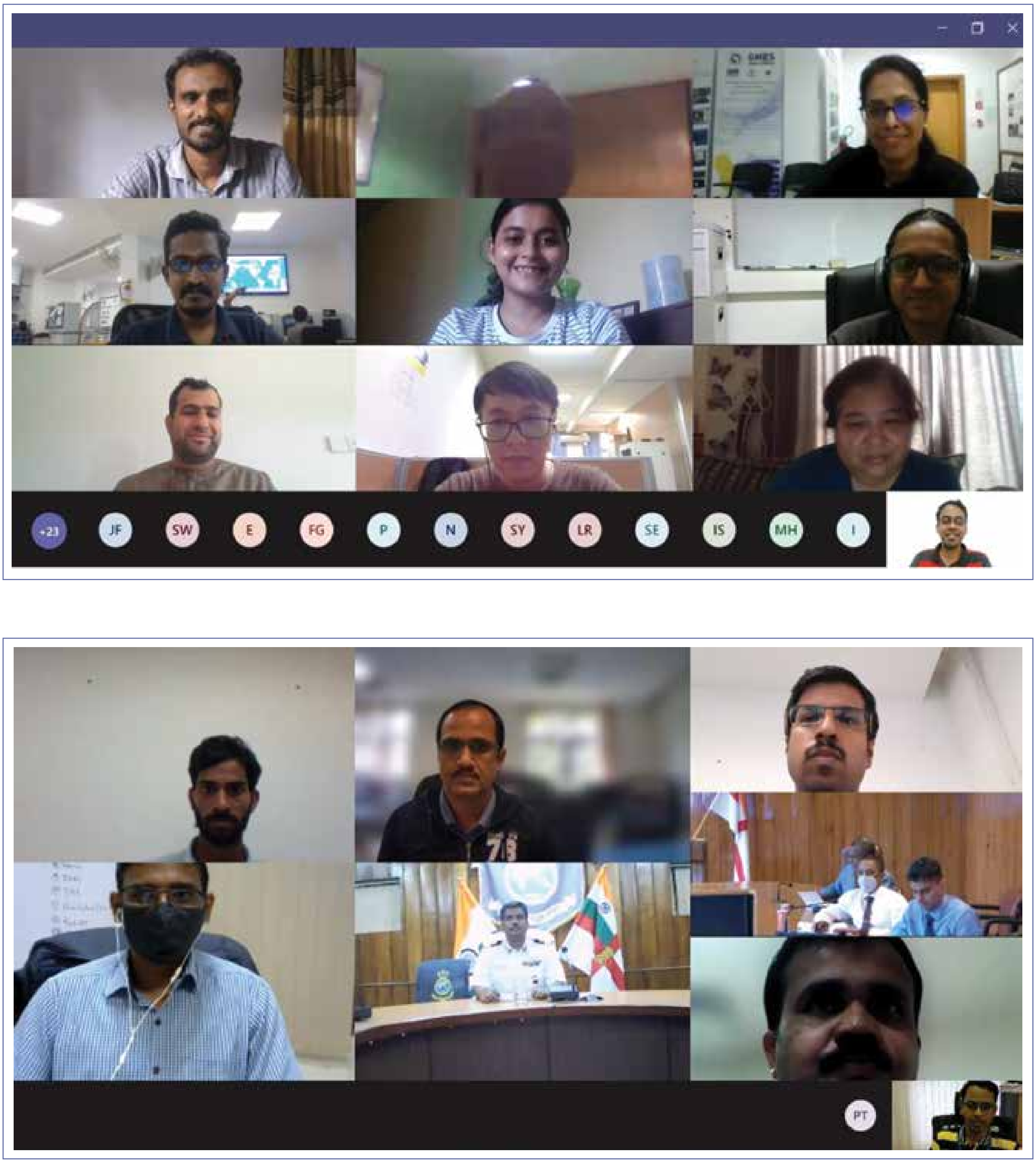


Fig 8.1 Screenshot taken during the training course organised by ITCOocean

8.2 Ocean Climate Change Advisory Services Workshop

To foster collaboration under the OCCAS program among the experts from various national institutes, IITs, and academia, a workshop was held in the hybrid mode on 15 December 2021. A total of 40 scientists attended this workshop. During the first part of the workshop, 15 presentations were made in 4 technical sessions focusing on the science and implementation methodology for each component of OCCAS, such as sea level, cyclones, storm surges & waves, biogeochemistry & HABS, and observations. The final session comprised a detailed panel discussion by Chairs/Co-Chairs of each technical session.

8 OUTREACH AND CAPACITY BUILDING

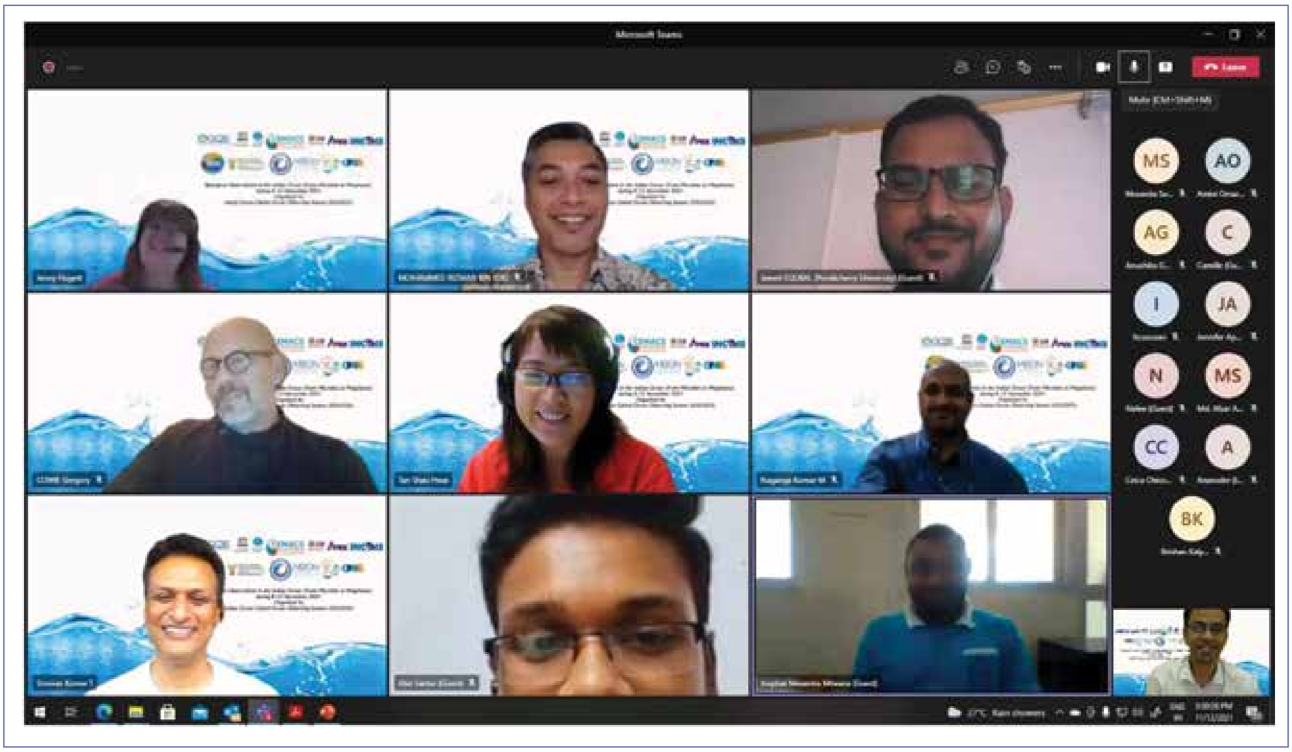


Fig. 8.2 Hybrid workshop on Ocean Climate Change Advisory Services (OCCAS) program under Deep Ocean Mission (DOM) conducted on 15 December 2021.

8.3 Tsunami Webinars and Meetings

8.3.1 Webinar on Tsunami Risk Reduction and Resilience

INCOIS and the National Institute of Disaster Management (NIDM), Ministry Home Affairs jointly organized a webinar on 'Tsunami Risk Reduction and Resilience' on 10 August 2021. INCOIS scientists made presentations on Indian Tsunami Early Warning System, Guidelines for Tsunami Emergency Response SOPs and Tsunami-Ready Programme.

8.3.2 Regional SOP Workshop for Broadcasting Media

Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) of IOC-UNESCO organised a regional workshop on Standard Operating Procedure (SOP) for Broadcasting Media during 07-09 September 2021 (hybrid meeting) to strengthen the involvement of media broadcasters in the tsunami early warning processes for Northwest Indian Ocean (NWIO) countries i.e., India, Iran, Oman, Pakistan, and UAE. As part of the workshop, Indian media representatives from Press Information Bureau, Doordarshan, All India Radio and a few other media personnel visited INCOIS on 08 September 2021 to know about the warning processes, SOPs, products, and to discuss the role of media in the warning process chain, etc. In addition, officials from National Disaster Management Authority (NDMA), also participated in the workshop at INCOIS. A 2nd regional SOP Workshop for Broadcasting Media was also conducted on 26-28 October 2021. Media representatives from Press Information Bureau, Doordarshan, All India Radio, National Disaster Management Authority (NDMA) were involved. Draft SOP for Broadcast media was prepared with support of media team and NDMA.

Fig. 8.3 Regional SOP Workshop for Broadcasting Media participants on 08 September 2021

8.3.3 World Tsunami Awareness Day

On the occasion of the 6th World Tsunami Awareness Day (WTAD) on 05 November 2021, school children visit was organized to ITEWC, INCOIS to improve the tsunami awareness and also distributed tsunami awareness material. Science Teachers of Zilla Parishad High School from Bachupally also visited INCOIS and had detailed discussions with INCOIS Scientists, as part of WTAD and Azadi Ka Amrut Mahotsav (AKAM).

8 OUTREACH AND CAPACITY BUILDING

Fig. 8.4 School Students and teachers visit to ITEWC as part of WTAD on 05 November 2021

8.3.4 Sensitization webinar on 'Tsunami Early Warnings and Tsunami Ready'

Sensitization webinar on 'Tsunami Early Warnings and Tsunami Ready Programme' conducted under the aegis of World Tsunami Awareness Day and Azadi Ka Amrut Mahotsav (AKAM) to Andhra Pradesh State Disaster Management Authority (APSDMA) officials on 05 November 2021.

8.3.5 Regional SOP Workshops for Disaster Management Organization (DMO)

IOTWMS of IOC-UNESCO organised a regional workshop on Standard Operating Procedure (SOP) for Disaster Management Organisations (DMO) during 12-14 October 2021 to strengthen the SOPs in the tsunami early warning processes. The workshop was focused on the Northwest Indian Ocean (NWIO) countries i.e., India, Iran, Oman, Pakistan, and UAE. The objectives of the workshop were to understand the national tsunami warning chains and the National Tsunami Warning Centre (NTWC) and DMO procedures, discuss and continue the work on unresolved issues related to DMO SOP.

Fig. 8.5 Regional SOP Workshops for DMO participation during 12-14 October 2021

8.4 OSF Trainings

The participants of the Maritime Search and Rescue (MSAR-2021) workshops, organised by the respective Maritime Rescue Coordination Centres of the Indian Coast Guard, were familiarized with the Search and Rescue Aid Tool (SARAT) and other important activities of INCOIS. These virtual meetings were held on 16, 18 and 23 September 2021 at Port Blair, Daman, and Mangalore, respectively.

Fig. 8.6 Indian Coast Guard officers (Port Blair-left and Daman-right) attending the online lecture on September 16 and 18, 2021, respectively

8.5 Integrated User Engagement and Feedbacks for improving services

A total of 25 user interaction workshops/similar meetings have been conducted in an integrated manner or separately with various categories of users during the reporting period (list is given below).

1. INCOIS Integrated User Interaction Workshop 2022 (online – based at Hyderabad), 02 February 2022 (~ 200 participants from the end users/ fishers/ NGOs/ Industry/ Navy/ CG/DM authority/Port& harbours/ Shipping/ Seafarers)
2. INCOIS integrated User Interaction Workshop for AP (in collaboration with MSSRF), 27 December 2021 (~40 fisher leaders/fishers attended).
3. INCOIS integrated User Interaction Workshop for TN south (in collaboration with MSSRF), 28 December 2021 (~30 fisher leaders/fishers attended).
4. INCOIS integrated User Interaction Workshop for TN North (in collaboration with MSSRF), 07 January 2022 (~30 fisher leaders/fishers attended).
5. User interaction, feedback, queries and clarifications on INCOIS services and warnings-OSF and Tsunami-on the aegis MSAR workshop on Maritime Search and Rescue, 08 Sep 2021, ICG, Vizhinjam (~40 participants).
6. User interaction, feedback, queries and clarifications on INCOIS services and warnings-OSF and Tsunami- on the aegis workshop on Maritime SAR, 25 November 2021, ICG, Haldia, West Bengal (~50 participants).
7. Interaction and requirement analysis meeting between INCOIS and offshore E&P industry in collaboration with DGH, 01 November 2021 (existing ONGC KG Basin users, AFCONS users were present – total 50 participants).
8. User Interaction Meeting entitled 'Connect to Industry' and given talk on INCOIS services and technology under the aegis of AKAM (existing paid users from 4 projects were present), 22 October 2021 (20 participants-online).
9. User Interaction done and feedback, queries and its clarifications done during interaction entitled 'INCOIS: Ocean Observation, Research and Services', 13 August 2021 (~ 100 attendees, ~40 INCOIS end users).
10. INCOIS organised a webinar on 'Tsunami Risk Reduction and Resilience' in coordination with National Institute of Disaster Management (NIDM) on 10 August 2021 (more than 200 participants - online).
11. INCOIS organised a workshop on Standard Operating Procedure (SOP) for Broadcasting Media on 08 September 2021 as part of IOC-UNESCO region workshop for Makran region. National media representative along with NDMA officials were attended in in the workshop (~15 participants - Hybrid: virtual & physical).

12. User Interaction webinar was conducted 'Tsunami Early Warnings and Tsunami Ready Programme' conducted under the aegis of AKAM and World Tsunami Awareness Day to Andhra Pradesh State Disaster Management Authority (APSDMA) officials on 05 November 2021 (~ 20 participant - online).
13. INCOIS scientists interacted with school teachers and children under the aegis of AKAM and World Tsunami Awareness Day on 05 November 2021 (~ 80 participant - physical).
14. INCOIS conducted a tsunami mock drill to 69 coastal communities of Odisha in coordination with OSDMA on 05 November 2021. Coastal communities actively participated and evacuated to safe shelters and the mock drill also to test the tsunami ready indicators.
15. INCOIS participated in two Communication Tests of ICG/IOTWMS and issued dummy bulletins to 25 Indian Ocean rim countries as a Tsunami Service Provider (TSP) on 09 June 2021 and 08 December 2021.
16. INCOIS organised a training on Indian Tsunami Early Warning System through ITCOOcean for Directorate of Naval Oceanology and Meteorology (DNOM) Naval personnel and International Liaison Officers on 13 December 2021 (~ 15 participants - online).
17. INCOIS scientist gave an invited online talk at World Env. Day event 'Fostering Ecosystem Approaches in Marine Resource Protection' by TNJ Fish. Univ., 05 June 2021 (~50 participants including users).
18. A webinar in Gujarati done under 'Azadi ka Amrit Mahotsav' on Webinar on 'INCOIS Ocean Research, Observations and Services', 30 August, 2021.
19. INCOIS & MSSRF jointly organised a feedback meeting with tuna fishers on 09 September 2021, and a total of 27 fishers from Kasimedu, Chennai district, participated.
20. An 'Open Day' event as a preamble to IISF-2021, on Friday 26 November 2021 during which about 250 high school and college students along with teachers and parents, as well as other citizens, visited INCOIS within a span of few hours.
21. Organised an online session "Data acquisition, processing of Remote Sensing data and GIS application developed by INCOIS" on 16 December 2021 for the training programme 'Application of Remote Sensing and Geographical Information System in Agricultural Development' by MANAGE (Nat. Insti. of Agri. Extn. Mgmt.), Hyderabad during 13-16 December 2021 (~30 participants -trainers).
22. User interaction, feedback, queries, and clarifications on INCOIS services and warnings- OSF and Tsunami- on the aegis workshop on Maritime SAR, 16 September 2021, ICG, Port Blair (~50 participants).
23. User interaction, feedback, queries, and clarifications on INCOIS services and warnings- OSF and Tsunami- on the aegis workshop on Maritime SAR, 18 September 2021, ICG, Daman (~40 participants).
24. User interaction, feedback, queries and clarifications on INCOIS services and warnings- OSF and Tsunami- on the aegis workshop on Maritime SAR, 23 September 2021, ICG, Mangalore (~50 participants).
25. INCOIS & MSSRF jointly organised a feedback meeting with tuna fishers on 09 September 2021 and a total of 27 fishers from Kasimedu, Chennai district participated in person.

9

RESEARCH HIGHLIGHTS

9

RESEARCH HIGHLIGHTS

9.1 A new turbulent scaling relation for the north Indian from the Lagrangian float data

Hydrographic measurements collected from the North Indian Ocean (NIO) using a Lagrangian float were used to study the turbulent scaling of the upper ocean. This study suggests that the Thorpe depth (LT), estimated from the hydrographic profiles (temperature and salinity), is a more useful metric to study instantaneous dissipation than the mixed layer depth (MLD). Then, by following the Thorpe scaling method, turbulent nighttime dissipation (ε_T) was estimated from the hydrographic data and found to be less than the total dissipation (ε). This difference between ε and ε_T increases with an increase in wind speed. Based on this dependency, a new scaling relation was found in the NIO waters between ε and ε_T for the nighttime convection as ε_T=1.15 Bo $\zeta^{0.5}$ as against the classical scaling of ε=0.64 Bo + 1.76 ζ^{-1} where ζ is a length scale ratio. This new relation holds good in the nighttime, purely wind-driven turbulence case, whereas it approaches the classical scaling relation in convective conditions. Similar calculations may be possible using routine Argo float and ship data, allowing more detailed global measurements of ε_T, thereby providing large-scale tests of turbulence scaling in boundary layers.

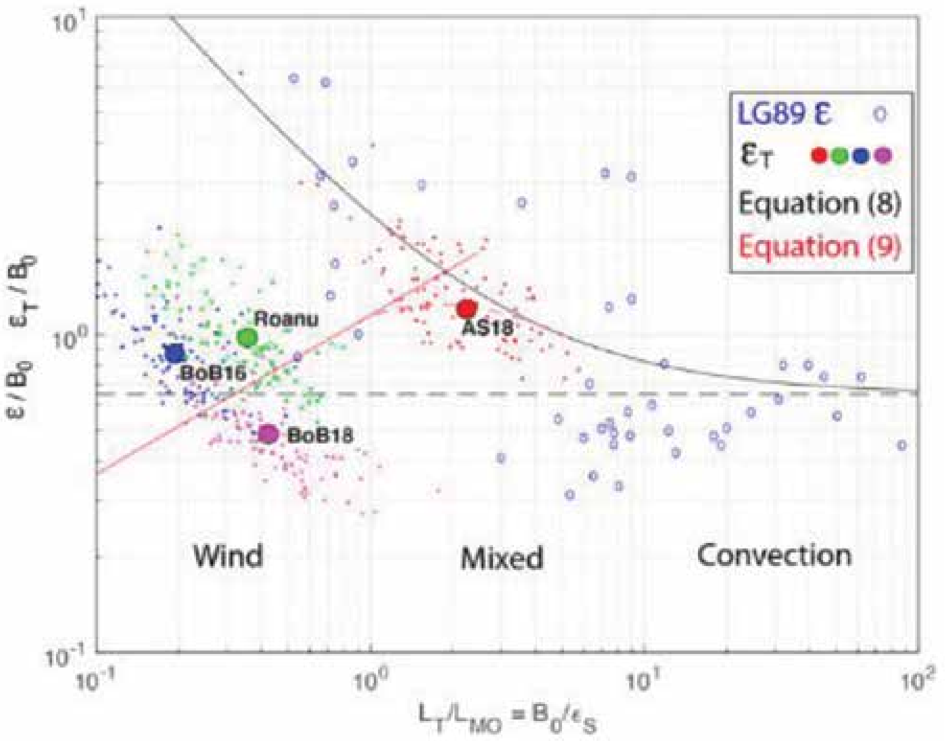


Fig. 9.1 Scaling of dissipation rate ε (open blue dots) and dissipation computed from Thorpe sorting εT (colored circles) for nighttime values from Lagrangian float data. The black curve is the classical scaling relation, and the red line shows the proposed scaling of εT from this study under wind-forced conditions.

Ref: Praveen Kumar B, D'Asaro, E., Kumar, S., Pattabhi, Rama Rao, E., & Ravichandran, M. (2021) Thorpe Turbulence Scaling in Nighttime Convective Surface Layers in the North Indian Ocean, Journal of Physical Oceanography, 51 (10), 3203-3216

9.2 Atmospheric Cold Pools and Their Influence on Sea Surface Temperature in the Bay of Bengal

Atmospheric cold pools (ACPs) generated from convective systems can significantly modulate air-sea interaction processes over the ocean. However, the modulation of sea surface temperature (SST) in response to intense air-sea interaction processes associated with ACPs is not yet documented in the Bay of Bengal (BoB). The present study, based on high-temporal resolution moored buoy observations, reveals a well-defined diurnal variability in the reduction of SST with an afternoon peak due to ACP activity in the BoB. One-dimensional mixed layer (ML) model sensitivity experiments suggest that the formation of the daytime thermocline and associated thin ML is the primary factor determining the enhanced reduction in SST during the afternoon compared to the night. The presence of this shallow daytime thermocline and thin ML amplifies the effects on SST of net surface heat loss and entrainment of cold sub-surface water associated with enhanced ACP wind speeds. The present study highlights that it is imperative to accurately represent ACP activity and associated air-sea interaction processes in the coupled model used for seasonal weather predictions.

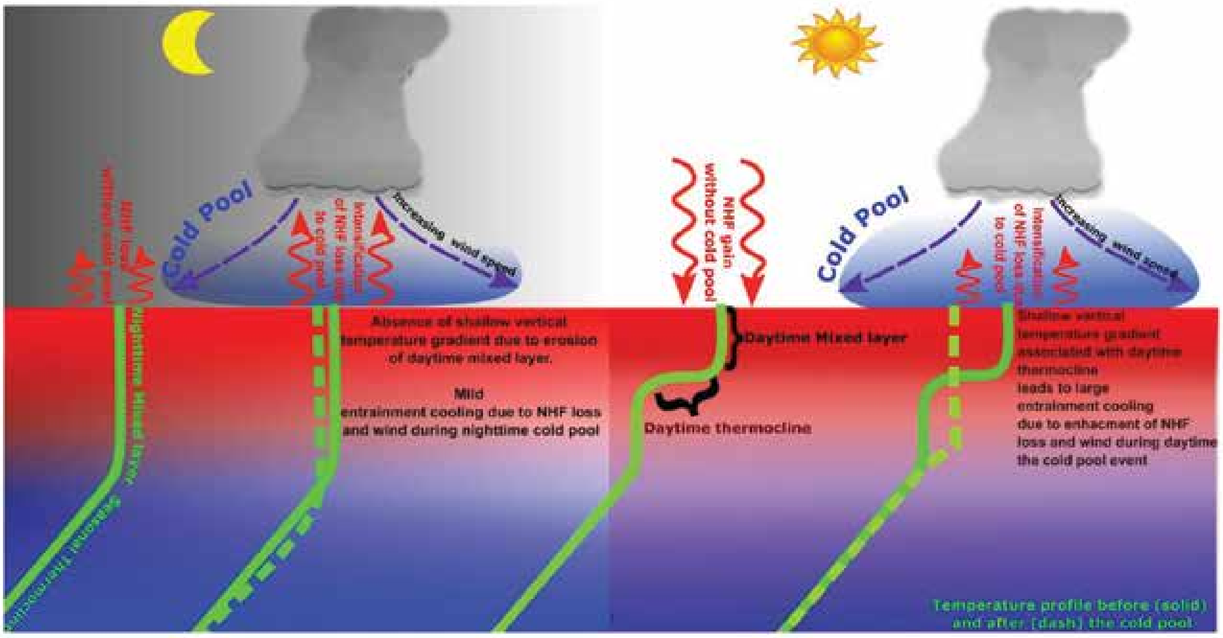


Fig. 9.2 The schematic diagram (not to scale) illustrates the different mixed layer responses to atmospheric cold pool events during the nighttime and daytime. The red arrow length represents the difference in the magnitude of net surface heat flux (upward indicates heat loss from the ocean).

Ref: Girishkumar, M. S., Joseph, J., McPhaden, M. J., & Pattabhi Ram Rao, E. (2021). Atmospheric cold pools and their influence on sea surface temperature in the Bay of Bengal. Journal of Geophysical Research: Oceans, 126, e2021JC017297. https://doi.org/10.1029/2021JC017297.

9.3 Madden-Julian oscillation winds excite an intraseasonal see-saw of ocean mass that affects Earth's polar motion

This study discovered a see-saw in oceanic mass in the Indo-Pacific basin during boreal winters. When the MJO winds over the Maritime Continent, which lies at the tropical interface between the Indian and Pacific Ocean, is cyclonic, the oceanic mass rises (falls) in the Indian (Pacific) Ocean. As the MJO winds reverse direction after 30-80 days, the oceanic mass falls (rises) in the Indian (Pacific) Ocean. The alternate rise and fall of these two basins continue from December to April of each year and is more pronounced during strong MJO events. This mass fluctuation manifests as a see-saw in the Indo-Pacific oceanic mass at intraseasonal timescales (30-80 days).

The large-scale mass redistribution associated with this see-saw is facilitated by the periodic reversal of the circulation of 2 Sv [1 Sv = 10 m^3s^{-1}] of water around the Australian continent in response to the periodic reversal of MJO winds. This mass redistribution alters the ocean angular momentum and thereby modulates the intraseasonal polar motion (or wobble) of the Earth. The strongest see-saw event of 2013 is found to have a detectable signature on intraseasonal polar motion fluctuation of the Earth. This is the largest wind-driven oceanic intraseasonal barotropic dynamics discovered till date.

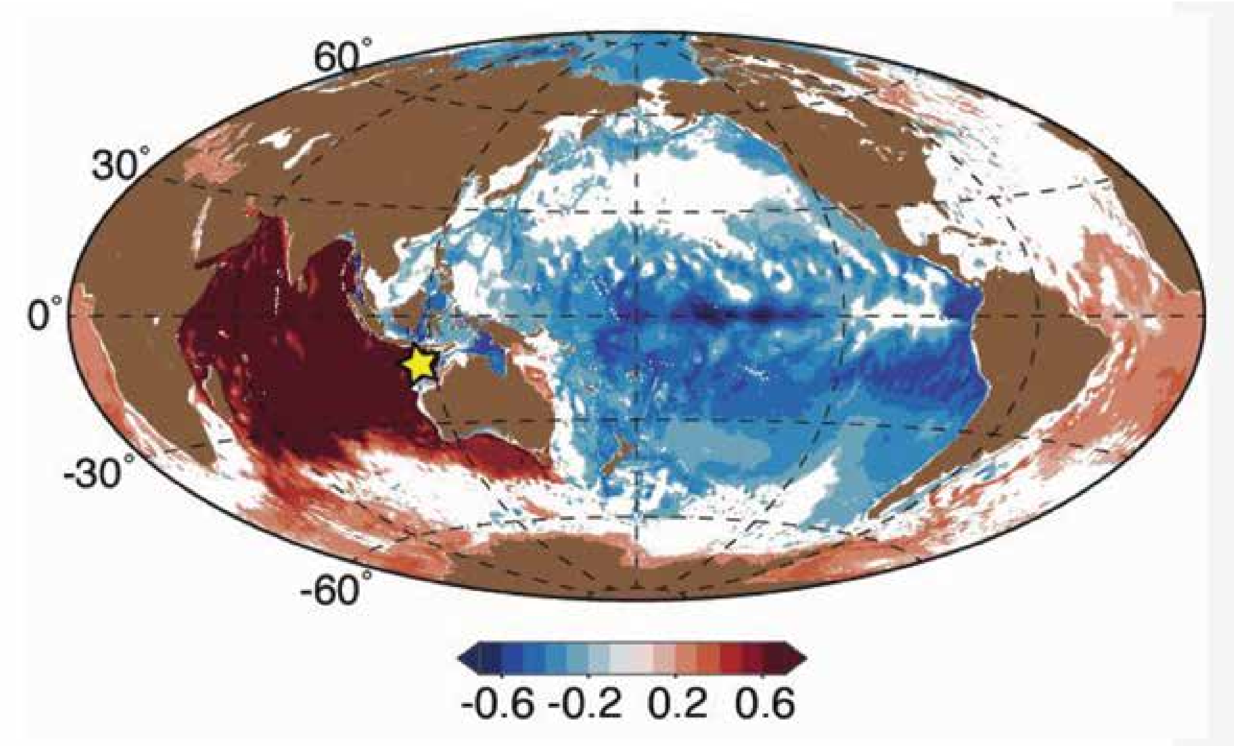


Fig. 9.3 Plot of correlation (>90% significance) of intraseasonal oceanic mass over the Maritime Continent at 117.94°E, 15.02°S (yellow star) with respect to the intraseasonal oceanic mass at all grid locations from the model, NEMO. The red patch in the Indian Ocean and the extensive blue patch in the Pacific Ocean is a testament of the see-saw in oceanic mass.

Ref: Afroosa, M., Rohith, B., Paul, A., Durand, F., Bourdallé-Badie, R., Sreedevi, P. V., de Viron, O., Ballu, V. & Shenoi, S.S.C. (2021). Madden-Julian oscillation winds excite an intraseasonal see-saw of ocean mass that affects Earth's polar motion. Communications Earth & Environment, 2, 139 https://doi.org/10.1038/s43247-021-00210-x

9.4 Role of light limitation on the initiation of phytoplankton blooms in the northern Arabian Sea

The Arabian Sea is one of the highest productive regions of the world ocean. During boreal winters, the strong convective mixing deepens the mixed layer in the Arabian Sea and hence brings nutrient-rich cold subsurface water into the euphotic zone thereby making this basin one of the most productive regions of the globe. A winter monsoon cruise has been undertaken onboard FORV Sagar Sampada (Cr. No: SS383) in the northeastern Arabian Sea to understand the physicochemical coupling on the bloom dynamics. The studies conducted present new insights into the physicochemical forcings of phytoplankton blooms.

Despite having a nutrient-enriched surface layer and a deeper mixed layer (>100 m), the observation shows a low chlorophyll concentration (0.1-0.3 µg/l) in the surface layer of the study region. Also, the study region showed a dominance of picophytoplankton with a negligible amount of diatom and *Noctiluca* bloom. Moreover, the euphotic depth was much shallower (~ 49 m) than the mixed layer suggesting the Sverdrup critical depth limitation in the northern Arabian Sea. This study demonstrate that bloom begins in this region only when the mixed layer shoals toward the euphotic zone by the later winter monsoon. This strongly implies that the initiation of phytoplankton bloom depends on water column re-stratification.

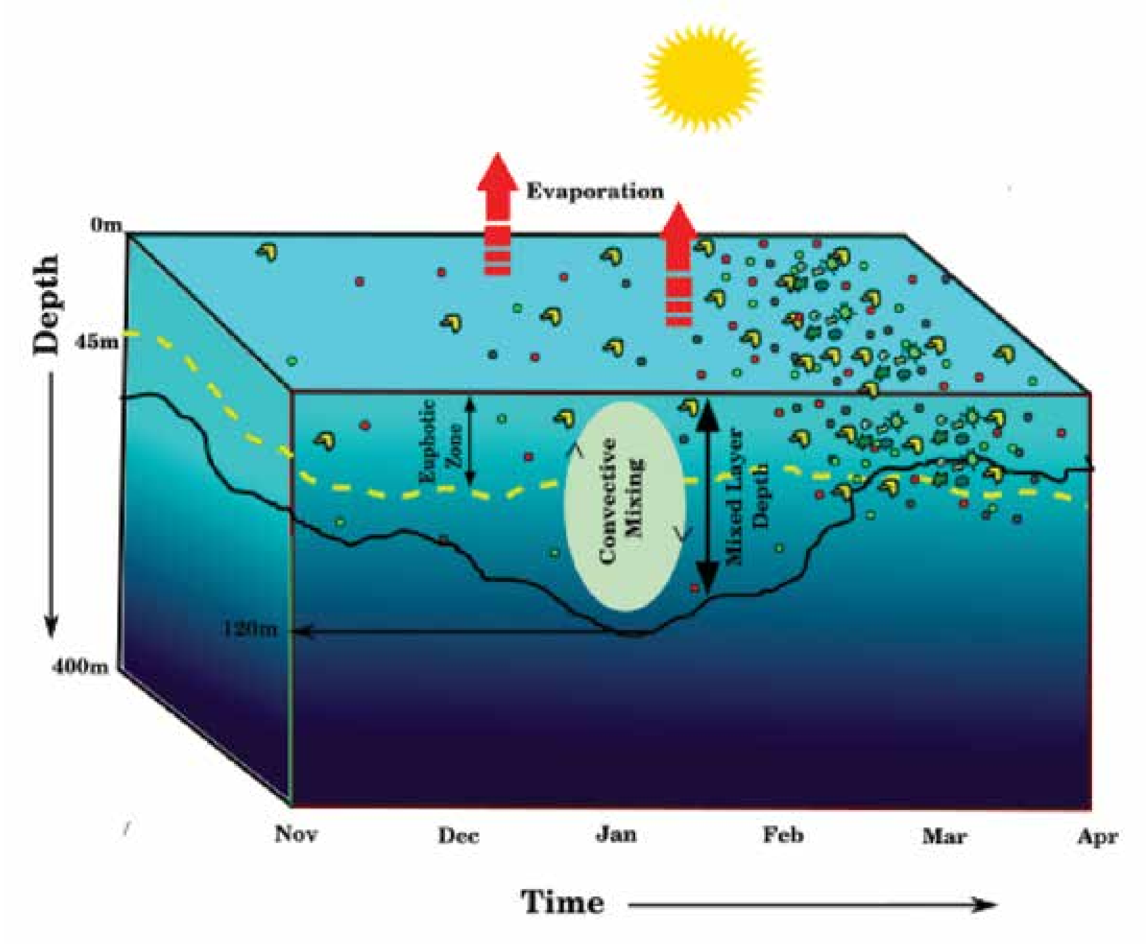


Fig. 9.4 Schematic diagram which shows the relation between mixed layer depth and euphotic depth on the initiation of phytoplankton blooms.

Ref: Lakshmi, R. S., Prakash, S., Lotliker, A. A., Baliarsingh, S. K., Samanta, A., Mathew, T., Chatterjee, A., Sahu, B. K. & Nair, T. M. (2021). Physicochemical controls on the initiation of phytoplankton bloom during the winter monsoon in the Arabian Sea. Scientific reports, 11(1), 1-10.

9.5 Implication of monsoon blooms variability on the dissolved oxygen concentration in the OMZ: a Bio-Argo study

The inter-annual variability in surface productivity and its impact on the dissolved oxygen concentration in the deeper layer of the central Arabian Sea (CAS) is studied using four years (2013-2016) record of chlorophyll and dissolved oxygen (DO) concentration from a Bio-Argo float. The float has remained in a small region [65°E-68.5°E and 17°N-19°N], enabling to develop an understanding of the year-to-year variability of the physical and biogeochemical parameters within this region. It was observed that though the surface blooms occur during both the monsoons, winter blooms were more prominent compared to the summer bloom in the study region. The intensity and duration of the bloom have been decreasing over the study period. A detailed analysis shows that the observed inter-annual variability in the summer bloom can be attributed to the variability in wind speed, oceanic stratification, and advection of nutrient-rich water from the western Arabian Sea. It was found that during both the monsoons, stratification has played a key role in reducing productivity in recent years. During the winter monsoon, the upwelling Rossby wave propagating from the west coast of India influenced productivity as north as 15ºN. The chlorophyll data from Bio-Argo float shows that the total surface chlorophyll concentration and backscattering (a proxy for particulate flux) in the oxygen minimum zone (OMZ) region have been decreasing during the study period. Consequently, the DO concentration in the deeper waters has also been increasing. The decrease in surface productivity, lateral advection from the west, and their manifestation on the export flux have reduced the oxygen demand in the deeper layer.

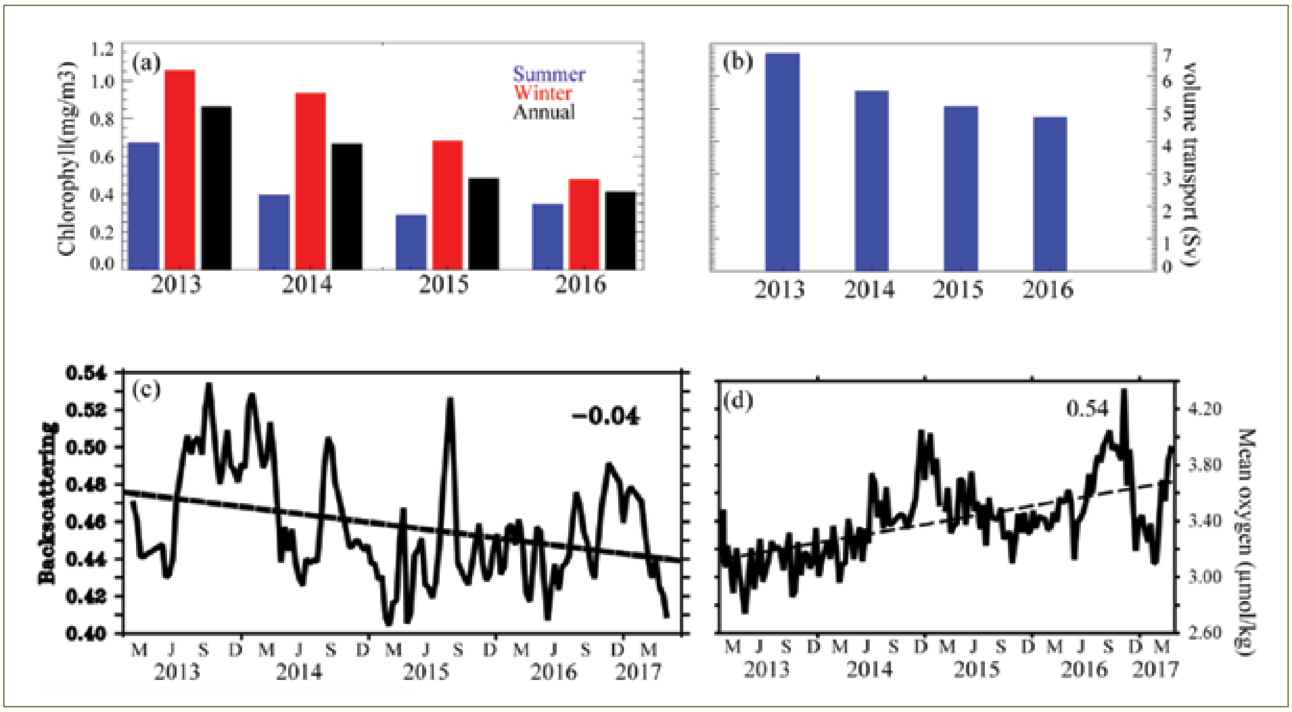


Fig. 9.5 (a) Bar plot of mean surface chlorophyll in mg/m^3 during SM (blue), WM (red) and the annually averaged (black) during 2013-2016; (b) Volume transport (Sv) averaged for Jul-Sep in the upper 100 m across 65°E from 5°N to 20°N during 2013-2016; (c) Time series of integrated backscattering (m^{-1}) in the OMZ and (d) Mean oxygen concentration in the OMZ with trend line overlaid. The slope of trend line per 4 years is listed on (c) and (d).

Ref: Mathew, T., Prakash, S., Shenoy, L., Chatterjee, A., Udaya Bhaskar, T.V.S., and Wojtasiewicz, B. (2021). Observed variability of monsoon blooms in the north-central Arabian Sea and its implication on oxygen concentration A bio-argo study. Deep Sea Research Part II Topical Studies in Oceanography, 184, 104935.

9.6 Nutrient stoichiometry in the coastal waters of the western Bay of Bengal and its impact on the chlorophyll variability

The seasonal variability of chlorophyll-*a* (chl-*a*) concentration and its response to available nutrients along the Bay of Bengal (BoB) coastal waters are studied using two cruise data. These cruises were undertaken in 2017 in the coastal water of the western BoB during pre-southwest monsoon season (PRSWM) and post-southwest monsoon season (POSWM) along 50 m isobath. It is observed that the chl-*a* concentration is more during the PRSWM season compared to the POSWM season. This study reported the presence of a cold-core eddy during PRSWM enhancing the vertical movement of nutrients to the surface, well-mixed waters, leading to an increase in the chl-*a* concentration. However, during the POSWM period, despite having higher nitrate concentration and adequate light in the water column, the surface chl-*a* is substantially lower than PRSWM. This study shows that the main factor controlling the lower chl-*a* concentration during the POSWM period is the molar ratio of ambient inorganic macronutrients. Nitrate to phosphate (N:P) and nitrate to silicate (N: Si) ratios are less than the Redfield values, which resulted in lower chl-*a* concentration. This study also highlights phosphate limitation off the Godavari during the high river discharge period for the first time, which calls for a more intense study to understand the phosphate-limitation in this region.

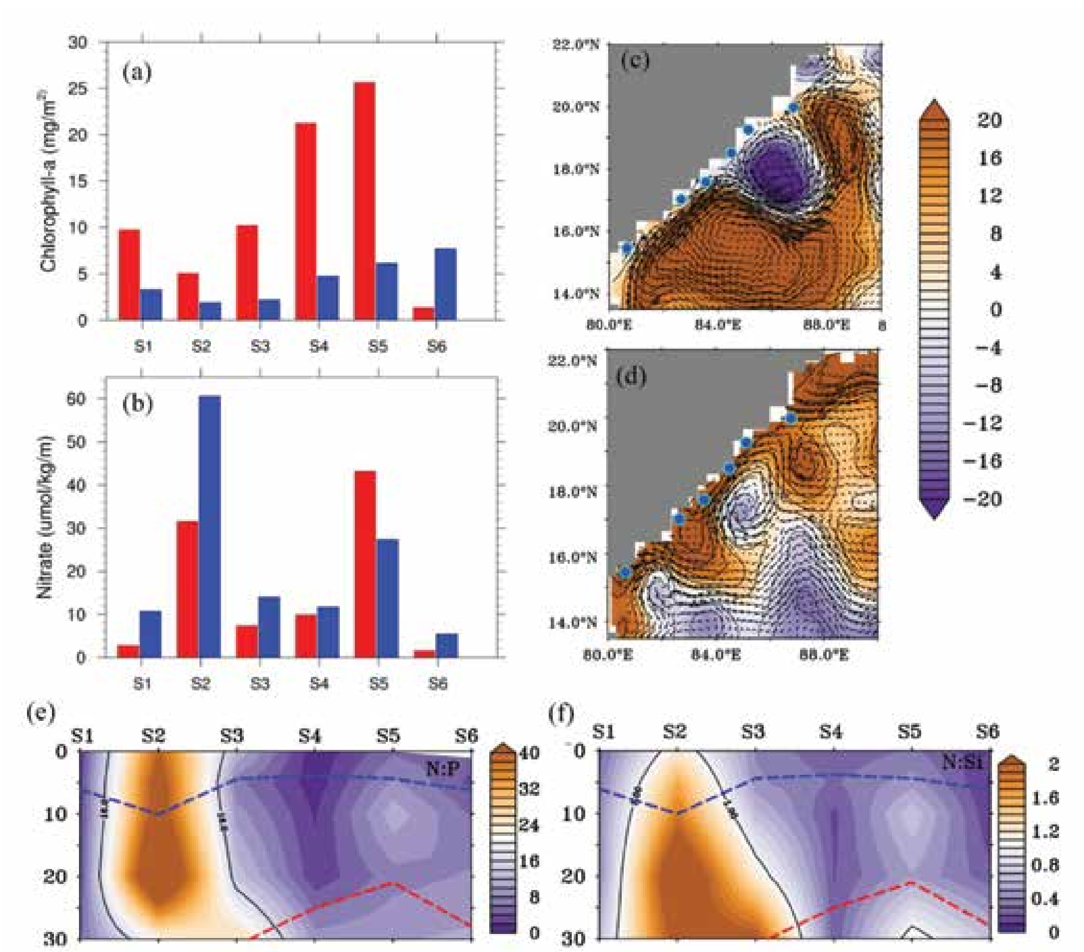


Fig. 9.6 (a) Integrated chlorophyll and (b) nitrate concentration in the upper 10 meters for PRSWM (red) and POSWM (blue) cruises. Satellite derived sea level anomaly during the (c) PRSWM and (d) POSWM cruises with its contours overlaid. Overlaid vectors are surface currents. Blue dot indicates the location of cruise stations. Ratio of the nutrients at all the stations during (e) PRSWM and (f) POSWM cruises. Blue and red dashed line over (e) and (f) indicates the MLD and the photic depth.

Ref: Mathew, T., Prakash, S., Baliarsingh, S.K., Samanta, A., Lakshmi, R.S., Lotliker, A. A., Chatterjee, A. and Balakrishnan Nair, T.M. (2021). Response of phytoplankton biomass to nutrient stoichiometry in coastal waters of the western Bay of Bengal. Ecological Indicators, 131, 108119.

9.7 Impact of coastal upwelling dynamics on the pCO_2 variability in the southeastern Arabian Sea

The upwelling systems are the most biologically productive areas in the world ocean. Their high productivity is intimately linked with shallow, intense oxygen minimum zones, which have high CO_2 concentrations, low pH values, and shallow aragonite saturation horizons. When these waters upwell and impinge on the euphotic zone, they impact the surface ecosystem and release CO_2 and N_2O, which are strong greenhouse gases, into the atmosphere. The physical and biogeochemical processes associated with upwelling strengthen the biological pump, which increases the biological contribution to the seasonal evolution of pCO_2 relative to the thermodynamic component. The upwelling zones are known to be biogeochemically active sites and are supersaturated with CO_2 with respect to the atmosphere due to the input of carbon-rich waters from deeper layers. However, the nutrient-rich water due to upwelling fuels the primary production and lowers the pCO_2. These two processes potentially influence the variation of CO_2 across the sea-air interface. The study examines the impact of the coastal upwelling dynamics on the surface ocean pCO_2 variability in the southeastern Arabian Sea during the southwest monsoon and discerns the factors controlling its spatio-temporal variability. The enhancement of upwelling-driven dissolved inorganic carbon is more in the near-surface waters than its removal by net biological processes in the southeastern Arabian Sea. The surface ocean pCO_2 variability-driven biological processes is notable only in the southern part of the southeastern Arabian Sea but not significant in controlling pCO_2 variability. The upwelling-driven physical dynamics subjugates the biological processes in inducing the surface ocean pCO_2 variability in the southeastern Arabian Sea.

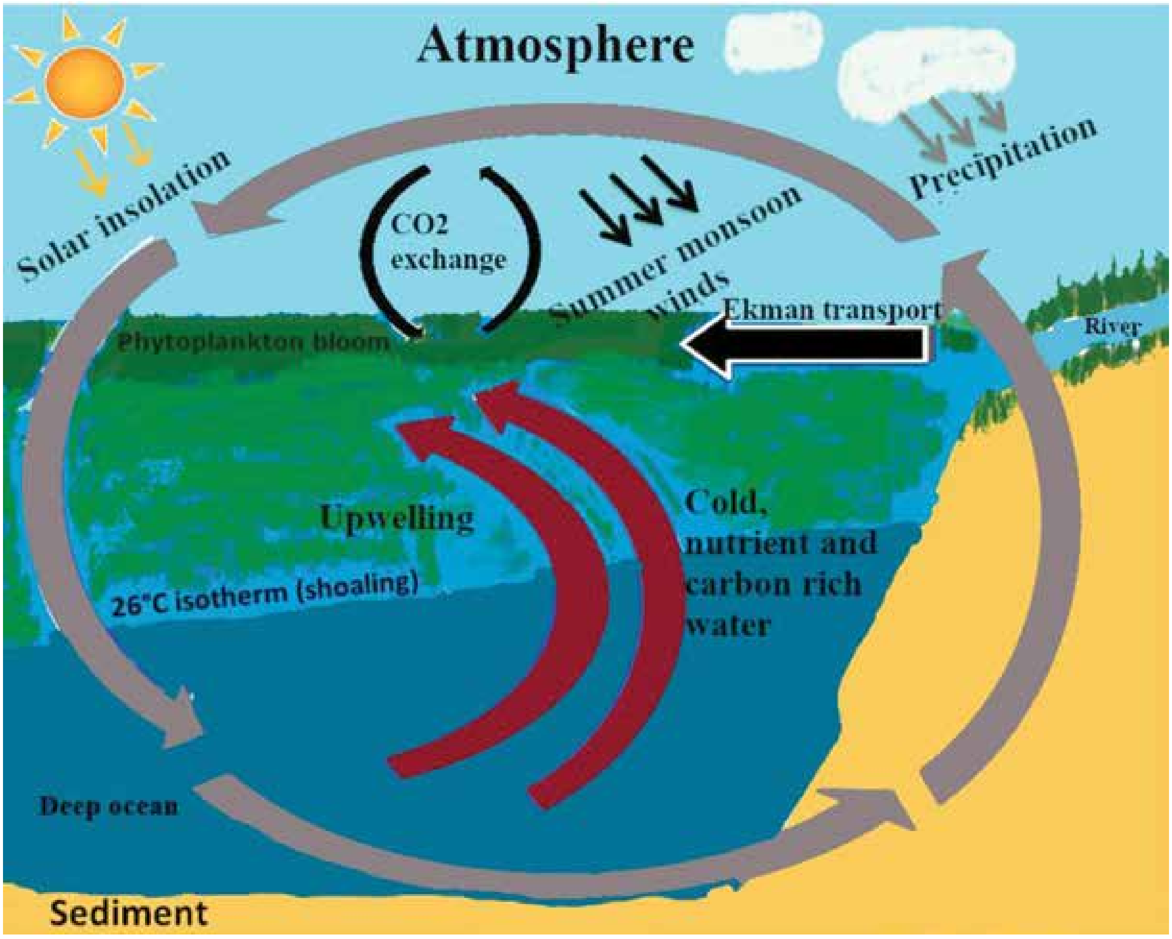


Fig. 9.7 A schematic diagram illustrating the influence of coastal upwelling dynamics on the upper ocean carbon cycle.

Ref: Ghosh, J., Chakraborty, K., Bhattacharya, T., Valsala, V., & Baduru, B. (2022). Impact of coastal upwelling dynamics on the pCO_2 variability in the southeastern Arabian Sea. Progress in Oceanography, 203, 102785.

9.8 Potential mechanisms responsible for spatial variability in intensity and thickness of Oxygen Minimum Zone in the Bay of Bengal

Spatial variability in boundaries and thickness of oxygen minimum zone (OMZ) is derived based on measured dissolved oxygen data obtained from sensors on board biogeochemical (BGC) Argo floats between 2013 and 2019 in the Bay of Bengal (BoB). Upper and lower boundaries of the OMZ varied from 60 m to 200 m and 100 m to 800 m respectively with the thickness of 80–650 m in the BoB. Relatively thicker OMZ is noticed in the northern than southern BoB associated with stratification. The oxygen concentrations in the OMZ in the north western (NW) was low (<1.5 µM) than north eastern (NE) BoB (2.5 µM) indicating that thick and intense OMZ occurs in the NW region associating with stratification and high primary production. Significant decrease in particle-back-scatter signal was observed toward offshore from shelf indicating organic matter from the shelf sediments may be supporting bacterial carbon demand in the OMZ. The particle backscatter signal peaked in the OMZ region with a higher signal in the northern than southern BoB and it is consistent with the low oxygen concentration in the former indicating that organic matter from shelf sediments may be supporting carbon needs in the OMZ. In addition to this, the occurrence of eddies significantly controls the intensity of the OMZ in the BoB through mixing at the upper boundary of OMZ. Therefore, this study suggests that spatial variations in intensity of OMZ in the BoB are governed by stratification, primary and export productions, organic matter decomposition, and eddy-driven mixing.

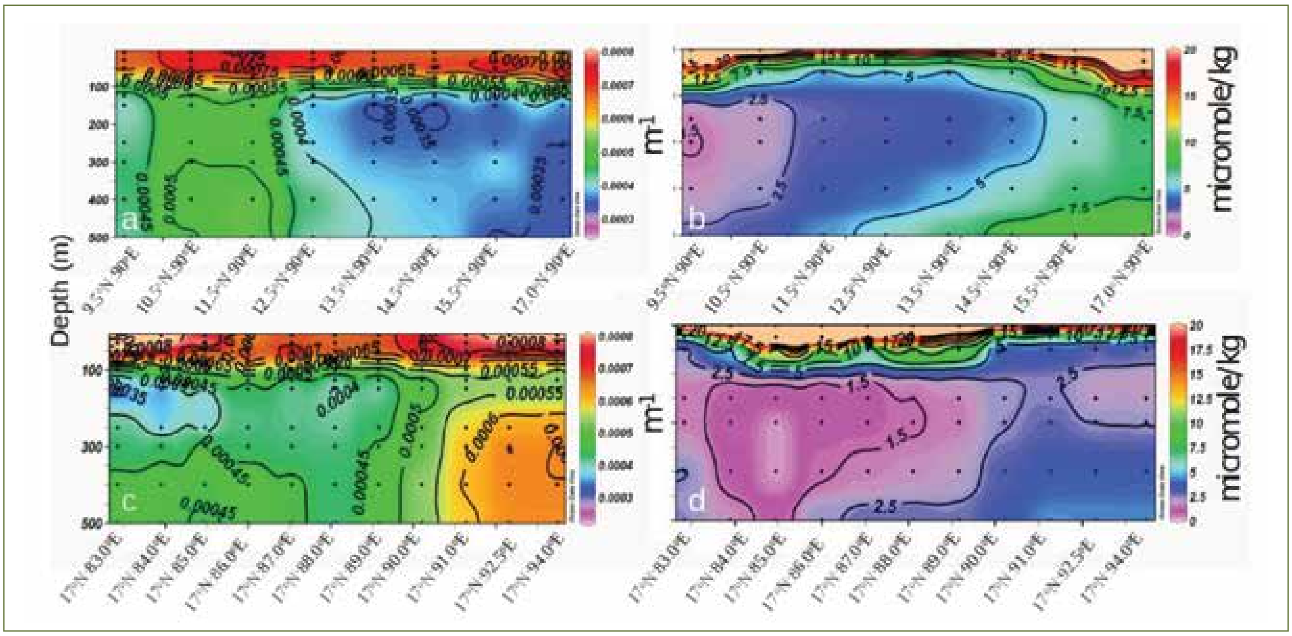


Fig. 9.8 Depth profiles of a) particle back-scatter (m^{-1}) and b) dissolved oxygen (µM) along the 90º E and (c) and (d) representing 17º N, respectively.

Ref: Udaya Bhaskar, T.V.S., Sarma, V.V.S.S., & Pavan Kumar, J. (2021). Potential mechanisms responsible for spatial variability in intensity and thickness of oxygen minimum zone in the Bay of Bengal. Journal of Geophysical Research: Biogeosciences, 126, e2021JG006341. https://doi.org/10.1029/2021JG006341

9.9 Ocean State Forecasting during VSCS "Ockhi" and a note on what is learnt from its characteristics: a forecasting perspective

Tropical Cyclone Ockhi was an intense cyclone in 2017, with a peculiar and long track, in the Arabian Sea. It caused severe damage to coastal infrastructure and inflicted the death of 282 people. Indian National Centre for Ocean Information Services (INCOIS) issued the Joint INCOIS-IMD (India Meteorological Department) bulletins on the Ocean State Forecasts (OSF) and alerts/warnings during Ockhi. Validation of the OSF from INCOIS using buoys reveals that the forecasts were in good agreement with the observations [average correlation 0.9, RMSE <0.8 m (for larger waves), and scatter index < 25%]. Climatological analysis of Genesis Potential Index (GPI) suggests that the southeast Arabian Sea, where the Ockhi was intensified, had all the favourable conditions for intensification during November/December. Moreover, it was found that four days before the genesis of Ockhi, the environmental vorticity and relative humidity were more favourable for the cyclogenesis compared to vertical wind shear and potential intensity. TC-Ockhi also intensified rapidly in a similar fashion like many of the earlier cyclones in this region behaved. Also, the cyclone track closely matched the background tropospheric winds. The present study suggests that the forecasters should investigate the background dynamic and thermodynamic conditions extensively in addition to multi-model guidance to better predict the genesis, intensity and track of the cyclones.

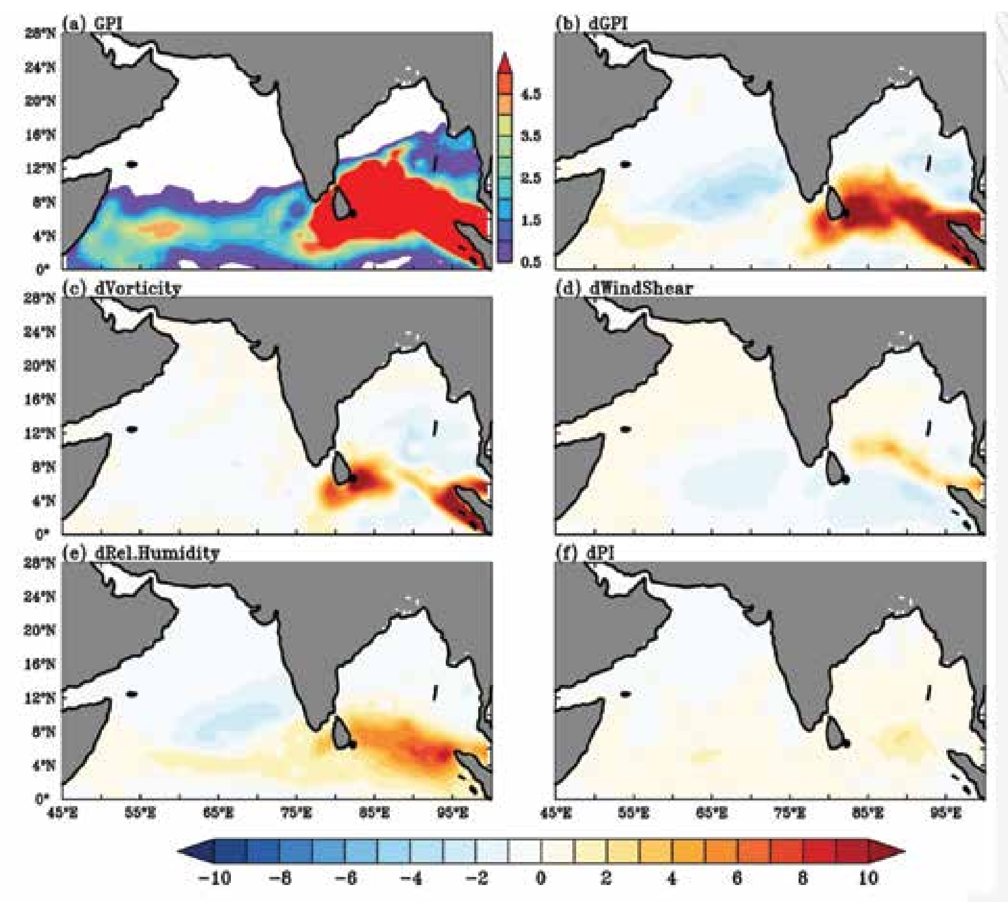


Fig. 9.9 (a) GPI, (b-f) anomaly (calculated from the daily mean) in the GPI (dGPI) and its respective terms in the dGPI (dvorticity, dwind shear, drelative humidity and dpotential intensity) during pre-TC-Ockhi period (24-28 November 2017). The colour scale below is common for the five different parameters b-f. Genesis location of the TC-Ockhi is marked as a black dot (off south-east of Sri Lanka). This figure clearly shows that on top of background conditions, primarily low-level vorticity and secondarily mid-tropospheric relative humidity were the dominant contributing factors, which led to an enhanced GPI during the TC-Ockhi period.

Ref: Harikumar, R., Sirisha, P., Modi, A., Girishkumar, M.S., Vishnu, S., Srinivas, K., Kumari, R., Grover, Y., Patro, D.K., Balakrishnan Nair, T.M. and Mohapatra, M. (2022). Ocean State Forecasting during VSCS "Ockhi" and a note on what we learnt from its characteristics: a forecasting perspective. Journal of Earth System Science, 131 92 https://doi.org/10.1007/s12040-022-01850-z

9.10 Ocean Fronts detection over the Bay of Bengal using changepoint algorithms - A non-parametric approach

Oceanic fronts are regions over the oceans where a significant change in the characteristics of the water masses is observed. Advanced Very High Resolution Radiometer (AVHRR) satellite imagery over the Bay of Bengal (BoB) shows regions which are populated by frontal structures. Over the BoB, some of the strongest gradients in temperature and salinity are observed. In recent years, there has been a tremendous growth in the availability of satellite imagery and the necessity of automated, fast detection of the frontal features is needed for services like potential fishing zones over open oceans. This study describes an algorithm to infer oceanic fronts over the BoB using changepoint analysis. The changepoint algorithm is combined in a novel way with a contextual median filter to detect frontal features in AVHRR imagery. Changepoint analysis is a non-parametric technique that does not put thresholds on the gradients of brightness temperatures of the satellite imagery. In the open oceans, the gradients of temperature and salinity are not sharp, and changepoint analysis is found to be a useful complementary technique to the existing front detecting methods when combined with contextual median filters.

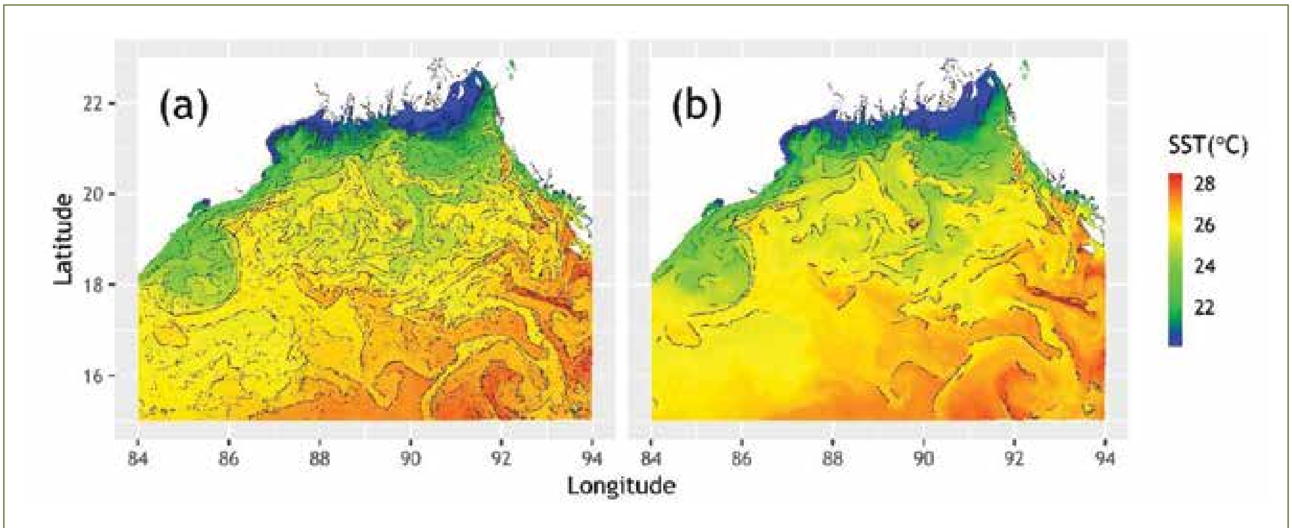


Fig. 9.10 Merging of the frontal features and the significant fronts after suppressing the background noise and small-scale features in AVHRR data of the Bay of Bengal on 10 January 2018; (a) Merged fronts; (b) Final fronts.

Ref: Reddem, V.S., Muthalagu, R., Bekkam, V.R., Eluri, P.R.R., Jampana, V. and Nimit, K. (2021). Ocean Fronts detection over the Bay of Bengal using changepoint algorithms – A non-parametric approach. Oceanologia, 63(4), 438-447. https://doi.org/10.1016/j.oceano.2021.05.003

9.11 Identifying rip channels along RK Beach, Visakhapatnam using video and satellite imagery analysis

Rip currents are one of the most well-known coastal hazards across most of the beaches. Identification and continuous monitoring of these currents are essential for the safety of beachgoers and prevent fatalities. RK Beach, Visakhapatnam is infamous for the highest recorded number of drowning deaths. In this work, a preliminary experimental study has been initiated with an objective of continuous monitoring and identification of significant rip channels along Visakhapatnam beaches from video imagery data by adopting and implementing an open-source, Quantitative Coastal Imaging Toolbox (QCIT). Ten minutes of video data were collected from temporarily installed cameras for different months. Later, QCIT was used to pre-process the video data, camera calibration, domain definition followed by rectification products. Rectification products contain single image products and pixel instruments. Single-image products such as Timex, and bright and dark images are obtained by calculating the average, maximum, and minimum intensity on the rectified frames, respectively. The phenomenon of persistent gaps in wave-breaking events that appear as dark spots on bright background from Timex images shows quasi-permanent rip channels.

9 RESEARCH HIGHLIGHTS

The locations of the rip channels extracted from the Timex images matched accurately to the hotspot maps of the rip currents obtained from the high-resolution satellite images, drifter and die experiments at the study site. Once the video camera is permanently set up, further statistical analysis with continuous data availability is also possible. With these essential results, INCOIS and SAC-ISRO (Space Application Centre, Indian Space Research Organisation) have embarked on a project with the primary objective of continuous monitoring and issuing operational forecasting alerts of rip currents by developing a coastal video surveillance system that also provides information on complex coastal and nearshore processes.

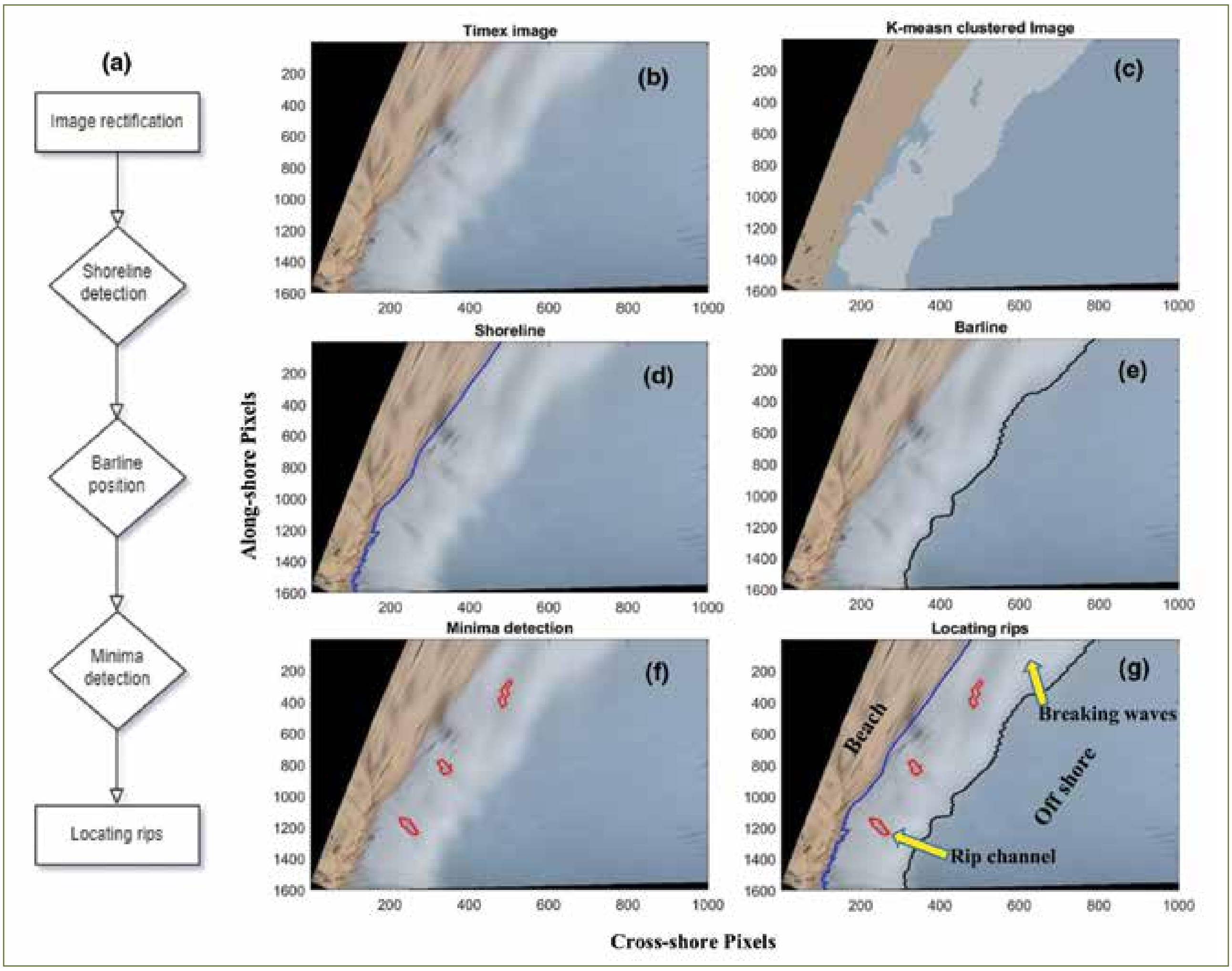


Fig. 9.11 (a) sequential flow chart to locate rips from timex images, (b) rectified timex image from RK Beach, Visakhapatnam, where the x-axis represents cross-shore while the y-axis represents along-shore, (c) the image is first segmented into four broad clusters using k-means clustering, (d) the boundary between beach and breaking zone is depicted well by this method, and used to estimate shoreline, (e) the offshore range of wave breaking is known as barline and can be extracted by clusters boundaries and pixel intensity threshold, (f) minimal detection in the surf zone by thresholding extreme pixel intensity values of the surf zone, (g) locating rips based on essential minima in the surf zone.

Ref: Borra, S., Nair, T. M., Joseph, S., Kumar, S. V., Sridevi, T., Harikumar, R., Srinivas, K., Grover, Y., Gireesh, B., Venkataswararao, K., Venkateswarlu, Ch., Anjaneyulu, A. and Prasad, K. V. S. R. (2022). Identifying rip channels along RK Beach, Visakhapatnam using video and satellite imagery analysis. Journal of the Indian Society of Remote Sensing, 1-18.

9.12 The role of anomalous oceanic features on enhancing flooding duration in Kuttanad region, Kerala

The study addressed the active role of met-ocean parameters on the heavy flooding that occurred during July 2018 in the Kuttanad region, Kerala. The analysis of seven years of wave data (model and observations) in the Indian Ocean showed a high anomaly of wave height during July 2018 off Kerala coast. The anomalous wave height seen off Kerala was not correlated with local wind anomaly and hence indicated the possible connection to the swell. The offshore observation at buoy (AD09) confirms the high wave heights are particularly due to the swell waves. Anomalous elevated non-tidal sea level was evident in the tide gauge data. Further, the study confirms the role of wave setup caused by high period (>14 s) and high swells (>1.5 m) at the Thottappally spillway for flooding intensification in the Kuttanad region. Hence, the narrow opening at Thottappally was not able to efficiently discharge the accumulating water, as the inflow greatly exceeded the outflow. Even though the main reason for the unprecedented flooding in the Kuttanad region is the excess rainfall and associated river discharge, the role of ocean also was pertinent. This study suggests that the met-oceanic parameters like winds, waves, sea level and a combination of them, can exacerbate the issues caused by the excessive rainfall and increased river discharge.

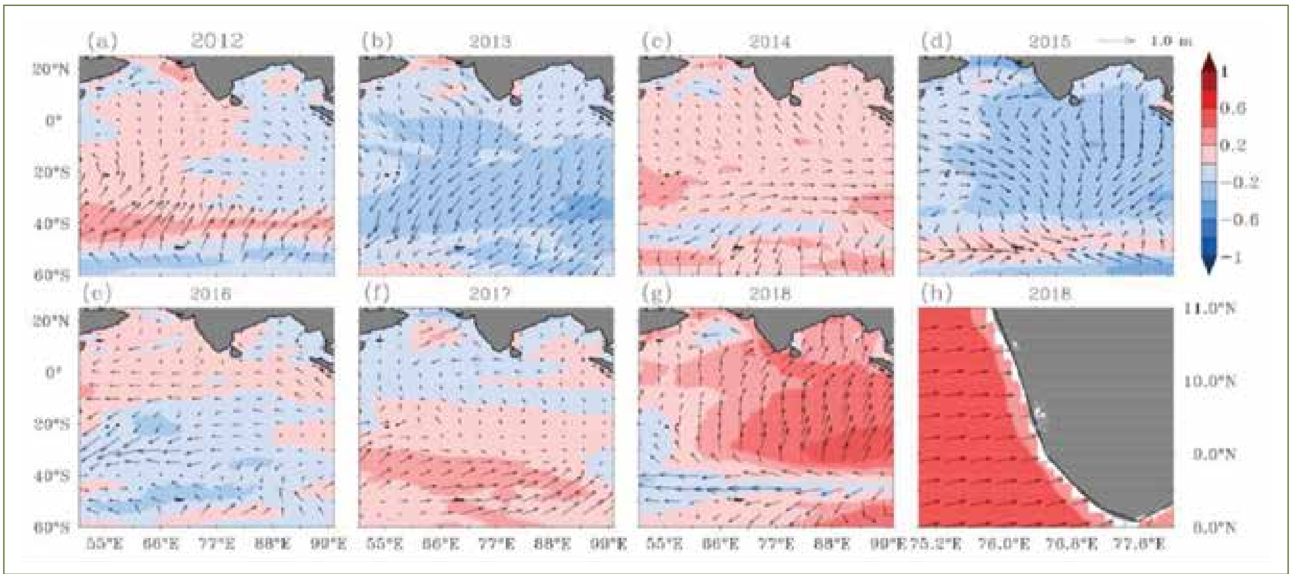


Fig. 9.12 Mean Swell Wave Height (shaded, m) and mean wave direction (vectors) anomalies for the month of July (2012-2018) for the Indian Ocean (a-g) and off coastal waters of Kerala (panel h).

Ref: Anuradha Modi, T.M.Balakrishna Nair, P.G. Remya, R Hairkumar, K Srinivas, G Srinivas. The role of anomalous oceanic features on enhancing flooding duration in Kuttanad region, Kerala (India). J Earth Syst Sci 130, 111 (2021). https://doi.org/10.1007/s12040-021-01599-x

9.13 Evaluation of winds from SCATSAT-1 and ASCAT Using Buoys in the Indian Ocean

Over the data sparse oceanic region, ocean surface winds from scatterometers onboard satellites play a crucial role to make accurate Numerical Weather Prediction model-based analysis. In the present study, ocean surface winds derived from the recently launched SCATSAT-1 for the year 2017 over the Indian Ocean are validated against the winds from the Moored and RAMA buoys. The validation results for ASCAT winds for the same period are also presented. The comparison of SCATSAT-1 (ASCAT) winds against off-shore OMNI buoy winds indicates that the mean differences for wind speed and wind direction are 0.5 m/s and -1.0° (0.39 m/s and -4.0°), and the RMSEs are 1.44 m/s and 23.0° (1.17 m/s and 25.0°), respectively. For the coastal OMNI buoys, the SCATSAT-1 (ASCAT) indicated that the mean differences for wind speed and wind direction are 1.6 m/s and -5° (1.15 m/s and -0.4°), and the RMSEs are 2.65 m/s and 46° deg, (2.1 m/s and 51°), respectively. Comparison with coastal buoys shows relatively higher errors in the satellite data compared to the buoy winds since, near coastal regions, the scatterometer winds tend to under-perform due to land contaminations. Quantified differences are almost similar for the comparison of SCATSAT-1/ASCAT with RAMA buoys. Overall, the quantified differences in the wind speed and direction between the SCATSAT-1 and buoys are closer to the satellite's mission specifications of 1.8 m/s and 20°, respectively and at par with the ASCAT accuracies. Moreover, results of comparison at buoy location and a case study during cyclonic conditions provided much needed confidence for assimilating SCATSAT-1 winds in atmospheric models.

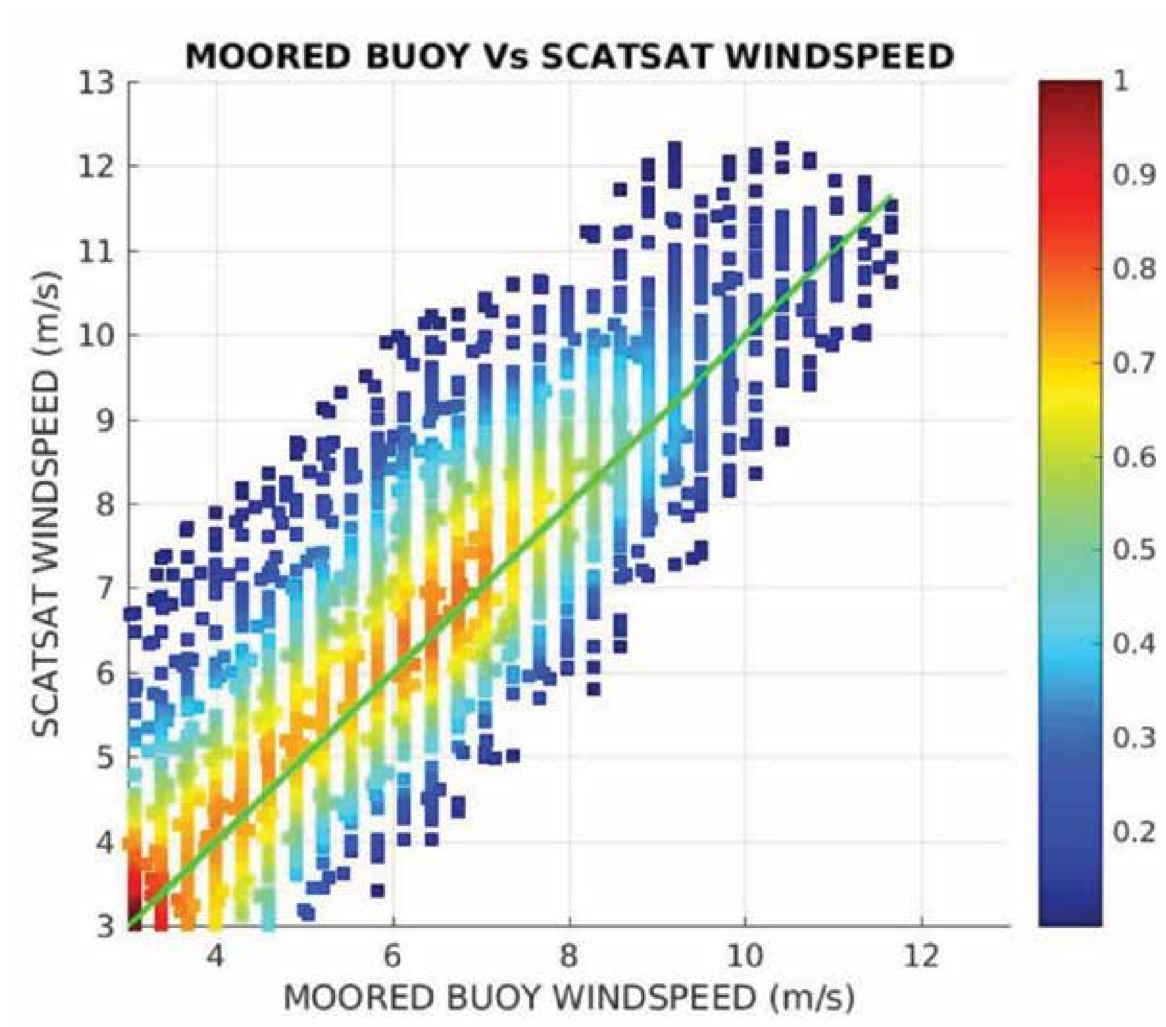


Fig. 9.13 Density scatter plot showing the comparison of SCATSAT-1 wind speed with offshore Moored Buoys winds for the year 2017

Ref: Modi, A., Munaka, S.K., Harikumar, R., Balakrishnan Nair, T. M., and Srinivas, K. (2021). Evaluation of Winds from SCATSAT-1 and ASCAT Using Buoys in the Indian Ocean. Journal of the Indian Society of Remote Sensing, https://doi.org/10.1007/s12524-021-01335-4

9.14 Optimal parameters for generation of gridded product of Argo temperature and salinity using DIVA

Determining an oceanographic parameter at regular grid positions, using a set of data at random locations both in space and time, is one of the most sought-after problems since long in the field of oceanography. In the present study, temperature and salinity profiles data obtained from Argo profiling floats were used, and data on regular grids were generated. Data-Interpolating Variational Analysis (DIVA) method was chosen for generating the gridded product. Extensive analysis was done to obtain correct choices of correlation length (L) and signal-to-noise ratio (λ) to arrive at an optimal gridded product. The gridded data obtained for different choices of L and λ was later validated with datasets deliberately set aside for performing these analyses. For each combination of L and λ, the resultant gridded data was also validated with subsurface data from OMNI buoys. Based on the statistics of comparison with OMNI, the best-fit choice for L and λ was concluded. Later, a comparative analysis was performed with the obtained gridded products from DIVA against the gridded product obtained from Objective Analysis (OA) to demonstrate the method's reliability. The resultant optimal combination of L and λ will be used for generating Argo gridded data, which will be subsequently used for generating value-added products like mixed layer depth, ocean heat content, D20, etc.

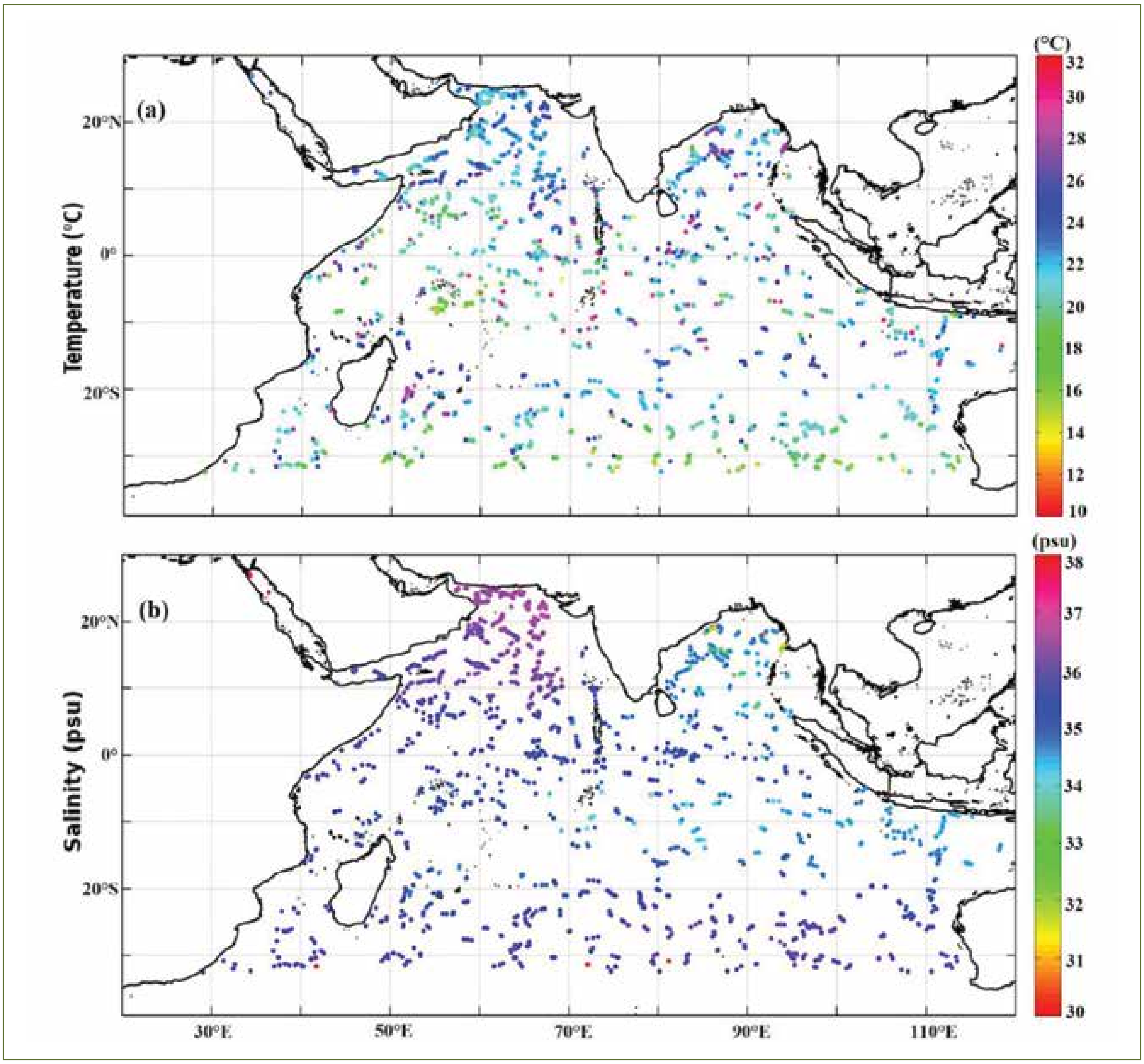


Fig. 9.14 (a) Temperature (°C) and (b) Salinity (PSU) observations from Argo profiling floats used to perform the analysis for a sample month of January 2016. Each dot represents the data availability in the region. Color of each observation represents the parameter range as represented by the color bar.

Ref: Jha, R., and Udaya Bhaskar, T.V.S. (2021). Optimal parameters for generation of gridded product of Argo temperature and salinity using DIVA. Journal of Earth System Science, 130:170, https://doi.org/10.1007/s12040-021-01675-2.

9.15 A framework for sea breeze front detection from coastal regions of India using morphological snake algorithm

Sea breezes are the most common winds experienced by people living in coastal regions. Sea breezes cause irregular climatic conditions. The collision of two powerful sea breezes fronts can cause severe thunderstorms across the coastal regions. Therefore, it is important to know the location of the sea breeze front to identify the regions that can be potentially affected by sea breezes. In order to detect the sea breeze front from satellite images, it is important to segment the satellite images. Image segmentation helps in extracting the objects of interest and make the image more meaningful for further processing. Then using contour detection, the sea breeze front can easily be extracted. A proper methodology with user interface has been proposed for detecting the sea breeze front from the satellite images.

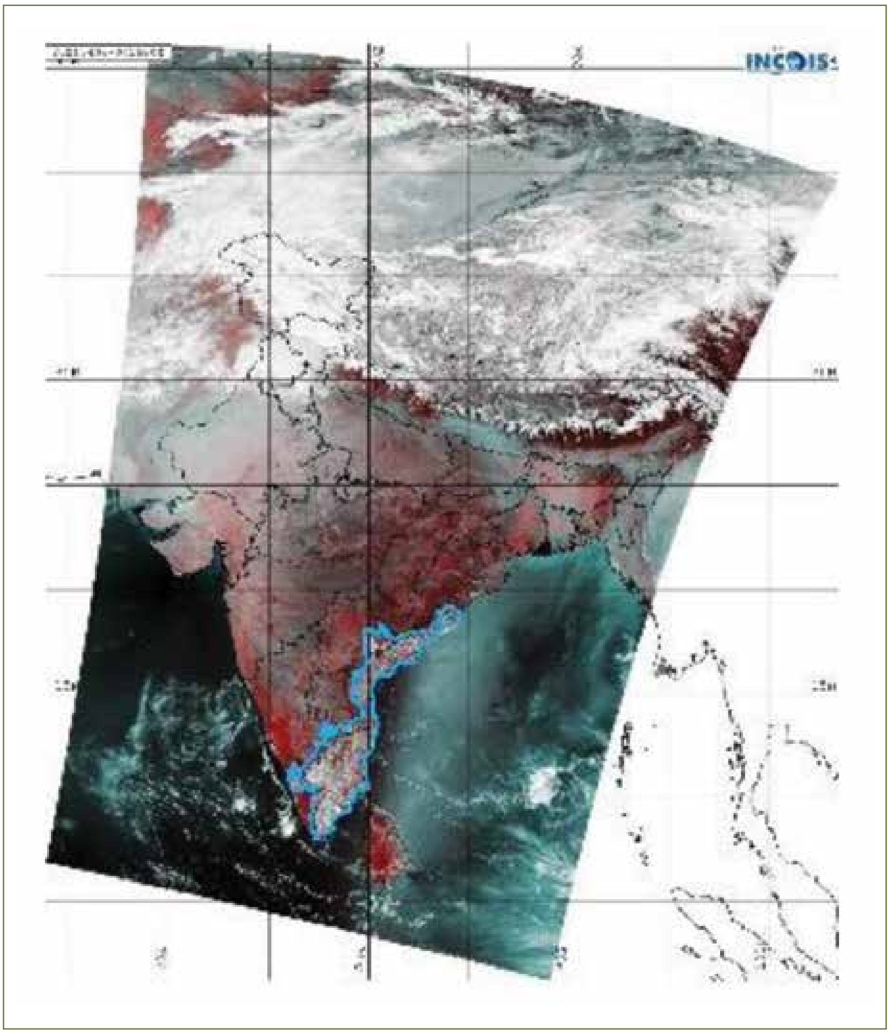


Fig. 9.15 Detected See breeze on 04 April 2021 over AVHRR FCC

Ref: Jaya Sai, P., Bhanu Prasad, M., Vasavi, S. and Geetha, G. (2022). A framework for Sea breeze Front Detection from Coastal Regions of India Using Morphological Snake Algorithm: ECS Transactions, 107 (1) 585-597.

9.16 Enhanced marine meteorological Atlas for Tropical Indian Ocean

A new marine meteorological climatology named Marine Meteorological Atlas for Tropical Indian Ocean (MaMetAtTIO) is generated from ship-based observations obtained from ICOADS-R3.0, IMD (India Meteorological Department), and NODPAC. Gridded fields of annual, monthly and individual year-month summaries at 1° × 1° grid resolution over 20° E - 120° E and 30° S – 30° N of air temperature, humidity, wind-speed, air pressure, sea surface temperature, cloud amount and heat, radiation and momentum flux are constructed. The net heat flux for TIO has been reduced by 14 W/m^2 by systematic bias correction of Beaufort estimated wind-speed. The enhancement in MaMetAtTIO with respect to ICOADS-R3.0 is evaluated as: 1) the net heat flux showed a difference of 4 W/m^2 in the West central Bay of Bengal region between ICOADS R3.0 and MaMetAtTIO, 2) the variability statistics of gridded fields have improved in MaMetAtTIO compared to ICOADS-R3.0, 3) in case of individual observations and gridded data, buoy data and Tropflux data correlate well with MaMetAtTIO respectively, compared to ICOADS-R3.0., 4) sea level pressure time series derived from MaMetAtTIO observations correlated well with MJO (Madden Julian Oscillation) index, 5) The dominant empirical orthogonal function of latent heat flux from MaMetAtTIO showed sharp distinct characteristics with respect to the monsoon characteristics compared to ICOADS R3.0.

Ref: Kameshwari, N., Udaya Bhaskar, T. V. S., Pattabhi Rama Rao, E. and Jampana, V. (2022). Enhanced marine meteorological atlas for tropical Indian Ocean. Journal of Earth System Science, 131(2), 1-21.

LIST OF PUBLICATIONS APRIL 2021- MARCH 2022

1. Acharyya, T., Sudatta, B. P., Srichandan, S., Baliarsingh, S. K., Lotliker, A. A., Raulo, S., ... & Samanta, A. (2021). Deciphering long-term seasonal and tidal water quality trends in the Mahanadi estuary. Journal of Coastal Conservation, 25(6), 1-16.
2. Afroosa, M., Rohith, B., Paul, A., Durand, F., Bourdallé-Badie, R., Sreedevi, P. V., ... & Shenoi, S. S. C. (2021). Madden-Julian oscillation winds excite an intraseasonal see-saw of ocean mass that affects Earth's polar motion. Communications Earth & Environment, 2(1), 1-8.
3. Aggarwal, R., Ugail, H., & Jha, R. K. (2022). A deep artificial neural network architecture for mesh free solutions of nonlinear boundary value problems. Applied Intelligence, 52(1), 916-926.
4. Anup, N., Vijith, V., Jithin, A. K., Rohith, B., Amol, P., & Francis, P. A. (2021). Quasi-biweekly oscillation in sea level along the western Bay of Bengal. Continental Shelf Research, 231, 104594.
5. Aparna, A. R., & Girishkumar, M. S. (2022). Mixed layer heat budget in the eastern equatorial Indian Ocean during the two consecutive positive Indian Ocean dipole events in 2018 and 2019. Climate Dynamics, 58(11), 3297-3315.
6. Baliarsingh, S. K., Lotliker, A. A., Srichandan, S., Parida, C., Roy, R., Naik, R. C., ... & Barik, K. K. (2021). Response of coastal phytoplankton pigment composition to tropical cyclone Fani. Marine Pollution Bulletin, 173, 113038.
7. Baliarsingh, S. K., Lotliker, A. A., Srichandan, S., Roy, R., Sahu, B. K., Samanta, A., ... & Jena, A. K. (2021). Evaluation of hydro-biological parameters in response to semi-diurnal tides in a tropical estuary. Ecohydrology & Hydrobiology, 21(4), 700-717.
8. Borra, S., Nair, T. M., Jospeh, S., Kumar, S. V., Sridevi, T., Harikumar, R., ... & Prasad, K. V. S. R. (2022). Identifying rip channels along RK Beach, Visakhapatnam using video and satellite imagery analysis. Journal of the Indian Society of Remote Sensing, 1-18.
9. Chakraborty, K., Valsala, V., Bhattacharya, T., & Ghosh, J. (2021). Seasonal cycle of surface ocean pCO2 and pH in the northern Indian Ocean and their controlling factors. Progress in Oceanography, 198, 102683.
10. Chatterjee, M., Shankar, D., Vijith, V., Sen, G. K., Sundar, D., Michael, G. S., ... & Das, M. (2021). Variation of salinity in the Sundarbans Estuarine System during the Equinoctial Spring tidal phase of March 2011. Journal of Earth System Science, 130(3), 1-25.
11. Chaudhuri, D., Sengupta, D., D'Asaro, E., & Shivaprasad, S. (2021). Trapping of Wind Momentum in a Salinity-Stratified Ocean. Journal of Geophysical Research: Oceans, 126(12), e2021JC017770.
12. Elizabeth, A. I., Effy, J. B., & Francis, P. A. (2022). On the upper ocean response of Bay of Bengal to very severe cyclones Phailin and Hudhud. Journal of Operational Oceanography, 15(1), 17-31.
13. Ghosh, J., Chakraborty, K., Chanda, A., Akhand, A., Bhattacharya, T., Das, S., ... & Wells, M. (2021). Outwelling of total alkalinity and dissolved inorganic carbon from the Hooghly River to the adjacent coastal Bay of Bengal. Environmental Monitoring and Assessment, 193(7), 1-14.

14. Giri, S., Chanda, A., Maity, S., Chakraborty, K., & Hazra, S. (2022). Role of tide and lunar phases on the migration pattern of juvenile Hilsa shad (Tenualosa ilisha) within a meso-macrotidal estuary. Journal of Fish Biology, 100(4), 988-996.
15. Giri, S., Chanda, A., Mondal, P. P., Samanta, S., Chakraborty, K., Maity, S., & Hazra, S. (2021). Role of biogeochemical parameters in delineating suitable habitats of juvenile Hilsa (Tenualosa ilisha) within an estuary. Environmental Biology of Fishes, 104(9), 1057-1072.
16. Girishkumar, M. S., Joseph, J., McPhaden, M. J., & Pattabhi Ram Rao, E. (2021). Atmospheric cold pools and their influence on sea surface temperature in the Bay of Bengal. Journal of Geophysical Research: Oceans, 126(9), e2021JC017297.
17. Harikumar, R., Sirisha, P., Modi, A., Girishkumar, M. S., Vishnu, S., Srinivas, K., ... & Mohapatra, M. (2022). Ocean state forecasting during VSCS Ockhi and a note on what we learned from its characteristics: A forecasting perspective. Journal of Earth System Science, 131(2), 1-20.
18. Jain, V., Shankar, D., Vinayachandran, P. N., Mukherjee, A., & Amol, P. (2021). Role of ocean dynamics in the evolution of mixed-layer temperature in the Bay of Bengal during the summer monsoon. Ocean Modelling, 168, 101895.
19. Jha, R. K., & Udaya Bhaskar, T. V. S. (2021). Optimal parameters for generation of gridded product of Argo temperature and salinity using DIVA. Journal of Earth System Science, 130(3), 1-14.
20. Jithin, A. K., & Francis, P. A. (2021). Formation of an Intrathermocline Eddy Triggered by the Coastal-Trapped Wave in the Northern Bay of Bengal. Journal of Geophysical Research: Oceans, 126(12), e2021JC017725.
21. Kameshwari, N., Bhaskar, T. V. S., Rama Rao, E. P., & Jampana, V. (2022). Enhanced marine meteorological atlas for tropical Indian Ocean. Journal of Earth System Science, 131(2), 1-21.
22. Kolukula, S. S., & Murty, P. L. N. (2022). Improving cyclone wind fields using deep convolutional neural networks and their application in extreme events. Progress in Oceanography, 202, 102763.
23. Kumar, B. P., D'Asaro, E., Sureshkumar, N., Rama Rao, E. P., & Ravichandran, M. (2021). Thorpe Turbulence Scaling in Nighttime Convective Surface Layers in the North Indian Ocean. Journal of Physical Oceanography, 51(10), 3203-3216.
24. Kumar, P., Sardana, D., Kaur, S., PG, R., & Weller, E. (2022). Influence of climate variability on wind-sea and swell wave height extreme over the Indo-Pacific Ocean. International Journal of Climatology.
25. Kumari, P. V., Thomas, S., Mohanty, P. C., Jayappa, K. S., Mahendra, R. S., & Gupta, A. (2021). Effect of Sea Surface Temperature Variation on Productivity and Fisheries off Karnataka, West Coast of India. Journal of the Indian Society of Remote Sensing, 49(12), 3027-3041.
26. Lakshmi, R. S., Prakash, S., Lotliker, A. A., Baliarsingh, S. K., Samanta, A., Mathew, T., ... & Nair, T. M. (2021). Physicochemical controls on the initiation of phytoplankton bloom during the winter monsoon in the Arabian Sea. Scientific reports, 11(1), 1-10.
27. Lotliker, A. A., Baliarsingh, S. K., Shesu, R. V., Samanta, A., Naik, R. C., & Balakrishnan Nair, T. M. (2021). Did the coronavirus disease 2019 lockdown phase influence coastal water quality parameters off major Indian cities and river basins?. Frontiers in Marine Science, 8, 648166.
28. Mahendra, R. S., Mohanty, P. C., Francis, P. A., Joseph, S., Nair, T. M., & Kumar, T. S. (2021). Holistic approach to assess the coastal vulnerability to oceanogenic multi-hazards along the coast of Andhra Pradesh, India. Environmental Earth Sciences, 80(18), 1-14.

29. Mandal, S., Behera, N., Gangopadhyay, A., Susanto, R. D., & Pandey, P. C. (2021). Evidence of a chlorophyll "tongue" in the Malacca Strait from satellite observations. Journal of Marine Systems, 223, 103610.
30. Martin, M., Abhilash, S., Pattathil, V., Harikumar, R., Niyas, N. T., Nair, T. B., ... & Osella, F. (2022). Should I Stay or Should I Go? South Indian Artisanal Fishers' Precarious Livelihoods and Their Engagement with Categorical Ocean Forecasts. Weather, Climate, and Society, 14(1), 113-129.
31. Mathew, T., Prakash, S., Baliarsingh, S. K., Samanta, A., Lakshmi, R. S., Lotliker, A. A., ... & Nair, T. B. (2021). Response of phytoplankton biomass to nutrient stoichiometry in coastal waters of the western Bay of Bengal. Ecological Indicators, 131, 108119.
32. Mishra, S., Sahoo, S., & Pandey, S. (2021). Research trends in online distance learning during the COVID-19 pandemic. Distance Education, 42(4), 494-519.
33. Modi, A., Munaka, S. K., Harikumar, R., Nair, T. M., & Srinivas, K. (2021). Evaluation of winds from SCATSAT-1 and ASCAT using buoys in the Indian ocean. Journal of the Indian Society of Remote Sensing, 49(8), 1915-1925.
34. Modi, A., Nair, T. M., Remya, P. G., Harikumar, R., Srinivas, K., & Srinivas, G. (2021). The role of anomalous oceanic features on enhancing flooding duration in Kuttanad region, Kerala (India). Journal of Earth System Science, 130(2), 1-10.
35. Mohanty, P. C., Kushabaha, A., Mahendra, R. S., Nayak, R. K., Sahu, B. K., Rao, E., & Kumar, T. S. (2021). Persistence of marine heat waves for coral bleaching and their spectral characteristics around Andaman coral reef. Environmental Monitoring and Assessment, 193(8), 1-9.
36. Murali, B., Kumar, M.G., Ravichandran, M., & Bharathi, G. (2021). Role of equatorial Indian Ocean convection on the Indian summer monsoon. Mausam, 72(2), 457-462.
37. Nimit, K. (2021). Ideas and perspectives: Ushering the Indian Ocean into the UN Decade of Ocean Science for Sustainable Development (UNDOSSD) through marine ecosystem research and operational services–an early career's take. Biogeosciences, 18(12), 3631-3635.
38. Padhi, S. K., Patro, S., Sahu, B. K., Baliarsingh, S. K., & Sahu, K. C. (2021). A preliminary study on the environmental factors triggering frequent bloom of diatom Asterionellopsis glacialis (Castracane) Round 1990 along west coast of Bay of Bengal. Indian Journal of Geo-Marine Sciences, 50(7), 533-541.
39. Pandi, S. R., Chari, N. V. H. K., Sarma, N. S., Chiranjeevulu, G., Kiran, R., Murthy, K. N., ... & Tripathy, S. C. (2021). Characteristics of conservative and non-conservative CDOM of a tropical monsoonal estuary in relation to changing bio geochemistry. Regional Studies in Marine Science, 44, 101721.
40. Pandi, S. R., Chari, N. V. H. K., Sarma, N. S., Lotliker, A. A., Tripathy, S. C., & Bajish, C. C. (2021). Spatiotemporal variability in the optical characteristics of dissolved organic matter in the coastal Bay of Bengal. International Journal of Environmental Science and Technology, 1-16.
41. Papolu, J. S., Prasad, M. B., Vasavi, S., & Geetha, G. (2022). A Framework for Sea Breeze Front Detection from Coastal Regions of India Using Morphological Snake Algorithm. ECS Transactions, 107(1), 585.
42. Parida, C., Lotliker, A. A., Roy, R., & Vinayachandran, P. N. (2022). Radiant heating rate associated with chlorophyll dynamics in upper ocean of Southern Bay of Bengal: A case study during Bay of Bengal Boundary Layer Experiment. Deep Sea Research Part II: Topical Studies in Oceanography, 196, 105026.
43. Pattiaratchi, C., van der Mheen, M., Schlundt, C., Narayanaswamy, B. E., Sura, A., Hajbane, S., ... & Wijeratne, S. (2022). Plastics in the Indian Ocean–sources, transport, distribution, and impacts. Ocean Science, 18(1), 1-28.
44. Peter, R., Kuttippurath, J., Chakraborty, K., & Sunanda, N. (2021). Temporal evolution of mid-tropospheric CO2 over the Indian Ocean. Atmospheric Environment, 257, 118475.
45. Phillips, H. E., Tandon, A., Furue, R., Hood, R., Ummenhofer, C. C., Benthuysen, J. A., ... & Wiggert, J. (2021). Progress in understanding of Indian Ocean circulation, variability, air–sea exchange, and impacts on biogeochemistry. Ocean Science, 17(6), 1677-1751.
46. Pradhan, M., Srivastava, A., Rao, S. A., Banerjee, D. S., Chatterjee, A., Francis, P. A., ... & Prasad, V. S. (2021).

Are ocean-moored buoys redundant for prediction of Indian monsoon?. Meteorology and Atmospheric Physics, 133(4), 1075-1088.

47. Prakash, K. R., Pant, V., Udaya Bhaskar, T. V. S., & Chandra, N. (2022). What Made the Sustained Intensification of Tropical Cyclone Fani in the Bay of Bengal? An Investigation Using Coupled Atmosphere–Ocean Model. Atmosphere, 13(4), 535.
48. Prasad, S. J., Balakrishnan Nair, T. M., Joseph, S., & Mohanty, P. C. (2022). Simulating the spatial and temporal distribution of oil spill over the coral reef environs along the southeast coast of Mauritius: A case study on MV Wakashio vessel wreckage, August 2020. Journal of Earth System Science, 131(1), 1-10.
49. Pravallika, M. S., Vasavi, S., & Vighneshwar, S. P. (2022). Prediction of temperature anomaly in Indian Ocean based on autoregressive long short-term memory neural network. Neural Computing and Applications, 34(10), 7537-7545.
50. Remya, P. G., Rabi Ranjan, T., Sirisha, P., Harikumar, R., & Balakrishnan Nair, T. M. (2022). Indian Ocean wave forecasting system for wind waves: development and its validation. Journal of Operational Oceanography, 15(1), 1-16.
51. Retnamma, J., Kalathil, B. K., Loganathan, J., Chinnadurai, K., Gupta, G. V. M., Chakraborty, K., & Sahu, K. C. (2021). Why the Gulf of Mannar is a marine biological paradise?. Environmental Science and Pollution Research, 28(45), 64892-64907.
52. Roy, R., Vinayachandran, P. N., Sarkar, A., George, J., Parida, C., Lotliker, A., ... & Choudhury, S. B. (2021). Southern Bay of Bengal: A possible hotspot for CO_2 emission during the summer monsoon. Progress in Oceanography, 197, 102638.
53. Sahoo, S., & Pandey, S. (2022). Characteristics and Inter-citation Network of 100 Most Influential Studies on Ocean Acidification: A Bibliometric Analysis. Science & Technology Libraries, 41(1), 56-72.
54. Seemanth, M., Remya, P. G., Bhowmick, S. A., Sharma, R., Nair, T. B., Kumar, R., & Chakraborty, A. (2021). Implementation of altimeter data assimilation on a regional wave forecasting system and its impact on wave and swell surge forecast in the Indian Ocean. Ocean Engineering, 237, 109585.
55. Sen, R., Pandey, S., Dandapat, S., Francis, P. A., & Chakraborty, A. (2022). A numerical study on seasonal transport variability of the North Indian Ocean boundary currents using Regional Ocean Modeling System (ROMS). Journal of Operational Oceanography, 15(1), 32-51.
56. Shesu, R. V., Udaya Bhaskar, T.V.S., Rama Rao, E. P., Ravichandran, M., & Rao, B. V. (2021). An improved method for quality control of in situ data from Argo floats using α convex hulls. MethodsX, 8, 101337.
57. Shesu, R.V., Muthalagu, R., Bekkam, V. R., Rama Rao, E. P., Jampana, V., & Nimit, K. (2021). Ocean Fronts detection over the Bay of Bengal using changepoint algorithms–A non-parametric approach. Oceanologia, 63(4), 438-447.
58. Shroyer, E., Tandon, A., Sengupta, D., Fernando, H. J., Lucas, A. J., Farrar, J. T., ... & Subrahmanyam, B. (2021). Bay of Bengal intraseasonal oscillations and the 2018 monsoon onset. Bulletin of the American Meteorological Society, 102(10), E1936-E1951.
59. Sirisha, P., Remya, P. G., Janardhanan, J., & Nair, T. B. (2022). Seasonal variation of wave power potential in the coastal areas of India. Current Science, 122(5), 584.
60. Snehashis, A., Vijaya, S. M., Kumar, M. K., & Shoaib, R. Characteristics of the Earthquake Swarms in the Andaman Sea Region, India, from 1960–2020.

61. Srichandan, S., Baliarsingh, S. K., Lotliker, A. A., Sahu, B. K., Roy, R., & Balakrishnan Nair, T. M. (2021). Unravelling tidal effect on zooplankton community structure in a tropical estuary. Environmental Monitoring and Assessment, 193(6), 1-21.
62. Srinivasa Kumar, T., & Manneela, S. (2021). A review of the progress, challenges and future trends in tsunami early warning systems. Journal of the Geological Society of India, 97(12), 1533-1544.
63. Steiner, Z., Sarkar, A., Liu, X., Berelson, W. M., Adkins, J. F., Achterberg, E. P., ... & Turchyn, A. V. (2021). On calcium-to-alkalinity anomalies in the North Pacific, Red Sea, Indian Ocean and Southern Ocean. Geochimica et Cosmochimica Acta, 303, 1-14.
64. Sunanda, N., Kuttippurath, J., Peter, R., Chakraborty, K., & Chakraborty, A. (2021). Long-term trends and impact of SARS-CoV-2 COVID-19 lockdown on the primary productivity of the North Indian Ocean. Frontiers in Marine Science, 1176.
65. Tiwari, P., Dimri, A. P., Shenoi, S. C., Francis, P. A., & Jithin, A. K. (2021). Impact of Surface forcing on simulating Sea Surface Temperature in the Indian Ocean–A study using Regional Ocean Modeling System (ROMS). Dynamics of Atmospheres and Oceans, 95, 101243.
66. Udaya Bhaskar, T. V. S., Sarma, V. V. S. S., & Pavan Kumar, J. (2021). Potential mechanisms responsible for spatial variability in intensity and thickness of oxygen minimum zone in the Bay of Bengal. Journal of Geophysical Research: Biogeosciences, 126(6), e2021JG006341.
67. Umamaheswari, T., Sugumar, G., Krishnan, P., Ananthan, P. S., Anand, A., Jeevamani, J. J. J., ... & Rao, C. S. (2021). Vulnerability assessment of coastal fishing communities for building resilience and adaptation: Evidences from Tamil Nadu, India. Environmental Science & Policy, 123, 114-130.
68. Valsala, V., Sreeush, M. G., Anju, M., Sreenivas, P., Tiwari, Y. K., Chakraborty, K., & Sijikumar, S. (2021). An observing system simulation experiment for Indian Ocean surface pCO2 measurements. Progress in Oceanography, 194, 102570.
69. Vinayachandran, P. N. M., Masumoto, Y., Roberts, M. J., Huggett, J. A., Halo, I., Chatterjee, A., ... & Hood, R. (2021). Reviews and syntheses: Physical and biogeochemical processes associated with upwelling in the Indian Ocean. Biogeosciences, 18(22), 5967-6029.
70. Vishwakarma, V., Pattnaik, S., Chakraborty, T., Joseph, S., & Mitra, A. K. (2022). Impacts of sea-surface temperatures on rapid intensification and mature phases of super cyclone Amphan (2020). Journal of Earth System Science, 131(1), 1-21.

Book Chapters

1. Acharyya, T., Sudatta, B.P., Raulo, S., Singh,S., Srichandan, S., Baliarsingh, S.K., Samanta,A., and Lotliker, A.A.(2021). A systematic review of biogeochemistry of Mahanadi river estuary: Insights and future research direction. In S.Das, and T.Ghosh (Eds.), Estuarine Biogeochemical Dynamics of the East Coast of India, pp. 57-80.SpringerNature.ISBN:978-3-030-68980-3.DOI: 10.1007/978-3-030-68980-3.
2. Juan Manuel Castillo, HuwLewis, AkhileshMishra, AshisMitra, JeffPolton, AshleyBrereton, Andrew Saulter, Alex Arnold, Segolene Berthou, Douglas Clark, JuliaCrook, AnandaDas, JohnEdwards, XiangboFeng, AnkurGupta, SudheerJoseph, NicholasKlingaman, Imranali Momin, Christine Pequignet, Claudio Sanchez, Jennifer Saxby, and Maria Valdivieso da Costa (2022), "The Regional Coupled Suite (RCS-IND1): applicationof a flexible regional coupled modelling framework to the Indian region at km-scale", Geoscientific Model Development Discussions., pp.1-54.CopernicusGmbH.
3. Padmanabham, J., Murty, P.L.N., Srinivasa Kumar, T., Udaya Bhaskar, T.V.S. (2022). An Integrated Decision Support System for Storm Surge Early Warning Using SOA. In: Reddy, A.B., Kiranmayee, B., Mukkamala, R.R., Srujan Raju, K. (eds) Proceedings of Second International Conference on Advances in Computer Engineering and Communication Systems. Algorithms for Intelligent Systems. Springer, Singapore. https://doi.org/10.1007/978-981-16-7389-4_9.
4. Sulochana Gadgil, PA Francis, P. N. Vinayachandran and Sajani S. (2021). Interannual variation of the Indian summer monsoon, ENSO, IOD and EQUINOO, Indian Summer MonsoonEd. C. Gnanaseelan, Springer.

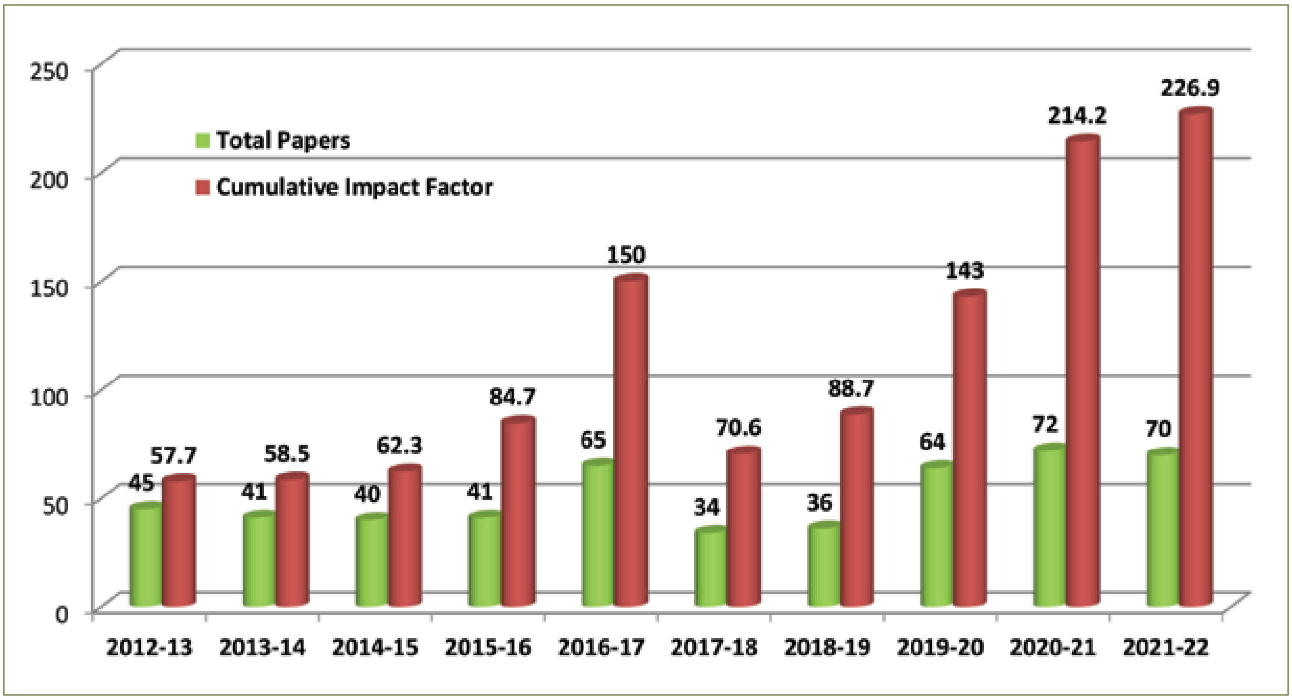
9 RESEARCH HIGHLIGHTS

Conference Paper

1. Nimit K., Gad Levy, Nurul Hazrina Idris, 2021.Preface: 15th Pan-Ocean Remote SensingConference (PORSEC) pre-conference proceedings (Abstracts and Full Papers).
2. T.M. Balakrishnan Nair, NimitK., AneeshL., Anuradha Modi, Sudheer Joseph.2021. Oceansat-3 Applications For Ocean State Forecast And Potential Fishing Zones Services.second International India Geoscience and Remote Sensing Symposium (InGARSS-2021), held during December 6-10.

Technical Report

1. R. Harikumar, K. Srinivas, M. Sourav, Nimit Kumar, B. Ajay, R.S. Mahendra, M.V. Sunanda, SudheerJoseph, T.M. Balakrishnan Nair, T.Srinivasa Kumar, On the INCOIS Integrated User Interaction Workshop-22 on 2/2/2022 and User Engagement, Analysis of Feedback and Further Requirements for the Improvement, Refinement and Expansion of the entire INCOIS Services", Technical report, ESSO-INCOIS-ARO-OSAR-TR-01(2022),Pg.74,2022.
2. N Kameshwari, TVS Udayabhaskar, BV Satyanarayan, "INCOIS-Real time Automatic Weather Station (IRAWS) dataset – Enhanced Quality control procedure", Technical report, ESSO-INCOIS-ODM-TR-02(2022), Pg.18, 2022.



Growth of publications in peer review journals and their cumulative impact factor

10

INVOLVEMENT IN INTERNATIONAL COORDINATION

10 INVOLVEMENT IN INTERNATIONAL COORDINATION

10.1 Indian Ocean Global Ocean Observing System (IOGOOS)

- Indian Ocean Global Ocean Observing System (IOGOOS) Secretariat at INCOIS successfully organized its 17th annual meeting and its allied programs 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 21-25 March 2022. During IOGOOS 17 general body meeting, Dr. T. Srinivasa Kumar, Director, INCOIS, was elected as Chair of IOGOOS for a period of two years.
- The IOGOOS Secretariat, in partnership with IOGOOS Member institutes and the SIBER community, has conducted two International Training programs.
  - “**Biological Observations in the Indian Ocean (From Microbes to Megafauna)**” was held during 08-11 November 2021. The training focused primarily on biological Essential Ocean Variables (EOVs) for functional groups, particularly, microbes, phytoplankton, zooplankton, and benthic invertebrates, but also briefly covered fish, turtles, and marine mammals, as well as habitat states such as hard corals, mangroves and seagrasses. Seventy students encompassing graduate students, research scholars, and young researchers from 22 countries, mainly covering the Indian Ocean RIM countries, attended the training along with trainers from 11 countries.
  - "**Modeling for Ocean Forecasting and Process Studies (MOFPS)**" was held during 06 -10 December 2021. The training focused on introducing the basic concepts of physical and dynamic oceanography and numerical modeling of the ocean general circulation, waves, tides, etc., in the context of operational applications of ocean modeling. 78 trainees comprising of students, researchers, officials, and nominees from met-ocean departments from 24 countries mainly covering the Indian Ocean RIM countries participated in the training program.
  - **A brainstorming session on "Modeling for Ocean Forecasting and Process Studies (MOFPS)"** was held on 10 December 2021 with panelists and participants from Australia, Bangladesh, Comoros, India, Maldives, and Saudi Arabia. The brainstorming session was to identify the ocean parameters required to know the existing capacities in ocean forecasting from the region, and to know the requirements of ocean forecasting. IOGOOS designed a brief survey to identify the required paramaeters, and about 59 participants have responded to the survey.
- Dr. T. Srinivasa Kumar, IOGOOS Chair, and Mr. M. Nagaraja Kumar, IOGOOS Secretary, participated in the 10th meeting of the Global Ocean Observing System (GOOS) Steering Committee meeting to discuss GOOS regional approaches with GOOS Regional Alliances and regional GOOS projects held virtually on 29 November 2021.
- Dr. T. Srinivasa Kumar, IOGOOS Chair, and Mr. M. Nagaraja Kumar, IOGOOS Secretary, participated in the 13th meeting of IndOOS Resource Forum (IRF) held virtually on 09 December 2021 and discussed and reviewed the requirement of resources towards enhancing the observations in the Indian Ocean.
- Dr. T. Srinivasa Kumar, IOGOOS Chair, and Mr. M. Nagaraja Kumar, IOGOOS Secretary, participated in the GOOS Regional Alliance Forum (GRA) meeting, held virtually on 16 December 2021 and discussed the plans to contribute to the UN Ocean Decade and the next GRA Leadership.

10.2 United Nations Ocean Decade for Sustainable Development (Ocean Decade)

- INCOIS submitted a proposal for the establishment of the Indian Ocean Region Decade Collaborative Centre (IOR-DCC) against the Call for Ocean Decade 01/2021 made by IOC-UNESCO. A virtual meeting was held on 13 December 2021 with IOC Ocean Decade Secretariat to discuss the submitted proposal.
- INCOIS participated in an online meeting on "Call for Decade actions No.02/2021"held on 13 October 2021 and exchanged its views on UN Decade of Ocean.
- India also made a voluntary contribution to the Intergovernmental Oceanographic Commission (IOC) of the UNESCO through one-time voluntary contribution of 50,000 USD to support the implementation of the UN Decade of Ocean for Sustainable Development.
- Dr. T. Srinivasa Kumar, Director, INCOIS, participated in the 54th session of the IOC Executive Council meeting and the 31st session of the IOC Assembly held virtually during 14-25 June 2021.
    - ➢ India strongly supported the United Nations Decade of Ocean Science for Sustainable Development (UN Ocean Decade) Programme and its implementation plan.
    - ➢ India strongly supported the elevation of the Status of the IOC Regional Committee for the Central Indian Ocean (IOCINDIO) to a Sub-Commission of IOC.
    - ➢ Dr. T. Srinivasa Kumar, Director, INCOIS, has been elected as the Vice-Chair of IOC from Group IV.

10.3 IOC Regional Committee for the Central Indian Ocean (IOCINDIO)

- Dr. T. Srinivasa Kumar, Director, INCOIS, has been elected as a member of the Open-ended inter-sessional Working Group (OEIWG) constituted to discuss the elevation of the status of IOCINDIO to a Sub-commission of IOC.
- Dr. T. Srinivasa Kumar, Director, INCOIS, participated in the First Meeting of the Open-ended intersessional Working Group (OEIWG) on the Status of the IOC Regional Committee for the Central Indian Ocean (IOCINDIO) held virtually on 28 February 2022, and discussed on the existing Programs, Projects, and Activities in the IOCINDIO Region.
- INCOIS participated in the 8th Intergovernmental Session of the IOC Regional Committee for the central Indian Ocean (IOCINDIO-VIII) held virtually during 17–19 May 2021. India, through INCOIS/MoES (the national focal point of India) has supported the proposal for the elevation of IOCINDIO as the Sub-commission of IOC-UNESCO.

10.4 Partnership for Observation of the Global Oceans (POGO)

- INCOIS continues to be a member of the Partnership for Observation of the Global Oceans (POGO).
- Dr. T. Srinivasa Kumar, Director, INCOIS, and Mr. M. Nagaraja Kumar, Scientist-F participated in the 23rd POGO Annual meeting held virtually during 24–28 January 2022. Mr. M. Nagaraja Kumar made a brief presentation on the new activities/developments at INCOIS and programs/projects being implemented by INCOIS.

10.5 International Oceanographic Data Exchange

The program "International Oceanographic Data and Information Exchange" (IODE) of the "Intergovernmental Oceanographic Commission" (IOC) of UNESCO was established in 1961 with the purpose of enhancing marine research, exploitation, and development, by facilitating the exchange of oceanographic data and information among the participating member states, and by meeting the needs of users for data and information products. INCOIS has been designated as the National Oceanographic Data Centre since 2004. INCOIS continued to provide data and information management services that underpin IOC programs in the areas of ocean science, ocean observations, tsunami warning and mitigation, and coastal area management. Mr. E. Pattabhi Rama Rao continues to act as the National Coordinator for 'Data Management'.

10.6 OceanSITES

The mission of OceanSITES is to collect, deliver and promote the use of high-quality data from long-term, high-frequency observations at fixed locations in the open ocean. OceanSITES typically aim to collect multi-disciplinary data worldwide from the full-depth water column as well as the overlying atmosphere. INCOIS has been designated as OceanSITES Data Assembly Centre (DAC). Shri. E. Pattabhi Rama Rao represented INCOIS on the OceanSITES Data Management Team, responsible for ocean data management by devising appropriate standards, formats, and quality controls for the data obtained from OMNI moorings deployed and maintained in the northern Indian Ocean.

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

- RIMES, an intergovernmental organization registered with the United Nations, aims to provide regional early warning services, including early warning of tsunamis and hydro-meteorological hazards, and to build the capacity of its member states. As per the MoU between MoES, Govt. of India, and RIMES, INCOIS continued to provide the ocean state forecasts for Comoros, Madagascar, Maldives, Mozambique, Seychelles, and Sri Lanka. INCOIS is receiving Seismic/GNSS data from Myanmar, Bhutan, and Nepal established by RIMES and INCOIS.
- Dr. T. Srinivasa Kumar, Director, INCOIS, along with INCOIS colleagues, had a meeting with Dr. A. R. Subbiah, Director, RIMES, and the team on 06 October 2021 to discuss MoES sanctioned projects and transfer mechanism of broadband Seismic station (20 Nos), GNSS (08 Nos) and SMA (08 Nos) established in Myanmar, Bhutan and Nepal under the project of "Implementation of prioritized technical capacity development projects in RIMES for Afro Asian Region".

10.8 SIBER International Programme Office

Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) is an international program co-sponsored by IMBeR (Integrated Marine Biosphere Research) and Indian Ocean Global Ocean Observing System (IOGOOS) that is focused on the Indian Ocean. The SIBER program aims to motivate and coordinate international interest in Indian Ocean research to improve the understanding of the role of the Indian Ocean in global biogeochemical cycles and the interaction between these cycles and marine ecosystem dynamics. INCOIS, hosts International Programme Office to coordinate the activities of SIBER. The SIBER program is co-chaired by Prof. Raleigh Hood, University of Maryland, Cambridge, USA, and Gregory Cowie, University of

Edinburgh, UK. Dr. Aneesh Lotliker, Scientist-E, and Head of Ocean Observation Network Division of INCOIS, assumed the charge of Executive Director, SIBER-International Programme Office in November 2021. The 11th meeting of SIBER Scientific Steering Committee (SSC) was convened on 10 January 2022. The focus of the meeting was to introduce the activities of SIBER and its modes of operation to Dr. Aneesh Lotliker. The SSC also discussed the available biogeochemical time-series data across the globe and advised on long-term time-series biogeochemical observations using autonomous sensors in the Indian Ocean. The SIBER-SSC also discussed the low coast instrumentation for biogeochemical parameters known as CoLab (Coastal Lan in a Box). In addition, the agenda for next meeting was finalized. The 12th meeting of SIBER-SSC was convened on 23 March 2022. During the meeting, SIBER-SSC reviewed the membership and possible funding. The co-chair provided updates on the SIBER products such as Deep-Sea Research Special Issues on IIOE-2/110°E, Biogeosciences review articles, and Elsevier book on the Indian Ocean. The SSC members also presented the plans for biogeochemical observations in India, Germany, France, South Africa, and United Kingdom. Subsequently, plans for SIBER post–2025 were discussed.

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

- The Second International Indian Ocean Expedition (IIOE-2) is a major global program co-sponsored by UNESCO-IOC, the Scientific Committee on Oceanic Research (SCOR), and IOGOOS. These international bodies, each involved in the science in the Indian Ocean, take responsibility for facilitating and funding the infrastructure of IIOE-2, including resourcing of the two Joint Program Offices (JPOs) with nodes in India (INCOIS, Hyderabad) and in Australia (IOC Perth Program Office, PPO). The major responsibility of IIOE-2 JPO India is to maintain IIOE-2 Website, facilitate endorsement of projects, outreach activities in the form of Ocean Bubble and Monthly Newsletter, management of the data generated from IIOE-2 cruises, facilitate Early Career Scientist Network (ECSN), and social media.
- Dr. Vladimir Ryabinin and Dr. Marie-Alexandrine Sicre continue to be co-chairs of the IIOE-2 Steering Committee (SC), whereas Dr. Satheesh Shenoi voluntarily stepped down as a co-chair of IIOE-2 SC. Dr. Aneesh Lotliker, Scientist-E, and Head, Ocean Observation Network, INCOIS, assumed the charge of the JPO-India coordinator in November 2021. During the reporting period, IIOE-2 JPO-Australia note was closed due to the discontinuation of the funding from IOC Perth office. Further, JPO-India continued to maintain IIOE-2 website (https://iioe-2.incois.gov.in), including timely updates on IIOE-2 expeditions and the metadata portal. A prototype was designed for (1) IIOE-2 Online Discussions Forum to discuss about any scientific topics among the registered users under IIOE-2, (2) website for Early Career Scientist Network (ECSN) under IIOE-2, and (3) WebGIS Application for IIOE-2 Endorsed Projects along with Buoys Observations Network. In addition, a Cyber Security audit was conducted through C-DAC, Hyderabad, India, certified by CERT-In, and the suggestions are incorporated to maintain the security of the IIOE-2 website and the data.
- The JOP-India also convened the fifth meeting of the steering committee (SC) during 21–22 March 2022. Three scientific projects were endorsed by the SC during fifth meeting from University of Western Australia, The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, and Scripps Institution of Oceanography. The SC also endorsed the IIOE-2 Data and Information Policy prepared by WG-2 (Data and Information Management) co-chaired by Mr. E. Pattabhi Rama Rao (India) and Dr. Harrison O. Ong'Anda (Kenya). JPO-India published two issues of the IIOE-2 newsletter during April 2022 (Volume-6, Issue-4) and May 2022 (Volume-6, Issue-5), along with two issues of The Indian Ocean Bubble-2 during April 2021 (Issue No 14) and December 2021 (Issue No 15). JPO-India also played a key role in organizing the International Indian Ocean Science Conference (IIOSC) 2022 virtually during 14-18 March 2022.

10 INVOLVEMENT IN INTERNATIONAL COORDINATION

10.10 International Indian Ocean Science Conference (IIOSC)-2022

- The International Indian Ocean Conference (IIOSC) was held virtually during 14-18 March 2022. The conference was initially planned to be held at Goa during March 2020. However, it was postponed due to the COVID-19 outbreak. 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 to mark the completion of 50 years of the first IIOE. The IIOSC provided a great platform for scientists working on different facets of the Indian Ocean to present their ideas, discuss outstanding issues, identify knowledge gaps and plan a way forward to address such issues. INCOIS hosted the conference in partnership with CSIR-National Institute of Oceanography (NIO), National Centre for Polar and Ocean Research (NCPOR), and Goa University.
- The conference was inaugurated by Dr. Jitendra Singh, Hon'ble Minister of State (Independent Charge) of the Ministry of Earth Sciences, Minister of State (Independent Charge) of Science & Technology, Minister of State in the Prime Minister's Office, and delivered his inaugural address through a recorded message. Dr. M. Ravichandran, Secretary, MoES, provided his keynote talk on India's Deep Ocean Mission. Dr. Marie Alexandrine Sicre, President, Scientific Committee on Ocean Research (SCOR) and Co-chair of IIOE-2 Steering Committee, Dr. T. Srinivasa Kumar, Director, INCOIS & Chair, IOGOOS, and Prof. Sunil Kumar Singh, Director, CSIR-NIO provided their remarks on this occasion. The guest of honor, Dr. Vladimir Ryabinin, IOC Executive Secretary & Co-Chair, IIOE-2, delivered a talk on "The United Nations Decade of Ocean Science for Sustainable Development, 2021-2030", mentioning the importance of UN Decade in enhancing our understanding and sustainable management of the oceans.
- The conference witnessed by over 400 participants, representing 20 countries and presented their research carried out in the Indian ocean across 14 themes. The organizing committee has also given specific emphasis to design sessions aimed at capturing ideas on how best the IIOE-2 framework can contribute to the challenges and expected outcome of the United Nations Decade of Ocean Science for Sustainable Development through five plenary sessions and talks by eminent researchers and moderated panel discussions on specific themes and addressed questions on how the IIOE-2 and broader Indian Ocean Research Community can galvanize actions to address and contribute to the UN Decade Challenges. The details of the IIOSC-2022 can be found at https://iiosc2020.incois.gov.in/

10.11 World Meteorological Organization (WMO)-Intergovernmental Oceanographic Commission (IOC) Joint Collaborative Board

- Dr. T. Srinivasa Kumar, Director, INCOIS, has been elected as Vice-Chair of the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) Joint Collaborative Board (JCB), representing IOC.
- Dr. T. Srinivasa Kumar, Director, INCOIS, delivered a talk on the "Indian Experience on the Ocean Value Chain, starting from Observations to Services" during the WMO RA II Side event on "Ocean Priorities: Towards a Regional cooperation Roadmap" held virtually on 29 September 2021.

- Dr. T. Srinivasa Kumar, Director, INCOIS, Dr. TVS Udaya Bhaskar, Scientist F, Dr. P A Francis, Scientist F, and Mr. M. Nagaraja Kumar, Scientist F participated in the WMO-IOC Joint Collaborative Board (JCB) meeting held virtually during 01-02 March 2022. Dr. T. Srinivasa Kumar co-chaired the meeting.

10.12 OceanPredict

OceanPredict is an international research and development network to accelerate, strengthen and increase the impact of ocean prediction. Ocean prediction is an essential component in the provision of routine oceanographic information for decision making purposes (defined as operational oceanography). OceanPredict started in 1999 as the Global Ocean Data Assimilation Experiment (GODAE), motivated by the Ocean Observation Panel for Climate (OOPC). The purpose of OceanPredict is to demonstrate the feasibility and value of ocean observation systems through the assimilation of observations into state-of-the-art ocean models for analysis and prediction. For the next decade, OceanPredict will advance ocean prediction science and operational capacity and partner with international entities to maximize the impact of operational oceanography outcomes on marine science, sustainable marine economies, and society. The rapidly growing public awareness of the threats posed by climate change presents the opportunity for OceanPredict to provide societal benefit in supporting sustainable development, enhanced resilience, and blue economy growth.

- Dr. Arya Paul, Scientist E, is a member of the data assimilation task team in Ocean Predict, which fosters coordination and monitors progress in (a) development of data assimilation algorithms, (b) development of coupled data assimilation methods, (c) assimilation of novel observations, (d) performance assessment of data assimilation applications in the operational community and many other activities.
- Biswamoy Paul, Scientist C, is a member of the Observation System Evaluation task team that supports observational communities by giving recommendations on observation system evolution from the OceanPredict perspective.

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

- As part of the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) of the Intergovernmental Oceanographic Commission of UNESCO, INCOIS is acting as Tsunami Service Provider (TSP), providing tsunami services to the Indian Ocean Region together with TSPs Australia & Indonesia. TSP-India provides services to Australia, Bangladesh, Comoros, France (La Réunion), India, Indonesia, Iran, Kenya, Madagascar, Malaysia, Maldives, Mauritius, Mozambique, Myanmar, Oman, Pakistan, Seychelles, Singapore, South Africa, Sri Lanka, Tanzania, Thailand, Timor Leste, UAE, and Yemen.
- INCOIS Scientists were involved in various capacities (Vice-chairs and members) in the ICG/IOTWMS in Steering Group, Working Groups, Task Team and participated in related virtual meetings and contributed to related activities.
- Contributed to Probabilistic Tsunami Hazard Assessment (PTHA) work of Makran Subduction Zone (MSZ) Project.
- IOTWMS Regional Webinar on Engagement of Media in the Tsunami Warning Chain was held on 17 June 2021. Media colleagues from India were participated in the webinar.
- IOTWMS First Regional Standard Operating Procedure Workshop (hybrid sessions) for Broadcasting Media in the Tsunami Warning Chain was held during 07-09 September 2021. As part of the workshop, media representative (PIB, AIR, DD) visited INCOIS and briefed on Indian Tsunami Warning Systems and its SOP and products.
- IOC-UNESCO organized a regional workshop on Standard Operating Procedure (SOP) for Disaster

Management Organizations and Broadcasting Media in Tsunami Warning Chain during 12-14 October and 26-28 October 2021. The workshops focused on the Northwest Indian Ocean countries i.e., India, Iran, Oman, Pakistan, and UAE.

- Indian Ocean Webinar on World Tsunami Awareness Day Strategic Pathway for IOTWMS within the Context of UN Decade for Ocean Science was held on 10 November 2021.
- The ICG/IOTWMS conducted virtual Intersessional Meetings on 23-24 November 2021. INCOIS Scientists and NDMA officials participated and presented India's National Report and TSP-India progress report.
- ICG/IOTWMS Communication Tests (22nd and 23rd) were conducted on 09 June 2021 and on 08 December 2021 to validate tsunami information dissemination process. INCOIS participated in COMMs test and issued test bulletins to 25 Indian Ocean rim countries as a Tsunami Service Provide.

10.14 Indian Ocean Rim Association (IORA)

- Indian Ocean Rim Association (IORA) is a dynamic organization of 23 Member States and 9 Dialogue Partners, with an ever-growing momentum for mutually beneficial regional cooperation through a consensus-based, evolutionary and non-intrusive approach.
- INCOIS is providing tsunami early warning services to all 23 IORA member states through ICG/IOTWMS framework. INCOIS has already initiated services in the Indian Ocean region through RIMES framework for Comoros, Madagascar Maldives and Mozambique, Seychelles and Sri Lanka.
- INCOIS has agreed to support in (i) Creating institutional frameworks and IORA policy guidelines for cooperation in Disaster Risk Management and Disaster Relief, Search And Rescue, and (ii) Developing DRM Capacities of IORA Member States through exchange programs, exposure visits, training and capacity building programs, joint exercises, etc.

10.15 Other International Collaborations / Activities

- Dr. T. Srinivasa Kumar, Director, INCOIS participated in the 1st EDM – Climate Sustainability Working Group meeting of G20 held during 21-24 March 2022, in Indonesia. India provided its inputs on the concept note related to "Promoting Ocean based solution to climate change through enhanced cooperation in Science, Research and Innovation".
- A meeting was held with Dr. Raghu Murtugudde, University of Maryland, to discuss the proposal from INCOIS to collaborate with GEOS. Under this collaboration, INCOIS wishes to synergize its international activities with GEOS goals and facilitate regional workshops, training activities, forecasts, observational platforms, etc.

11

GENERAL INFORMATION

11 GENERAL INFORMATION

11.1 Awards and Honours

11.1.1 CII Industrial Innovation Awards-2021

INCOIS was conferred with CII Industrial Innovation Awards-2021 under the category 'Top Innovative Research Institutions-2021' for its development of the GEMINI System, which can disseminate Ocean Information Services to users while they are out of mobile range.

Fig. 11.1 Screenshot taken during the announcement of the award winners

11.1.2 International Recognition

Dr. T. Srinivasa Kumar, Director, INCOIS was elected as a Vice Chair of the IOC-UNESCO representing Electoral Group IV, and appointed as Chair of the UN Ocean Decade Tsunami Programme Scientific Committee, Chair of the Indian Ocean Global Ocean Observing System, and Co-Chair of the IOC-WMO Joint Collaborative Board.

11.1.3 MoES Awards

For his outstanding contribution to ocean sciences, Dr. Sudheer Joseph, Scientist-F & Division Head, ARO, was awarded Certificate of Merit 2021 during MoES Foundation Day-2021 celebrations at Prithvi Bhavan, New Delhi, on 27 July 2021.

11.1.4 Fellow Telangana Academy of Sciences

Dr. Kunal Chakraborty, Scientist-E elected as 'Fellow of the Telangana Academy of Sciences (FTAS)' for the year 2020 in recognition of his contributions to science & technology.

11.1.5 Associate Fellow of Telangana Academy of Sciences

Dr. PG Remya, Scientist-D elected as 'Associate Fellow of the Telangana Academy of Sciences (AFTAS)' for the year 2020 in recognition of her contributions to science & technology.

11.1.6 Awards of Doctor of Philosophy (Ph.D.)

Table 11.1 List of staff awarded the degree of Ph.D. during 2021-22

Sl No.	Name & Designation	Guides Name	Subject	University/ Department	Thesis Title
1	Dr. Rohith B, Project Scientist-B	Prof. S.S.V.S. Ramakrishna, Andhra University & Dr. S.S.C. Shenoi, Former Director, INCOIS	Meteorology & Oceanography	Department of Meteorology & Oceanography, Andhra University, Visakhapatnam	Intraseasonal Barotropic Sea level variability in the Tropical Indian Ocean
2	Dr. Jithin Abraham, Project Scientist-B	Prof. S.S.V.S. Ramakrishna, Andhra University & Dr. Francis P.A., Scientist-F, INCOIS	Meteorology & Oceanography	Department of Meteorology & Oceanography, Andhra University, Visakhapatnam	Energetics and Variability of Internal Tides in The Bay of Bengal
3	Dr. Effy B John, SRF	Prof. S.S.V.S. Ramakrishna, Andhra University & Dr. Francis P.A., Scientist-F, INCOIS	Meteorology & Oceanography	Department of Meteorology & Oceanography, Andhra University, Visakhapatnam	Coupled Ocean-Atmosphere Processes in the Tropical Oceans and their link to Indian Summer Monsoon Rainfall
4	Dr. Sidhartha Sahoo, Scientific Assistant-B	Prof. R.K. Mahapatra, Professor & Head, Department of Library & Information Science, Tripura University	Library & Information Science	Faculty of Social sciences and Humanities, Berhampur University, Odisha	Return On Investment (ROI) of Electronic Information Resources: An Evaluative Study on Selected Scientific & Research Institute's Libraries In Odisha

11.2 Memorandum of Understanding

11.2.1 INCOIS signed an MoU with the Directorate-General of Hydrocarbon (DGH) on 22 March 2022 to strengthen the safety and security of offshore E&P operations in India.

Fig. 11.2 Photos taken during the signing of MOU between INCOIS & DGH

11.2.2 INCOIS signed an MoU with IIT Madras for collaborative research in the field of ocean observations through field campaigns using state-of-the-art oceanographic instrumentation. The collaboration aims to improve understanding of the role of various physical processes on air-sea interactions, particularly the unexplored areas of the Northern Indian Ocean.

Fig. 11.3 Screenshot of the MOU event between INCOIS & IIIT Madras for collaborative research and knowledge exchange

11.2.3 INCOIS and DGH signed an MoU on 11 October 2021 for collaborations between the institutes for providing customized weather & ocean state forecasting and emergency services.

Fig. 11.4 Photos during signing of MOU between INCOIS & DGH

11.3 Official Language Implementation

Official Language Implementation Committee (OLIC) coordinates and implements the official language programme in INCOIS. OLIC also implements the annual programme released by the Department of Official Language, Ministry of Home Affairs, Government of India in INCOIS. During the reporting period, OLIC conducted four quarterly meetings to plan and execute the targets set in the annual programme and to assess their progress. The committee organized quarterly Hindi workshops to familiarize the employees with the tools available to help them maximize their work with ease in the official language. The 'Hindi Pakhwada' was held during 01-14 September 2021 and various competitions such as essay writing, recitation, e-poster, extempore speech were organised on the theme of "Azadi Ka Amrit Mahotsav" for INCOIS employees and their children. INCOIS also attended the half-yearly meeting organized by the Town Official Language Implementation Committee (TOLIC), and necessary actions were taken based on the suggestions received. The action items of Hon'ble Vice-President's 7-point charter were discussed in the OLIC meetings, and a roadmap was laid to achieve the goals, which includes finalization of arrangements for teaching regional language to employees, issuing directives toward preparation of PhD abstracts in trilingual form, and so on. INCOIS also utilized available cash awards & incentives scheme towards implementing the official language and maximizing the work done in the official language in the institution.

11.4 INCOIS Foundation Day

INCOIS commemorated its 24th Foundation Day on 03 February 2022. The Foundation Day Talk was delivered by Dr. Pierre Bahurel, Director General, Mercator Ocean, on 'Ocean Prediction and the UN Decade opportunity'. Dr. M. Ravichandran, Secretary, MoES, and Chairman, INCOIS Governing Council presided over the event. The former Directors Dr. K. Radhakrishnan, Dr. Shailesh Nayak, and Dr. S.S.C. Shenoi, shared their insights and wished INCOIS more success under the leadership of the present Director, Dr. T. Srinivasa Kumar. An integrated user interaction workshop was conducted in an online mode on 2 February 2022 as part of commemorating the foundation day. The workshop was inaugurated by Dr. S.C.L. Das, Director General, DGH, and Guest of Honour of the event. Around 200 end-users from various categories such as fisher folks, Non-Governmental Organizations, Industry, Navy, CG, Disaster Management Authority, Port & Harbours, Shipping industries, and seafarers participated in the event. The inaugural session was followed

Fig. 11.5 Screenshot of 24th Foundation day celebration of INCOIS and the talk delivered by the Chief Guest

by three technical sessions, namely, (I) Fisheries and ecosystem services and advisories, (II) Ocean warning and alert services, and (III) Value-added, user-customized & commercial products and services.

11.5 Women’s Day Celebrations

Women's Day celebration was held at INCOIS on 8 March 2022. Dr. Purnima Jalihal, Scientist-G, NIOT was the chief guest of the event. An interactive session was held with her virtually. During the discussion, she stressed the requirement of 'gender equality ' and a work environment conducive for women employees, flexible working hours, and crèche facilities for the ease of women employees in government organisations. A documentary on the theme of women and climate change was prepared and live streamed during the event. A cultural programme was also conducted through virtual mode. As part of the celebration, a photography competition was held for the employees of INCOIS.

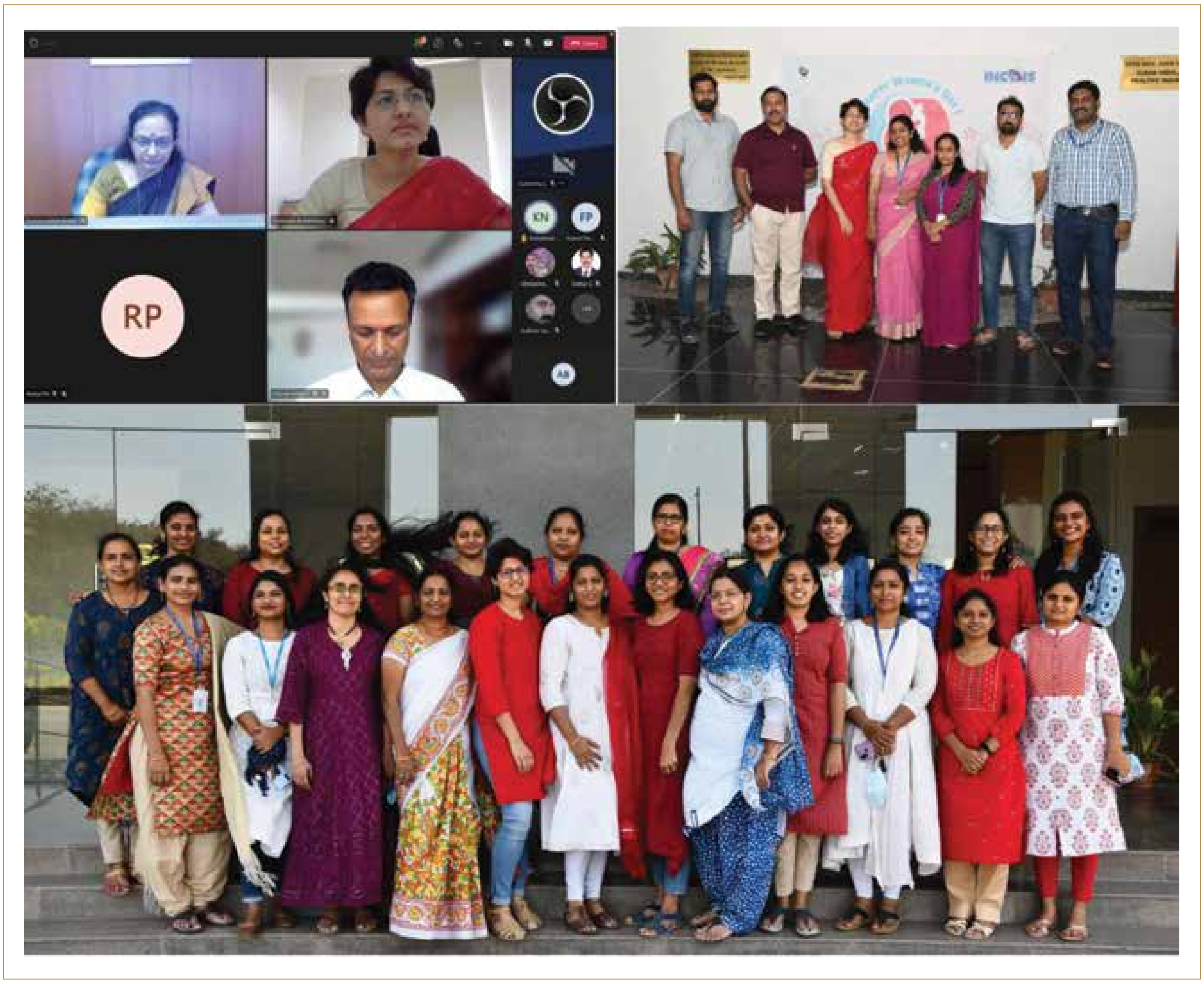


Fig. 11.6 Collage images of Women's Day celebration & interactive session with the chief guest

11.6 Rashtriya Ekta Diwas

INCOIS celebrated the birth anniversary of Shri Sardar Vallbhbhai Patel and observed 'Rashtriya Ekta Diwas' (National Unity Day) on 31 October 2021. Director, INCOIS took the pledge and read the same using the public address system. All staff followed the same and took the pledge from their respective desk.

11.7 Samvidhan Diwas

Director, INCOIS, and all staff of INCOIS took the Preamble on 26 November 2021 as part of our National Constitution Day (Samvidhan Diwas) celebrations.

11.8 World Ocean's Day Celebration

INCOIS celebrated the "World Ocean's Day" on 8 June 2021. On this occasion, Dr. S.R. Shetye, Chairman, RAC, INCOIS, Former Director, NIO, and Former Vice Chancellor, Goa University, delivered a lecture on 'The Physics of the Ocean at India's Doorstep'. The virtual event was attended by senior scientists and staff of INCOIS and several researchers from other national and international institutes. A group of early career oceanography professionals in the country had organized an art competition on the occasion of World Ocean's Day. Winners of the competition were announced by Director, INCOIS during the event. A video showcasing the research conducted by the early career young oceanographers was exhibited during the event.

Fig. 11.7 Screenshots of World Ocean's Day celebrations

11.9 International Yoga Day

INCOIS celebrated International Yoga Day on 21 June 2021. An online session with the theme "Yoga for Unity and Well Being" was organized at INCOIS. Director, INCOIS delivered the welcome remarks and highlighted the importance & effect of yoga on human health. Shri Satish Kumar, Yoga Teacher Yoga Teacher / Volunteer, Dhyana Yoga PYC, Hyderabad conducted a yoga practical session and discussed the yoga and current COVID-19 pandemic situation. Senior scientists and staff from INCOIS also joined the online session.

11.10 World Tsunami Awareness Day

As part of world tsunami awareness day on 5 November 2021, Director, INCOIS, delivered an inaugural address in a webinar on "Advances in Tsunami Sciences and its Disaster Risk Reduction" conducted by the National Institute of Disaster Management (NIDM). To improve the awareness of tsunami among school children, a visit was organized for 70 students of Bhashyam School to Tsunami Warning Centre and tsunami awareness material was distributed to school children. Science teachers from Zilla Parishad High School, Bachupally, Hyderabad also visited INCOIS and had detailed discussions with INCOIS Scientists as part of world tsunami awareness day and Azadi Ka Amrut Mahotsav. A sensitization webinar on Tsunami Early

Fig. 11.8 Collage images of world tsunami awareness day celebration and campus visits of school students

Warnings and Tsunami Ready Programme was conducted for Andhra Pradesh State Disaster Management Authority Officials. UNESCO-IOC made an awareness video on Odisha Tsunami Ready. India is the first country in the Indian Ocean Region, and Odisha is the first state to achieve the Tsunami Ready recognition in two of its villages (Venkatraipur and Noliasahi).

11.11 Swachch Bharat Programme

INCOIS has been diligently carrying out Swachch Bharat Abhiyan across the year 2021-22. The activities carried out under the Swachh Bharat Abhiyaan during first quarter (01 April 2021 – 30 June 2021) of the financial year 2021 – 2022 include regular campus cleaning and gardening activities, using outsourced housekeeping staff, and campus sanitization as a precautionary measure against COVID-19 pandemic. As part of Swachch Bharat activities, INCOIS organized a general health awareness program with the help of a nutritionist from a nearby hospital. The program offered a lecture and an interactive session on the post-covid 19 diet. INCOIS staff actively participated in the event and benefited from the interactions with the expert. All the activities were carried out with minimal physical gathering keeping in mind all the instructions and guidelines issued by the M/o Home Affairs and M/o Health and Family Welfare in the current Covid-19 pandemic.

Fig. 11.9 Photos of campus sanitation and swachhata activities at INCOIS

11.12 Vigilance and RTI Activities

Shri E. Pattabhi Rama Rao Scientist 'G' and Group Director, OMDA, has been designated as the Vigilance Officer of INCOIS with effect from 14 July 2021. No new complaints were received during the period 01 April

2021 to 31 March 2022. INCOIS observed 'Vigilance Awareness Week' from 26 October - 01 November 2021 with the theme "Independent India @ 75: Self Reliance with Integrity". As per the instructions of Govt. of India guidelines, an integrity pledge was organized for all the staff of INCOIS on 26 October 2021. Director, INCOIS, led the pledge-taking ceremony.

In accordance to the Right to Information Act (RTI) 2005, INCOIS related queries were regularly updated on the INCOIS website in the prescribed format. Shri E. Pattabhi Rama Rao, functioned as the Public Information Officer until July 14, 2021 and after that, the responsibility was taken over by Shri M. Nagaraja Kumar, Scientist-F, from July 15, 2021, onwards. Director, INCOIS is the first appellate authority. Under the RTI, 22 requests were received, and the requested information were provided. During this period, no first appeal was received and disposed off under the RTI act.

11.13 Azadi Ka Amrit Mahotsav celebrations

As part of Azadi Ka Amrit Mahotsav various activities were organized at INCOIS (MoES) throughout 2021-22. These activities focused on improving the outreach of 1) INCOIS activities and services and 2) India's achievements in the past 75 years in the field of Earth sciences with special emphasis on ocean sciences. The activities were grouped into the following mega-events.

11.13.1 Swachhata Pakhwada

INCOIS observed Swachhata Pakhwada during the first fortnight of July 2021 (01 – 15 July 2021). During this event, INCOIS carried out many activities such as plantation, raising awareness among all the shopkeepers in INCOIS vicinity, self-desk cleaning by employees, thorough cleaning & sanitization on the campus, e-poster competition for employees, e-essay and e-drawing competition for children of INCOIS employees. A webinar on 'Need for Swachatha during Covid Pandemic Period' was also delivered by Dr. J. Archana, M.D., Assistant Professor, Gandhi Medical College, Hyderabad.

11.13.2 Iconic week of Ministry of Earth Sciences

The MoES and its institutes, including INCOIS, were assigned the week of 18-24 October, 2021 to be celebrated as MoES iconic week. During this, INCOIS conducted various activities including visit of Divyangjan (visually impaired and differently abled) students from the National Institute for the Empowerment of Persons with Intellectual Disabilities (NIEPID, Hyderabad) to INCOIS. INCOIS also hosted online quiz, poetry, and poster competitions for the school students in and around Hyderabad. Winners of these competitions were given certificates, medals, and prizes by Director, INCOIS. Another innovative programme was an online panel discussion on 'Career Opportunities and Challenges for Women in Earth Sciences' in which women scientists of MoES and its various institutes participated. The panel discussion was broadcasted live & then archived on the INCOIS YouTube channel. INCOIS collaborated with Reliance Foundation and M S Swaminathan Research Foundation (MSSRF) to organize online interaction programmes with fishermen from the east and west coast of India respectively. In a separate connect-to-industry (iConnect) programme, representatives from maritime boards, fishery industries, start-up firms, instrumentation firms and other private companies participated in an online session 'Connect to Industry on Ocean Services and Technology'. Screening of documentary films depicting INCOIS services and activities was carried out at schools in and around Hyderabad and a few schools in Andhra Pradesh.

11.13.3 Adoption of village and school

As part of Azadi Ka Amrit Mahotsav and as per the instructions of MoES, INCOIS adopted a Nachugunta village of Krishna District, Andhra Pradesh. INCOIS will help the villagers to solve their problems through scientific means and help to mitigate disaster risk. INCOIS is working to make the village Tsunami Ready and ready for other ocean disasters like cyclones, storm surges, etc.

As part of this programme, INCOIS adopted Zilla Parishad High School (ZPHS), Bachupally, Hyderabad, to build the capacity and develop enthusiasm for science among school children. Science teachers from the school visited INCOIS on 5 November 2021 and had detailed discussions with INCOIS Scientists as part of world tsunami awareness day and Azadi Ka Amrut Mahotsav. INCOIS will continue to provide transfer of scientific knowledge to the teachers and students through visits to INCOIS, delivery of talks and interactions with our scientists, etc.

11.13.4 Hackathons

INCOIS scientists served as nodal officers for ASEAN-India Hackathon 2021 and Smart India Hackathon (SIH) conducted by the Ministry of Education's Innovation Cell (MIC). INCOIS provided problem statements for the participants, mentored their projects, and evaluated their entries.

11.13.5 Regional language Webinars

INCOIS scientists delivered lectures on INCOIS activities, services, and research on different regional languages under 'Azadi ka Amrit Mahotsav'.

11.13.6 India International Science Festival (IISF) 2021

INCOIS has observed the Open Day event as a preamble to IISF2021 celebrations on 26 Nov 2021, during which about 250 high school and college students, teachers and parents, and other general public, visited INCOIS laboratories facilities. INCOIS also participated in the Mega Science Technology and Industry Expo event, part of the India International Science Festival (IISF)-2021, co-organized by NCPOR and ViBha at Goa during 10-13 December 2021. Thousands of visitors, including school students and divyangjan were introduced to the unique activities of INCOIS. Major attractions of INCOIS display were the satellite telemetry tag that INCOIS used for tuna studies and GEMINI (GAGAN-Enabled Mariner's Instrument for Navigation and Information) - a low-cost indigenous satellite data receiver for offshore connectivity. The INCOIS pavilion was visited by dignitaries including Dr. M.

Fig. 11.10 Visit of dignitaries to INCOIS pavilion at India International Science Festival (IISF)-2021, Goa

Ravichandran (Secretary, MoES), Dr. Indira Murty (MoES-JS), Prof. Sunil Kumar Singh (Director, CSIR-NIO), and Dr. Shekhar Mande (DG-CSIR and Secretary, DSIR). INCOIS scientists also participated in the daily sessions with students under the Science Village Festival event of IISF-2021.

11.13.7 Festival of SCoPE (Sci Comm Popularization & its Extension) for all

As a part of Azadi Ka Amrit Mahotsav, various ministries, including MoES and Office of Principal Sc Adv to GoI organized the 'Festival of SCoPE (Sci Comm Popularization & its Extension) for all' with the tagline of 'Vigyan Sarvatra Pujyate'. This was organized at seventy-five (75) locations across India during the science week of 22-28 February 2022 and culminated on National Science Day. In Hyderabad, it was hosted at ICMR-NIN where INCOIS represented MoES. The activities of INCOIS were highly appreciated by visitors including students, citizens, and dignitaries such as Shri G Kishan Reddy, Hon'ble Minister of Tourism & Culture, Government of India. Similar to IISF-2021, GEMINI and PSAT (tuna-tag) attracted a lot of attention across the spectrum of visitors. INCOIS team also distributed pamphlets, copies of GnY (Geography 'n You)'s INCOIS special issue, and the latest INCOIS Annual Report, in multiple languages.

Fig. 11.11 Photos taken during visit of Hon'ble Minister of Tourism & Culture, Government of India to INCOIS stall in Festival of SCoPE, NIN, Hyderabad

11.13.8 Fit India Freedom Run

Fit India Freedom Run 2.0 launched at INCOIS as part of Azadi Ka Amrit Mahotsav. Scientists and staff participated in the event.

Fig. 11.12 Photos of the Fit India Freedom Run 2.0 event at INCOIS as part of AKAM

11.14 Visit of Dr. Shekhar Mande

Dr. Shekhar Mande, Secretary, MoES & DG, CSIR, visited INCOIS on 17 September 2021. During the visit, he chaired INCOIS Governing Council/Society meeting and interacted with the scientists & staff of INCOIS.

Fig. 11.13 Phots taken during Dr. Shekhar Mande, Secretary, MoES & DG, CSIR visit to INCOIS and interaction with scientists

11.15 Academic Projects/Internship carried out by students at INCOIS (Online Mode)

Table 11.2 List of students conducted their project/internship work at INCOIS during 2021-22

1.	Mr. R Sai Srikar	Vignan Institute of Technology & Science, Hyderabad	Udaya Bhaskar TVS
2.	Ms. T Lalitha	Vignan Institute of Technology & Science, Hyderabad	Udaya Bhaskar TVS
3.	Mr. Shaneeb E	Pondicherry University, Port Blair Campus, A&N	Siva Srinivas K
4.	Mr. Risal KV	Pondicherry University, Port Blair Campus, A&N	Balakrishnan Nair T.M
5.	Mr. Nakul J Krishnan	JAIN University, Bangalore	PG Remya
6.	Ms. Swathi V	Jawaharlal Nehru Technological University Hyderabad	Srinivasa Rao N

7.	Ms. Harshitha V	Jawaharlal Nehru Technological University Hyderabad	Srinivasa Rao N
8.	Ms. Udayashree K	Jawaharlal Nehru Technological University Hyderabad	Srinivasa Rao N
9.	Mr. Joseph Antony	Cochin University of Science and Technology (CUSAT), Kochi	Girish Kumar M. S.
10.	Mr. Abhinandu C R	Cochin University of Science and Technology (CUSAT), Kochi	Sudheer Joseph
11.	Ms. Maria Sansanna	Cochin University of Science and Technology (CUSAT), Kochi	Francis P.A.
12.	Ms. Aparna Balasaheb	Amrita Vishwa Vidyapeetham, Kerala	Prakash Chandra Mohanty
13.	Ms. Nanditha Rajan	Amrita Vishwa Vidyapeetham, Kerala	Prakash Chandra Mohanty
14.	Mr. Gowtham Vasudev	Amrita Vishwa Vidyapeetham, Kerala	Murali Krishna
15.	Ms. Chennuri Jahnavi	Gokaraju Rangaraju Institute of Engineering & Technology, Hyderabad	Kiran Kumar N
16.	Mr. Kommu Sreeraj	SRM Institute of Science & Technology Tamil Nadu	Srinivasa Rao N
17.	Ms. P Taniya Raj	Central University of Karnataka	Mahendra R.S.

11.16 Deputation Abroad

Dr. T. Srinivasa Kumar, Director, INCOIS, was deputed to Yogyakarta, Indonesia, to attend "G20 1st Environment Deputies Meeting and Climate Sustainability Working Group (EDM-CSWG)" meeting during 21-24 March 2022.

11.17 INCOIS Audio Video (AV) infrastructure facilities

Hybrid conference rooms at the Board room & Information Block at INCOIS have been successfully set up.

Fig. 11.14 INCOIS Board room and Information Conference hall with the latest AV solution

11.18 Estate Management and other infrastructure services

- 611.30 kWp Rooftop solar power plant installed at INCOIS yielded financial savings of Rs.33 lakhs (approx.) and saved 1,86,512 kgCO_2e. Due to the solar installation and other energy savings practices, the maximum contract demand of INCOIS is reduced from 1000KVA to 700KVA, which has further led to a financial savings of Rs.12 lakhs p.a.

- 50 KLD Sewerage Treatment Plant installed at INCOIS efficiently treated 100% of its inflow sewerage water. HMWSSB had acknowledged and bestowed a 50% rebate in the sewerage cess to the tune of Rs.5 lakhs for the last FY.
- INCOIS established the National Glider Lab with a dedicated test facility to test the glider's functionality and its instrumentation at the lab.
- The campus is upgraded to 100% LED lamps, and INCOIS is 100% committed to energy efficiency and power savings practices through its estate management activities.

11.19 List of International Meetings attended by INCOIS Official (Virtual Mode)

- Dr. T. Srinivasa Kumar, Director, INCOIS participated in the Ocean Decade - Informal meeting national decade coordination mechanisms organized by the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNECO) on 1 April 2021. Dr. Satya Prakash, Scientist-E, INCOIS and Cdr. Prashant Srivastava, MoES also participated in the meeting.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in the Second International Indian Ocean Expedition (IIOE-2) Steering Committee Meeting hosted by IIOE-2 JPO(India Joint Project Office) India & Australia on 12 April 2021. Shri Pattabhi Rama Rao, Group Director, OMDA, Dr. Satya Prakash, Scientist-E and Shri Kiran Kumar, Scientist-E also attended the meeting from India Joint Project Office.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in a meeting between ISRO, INCOIS and CNES/KINIES to discuss about receiving Argos data from Oceansat 3 satellite at INCOIS ground station on 16 April 2021. Shri BVS Satyanarayana, Group Director, ICTD, Shri Pattabhi Rama Rao, Group Director, OMDA and senior scientists from INCOIS also attended the meeting.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in a discussion meeting with National NOAA, USA on ‘Dry run for the BGC-Argo Fisheries Panel’ on 20 April 2021.
- Shri Pattabhi Rama Rao, Group Director, OMDA, INCOIS attended the 26th session of the IODE Committee of IOC of UNESCO during 20-23 Apr 2021.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in the expert meeting of the INAE subcommittee on “Global Warming and impact on coastal region submergence” on 28 April 2021. On the same day he also participated in the 17th Session of CLIVAR/IOC-GOOS Indian Ocean Region Panel (IORP-17).
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in a virtual meeting with Scientists from Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia regarding the Australia-India Indo-Pacific Oceans Initiative Partnership between CSIRO and INCOIS on 5 May 2021. Director, NCCR, Programme Director, MoES and senior INCOIS scientists also took part in the meeting.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated in BGC Argo Workshop on 4 May 2021. In particular, the workshop focused on connections between the Biogeochemical-Argo array and fisheries, regional carbon budget verification, and environmental forecasting with emphasis on the open ocean to coastal system linkage.
- Dr. T. Srinivasa Kumar Director, INCOIS participated in the meeting of A G7 future of the Seas and Ocean initiative Event; The Global Biogeochemical-Argo Fleet: knowledge of Action and held discussion on Fisheries and Fisheries Management on 12 May 2021.

- Dr. T Srinivasa Kumar, Director, INCOIS participated in the Fifty-fourth Session of the IOC Executive Council on 14 June 2021, and the Thirty-first Session of the IOC Assembly during 14–25 June 2021 (online sessions). Indian delegations comprises of Ms. Mallika Sudhir, Second Secretary, Permanent Delegation of India to UNESCO; Dr. Ramadass, Director, NIOT, Ministry of Earth Sciences; Cdr. Prashant Srivastava, Programme Director, Ministry of Earth Sciences; Mr. Anoop Dhingra, Director, UNES, Ministry of External Affairs and Dr. S.S.C. Shenoi, Former Director, INCOIS also participated the meeting in his ex-officio capacity as Vice Chair, IOC.
- Dr. T Srinivasa Kumar, Director, INCOIS was elected as the Vice Chair of IOC and also India was elected for a seat in the Executive Council of the IOC of the UNESCO during the 31st session of the Assembly held during 14 – 24 June 2021.
- Dr. T Srinivasa Kumar, Director, INCOIS participated as a panelist in the IOC Assembly - Thematic Webinars 2021; Towards Global Tsunami Awareness: Tsunami ready communities conducted by IOC, UNESCO on 11 June 2021.
- Shri Pattabhi Rama Rao, Group Director, OMDA, INCOIS along with senior scientists of INCOIS participated in the RAMA-OMNI data portal demonstration with NIOT and NOAA-PMEL on 3 June 2021.
- Dr. T Srinivasa Kumar, Director, INCOIS participated in the 21st Meeting of the UN open - ended informal consultative process on Oceans and the Law of Sea (ICP) during 14-18 June 2021. The Dr Vijay Kumar, Sc G, MoES, Mr. Pattabhi Rama Rao, Group Director, INCOIS, Dr Prashant Srivastava, Sc F, MoES, Dr Sandip Kumar Mukhopadhyay, Sc F, MoES, Dr. Abhisek Chatterjee, Scientist, INCOIS and Mr. R. S. Mahendra, Scientist, INCOIS also attended the meeting.
- Dr. T. Srinivasa Kumar, Director, INCOIS attended the Regional Webinar on "Engagement of Media in the Tsunami Warning Chain with Focus on the North West Indian Ocean" conducted by IOTIC and ICG/IOTWMS on 17 June 2021 and presented "Tsunami Early Warning Systems set-up in the Indian Ocean region". From India, Dr. Pavan Kumar Singh, Joint Advisor, NDMA; Mr. Abhishek Shandilya, Consultant IEC in NDMA; Mr. Tapas Bhattacharya, Correspondent, DD; Mr. Patanjali Kumar, Ms M.V. Sunanda, Mr. J. Padmanabham and Mr. B. Ajay Kumar, INCOIS participated in the webinar. The webinar contributed towards the strengthening the engagement of the media in the tsunami early warning processes in the Makran region.
- Dr. T Srinivasa Kumar, Director, INCOIS participated in a meeting with JAMSTEC, Japan along with senior colleagues from NCCR, IITM and MoES to discuss opportunities for scientific collaboration between Japanese and Indian Institutions in the areas of Climate change and Sea Level on 25 June 2021.
- Dr. T. Srinivasa Kumar, Director, INCOIS, Chair, Indian Ocean Global Ocean Observing System (IOGOOS) participated in the GOOS Regional Alliances Forum X meeting organized by UNESCO - Intergovernmental Oceanographic Commission virtually during September 9-10,2021.
- Dr. T. Srinivasa Kumar, Director, INCOIS participated as a key note speaker in the RAII Session on the The Asian region emphasizes the importance of the ocean being conducted by WMO on 29 September 2021. He stressed on the importance of regional cooperation to bolster ocean observing and prediction systems as well as to develop the capacity of national agencies. Moreover, he highlighted the earth system approach adopted by INCOIS for its services to be aligned with strategies laid out by the WMO and IOC.
- Dr. T. Srinivasa Kumar, Director, INCOIS delivered a talk on 'Ocean Information and Advisory Services' at the MoES-UKRI COP26 Partnership Event on Adaptation and Resilience meeting on 29 September 2021
- On the occasion of Pravasi Bharatiya Divas, Dr. T. Srinivasa Kumar, Director, INCOIS was a moderator for the Panelists of Technical Session during the Virtual PBD Conference on "Future of Natural Resources (Hydrocarbons, Rare Earth Metals and Blue Economy)" held on 29 October 2021 organized by Ministry of External Affairs, Government of India and MoES.
- The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) of IOC-UNESCO conducted virtual Intersessional Meetings on 23-24 November

2021. INCOIS Scientists and NDMA officials participated and presented India's National Report and TSP-India progress report.

- Dr. T. Srinivasa Kumar, Director INCOIS and Vice-Chair of IOC-UNESCO participated in the IOC officers meeting during 17-21 January 2022 in virtual mode.
- Dr. T. Srinivasa Kumar, Director, INCOIS attend the 'G20 1st Environment Deputies Meeting and Climate Sustainability Working Group (EDM-CSWG)' meeting during March 21-24, 2022 at Yogyakarta, Indonesia.

11.20 INCOIS Human Capital

Category/Designation	Regular	Category/ Designation	Project Mode
Scientific Staff			
Director	01	Project Sci - D	01
Scientist 'G'	03	Project Sci - C	04
Scientist 'F'	05	Project Sci - B	19
Scientist 'E'	18	Project Assistant	23
Scientist 'D'	09	Admin Assistant/ Office Assistant/ Jr. Office Asst.	09
Scientist 'C'	00	Lab Attendants	06
Scientist 'B'	01	Driver-cum-Attendant	04
Scientific Support Staff	16	Consultants	01
Scientific Assistant B		Research Fellows (Ph.D Programme/ Women Scientist/Post Doctoral Fellow)	18
Scientific Assistant A	03		
Administrative Staff			
Manager	01		
Jt. Manager	02		
Asst. Manager	04		
Sr. Executive	03		
Total:	**66**	**Total:**	**85**

Vacant positions:

- one post of Scientist -G (base post of Scientist-C) on lien to INCOIS as Director.
- one post of Scientist-C vacant due to death of official in service.
- two posts of Scientist-B & one post of Scientist-E vacant due to technical resignation.

12

ACRONYMS

12 ACRONYMS

ABIS	:	Algal Bloom Information System
ADCIRC	:	Advanced CIRCulation model
ADCP	:	Acoustic Doppler Current Meter Profiler
ADPC	:	Automatic Data Processing Chain
AKAM	:	Azadi Ka Amrit Mahotsav
APSDMA	:	Andhra Pradesh State Disaster Management Authority
AWS	:	Automatic Weather Stations
BIO	:	Biogeochemical State of the Indian Ocean
BoB	:	Bay of Bengal
BPR	:	Bottom Pressure Recorder
CBAS	:	Coral Bleaching Alert System
CII	:	Confederation of Indian Industry
CMIP6	:	Coupled Model Intercomparison Project phase 6
CMLRE	:	Centre for Marine Living Resources and Ecology
CRV	:	Coastal Research Vessel
CSIR	:	Council of Scientific and Industrial Research
DDS	:	Digital Display Systems
DoF	:	Directorate of Fisheries
DOM	:	Deep Ocean Mission
DSC	:	Diapycnal Spiciness Curvature
DSS	:	Decision Support System
ECFS	:	Eddy Covariance Flux System
ERP	:	Enterprise resource planning
ERSEM	:	European Regional Seas Ecosystem Model
ESM	:	Earth System Model
ESSD	:	Earth System Science Data Portal
FEM	:	Finite Element Mesh
FFMA	:	Fisher Friend Mobile Application
FSI	:	The Fishery Survey of India
FTP	:	File Transfer Protocol
FVCOM	:	Finite Volume Community Ocean Model
GDP	:	Global drifting buoy programme
GEMINI	:	Gagan Enabled Mariner's Instrument for Navigation and Information
GFDL	:	Geophysical Fluid Dynamics Laboratory
GHRSST	:	Group for High Resolution Sea Surface Temperature
GNSS	:	Global Navigation Satellite System
GNSS	:	Global Navigation Satellite System
GODAE	:	Global Ocean Data Assimilation Experiment

GODAS	:	Global Ocean Data Assimilation System
GOOS	:	Global Ocean Observing System
GSHSS	:	Global Self-consistent, Hierarchical, High-resolution Geography Database
GSI	:	Geological Survey of India
GTS	:	Global Telecommunication System
HOOFS	:	High-resolution Operational Ocean Forecast and reanalysis System
HPC	:	High performance computing
ICG/IOTWMS	:	Intergovernmental Coordination Group for the Indian Ocean
ICT	:	Information & Communication Technology
IIOE	:	International Indian Ocean Expedition
IIOSC	:	International Indian Ocean Science Conference
IITM	:	Indian Institute of Tropical Meteorology
IMD	:	Indian Meteorological Department
INCOIS	:	Indian National Centre for Ocean Information Services
IndOOS	:	Indian Ocean Observing System
INS	:	Indian Navy Ship
INSAT	:	The Indian National Satellite
IOC	:	Intergovernmental Oceanographic Commission of UNESCO
IOCINDIO	:	IOC Regional Committee for the Central Indian Ocean
IOGOOS	:	Indian Ocean Global Ocean Observing System
IORA	:	Indian Ocean Rim Association
IOR-DCC	:	Indian Ocean Region Decade Collaborative Centre
IORP	:	Indian Ocean Regional Panel
ITCOocean	:	International Training Centre for Operational Oceanography
ITEWC	:	Indian Tsunami Early Warning Centre
JPO	:	Joint Project Office
LDCL	:	Lakshadweep Development Corporation Ltd
LETKF	:	Local Ensemble Transform Kalman Filter
MHVM	:	Multi-Hazard Vulnerability Mapping
MJO	:	Madden-Julian oscillation
MOES	:	Ministry of Earth Sciences
MOFPS	:	Modeling for Ocean Forecasting and Process Studies
MOM	:	Modular Ocean Model
MSSRF	:	MS Swaminathan Research Foundation
MV	:	Merchant Vessel
NCEP	:	National Centers for Environmental Prediction
NCESS	:	National Centre for Earth Science Studies
NCPOR	:	National Centre for Polar Ocean Research
NDBC	:	National Data Buoy Center
NDMA	:	National Disaster Management Authority
NHO	:	National Hydrographic Office
NIO	:	National Institute of Oceanography
NIO	:	National Institute of Oceanography
NIOT	:	National Institute of Ocean Technology

12 ACRONYMS

NIOT	:	National Institute of Ocean Technology
NOAA	:	National Oceanic and Atmospheric Administration
OCCAS	:	Ocean Climate Change Advisory Services
OCM	:	Ocean Colour Monitor
OLIC	:	Official Language Implementation Committee
OMNI	:	Ocean Moored buoy Network for Northern Indian
OON	:	Ocean Observation Network
OOPC	:	Ocean Observation Panel for Climate
OOPSD	:	Open Ocean Propagation Scenario Database
OSMART	:	Ocean Services, Modelling, Application, Resources and Technology
PMEL	:	Pacific Marine Environmental Laboratory
POGO	:	Partnership for Observation of the Global Oceans
PTHA	:	Probabilistic Tsunami Hazard Assessment
R&D	:	Research & Development
RAIN	:	Regional Analysis of the Indian Ocean
RAMA	:	Research Moored Array for African Asian Australian Monsoon Analysis
RECCAP	:	REgional Carbon Cycle Assessment and Processes
RIMES	:	Regional Integrated Multi-Hazard Early Warning System for Asia and Africa
ROMS	:	Regional Ocean Modeling System
SAIC	:	Science Applications International Corporation
SCI	:	The Shipping Corporation of India
SDAP	:	Service Data Adaptation Protocol
SG	:	Slocum Gliders
SIBER	:	Sustained Indian Ocean Biogeochemical and Ecological Research
SMA	:	Strong Motion Accelerometer
SMA `	:	Strong Motion Accelerometer
SRCNN	:	Super-Resolution Convolutional Neural Network
SST	:	Sea Surface Temperature
SWAN	:	Simulating WAves Nearshore
TWMS	:	Tsunami Warning and Mitigation System
VECS	:	VSAT aided Emergency Communication System
VSAT	:	Very Small Aperture Terminal
WMO	:	World Meteorolical Organization
XBT	:	eXpendable Bathy Thermographs
XCTD	:	eXpendable Conductivity, Temperature and Depth

13

FINANCE

K. PRAHLADA RAO & CO.
CHARTERED ACCOUNTANTS

H.No. 3-6-84/12&13, Flat # 402, Legend Venkatesha, Beside Taj Mahal Hotel,
Narayanguda, Hyderabad - 500 029. Telangana, India.

Phone : 040-40151768, E-mail: kprauditors@yahoo.com ; www.kprandco.com

AUDITORS' REPORT

To
The Chairman and Members,
Governing Council,
ESSO-INDIAN NATIONAL CENTRE FOR
OCEAN INFORMATION SERVICES,
Ocean Valley, Pragathinagar (B.O), Nizampet (S.O)
Hyderabad – 500090, India

We have audited the attached Balance Sheet of **INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES** as at 31st March, 2022, and also the Income & Expenditure Account and Receipts & Payments Account for the year ended on that date annexed thereto. These financial statements are the responsibility of the Society's Management. Our responsibility is to express an opinion on the financial statements based on our audit.

We conducted our audit in accordance with auditing standards generally accepted in India. Those Standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material mis-statements. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion and report that:

1. We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit.
2. In our opinion, proper books of account as required by the Society, have been kept by the Society so far as appears from our examination of such books.
3. The Balance Sheet, Income and Expenditure Account and Receipts and Payments Account are in agreement with the books of account.
4. In our opinion and to the best of our information and according to the explanations given to us and subject to the notes forming part of accounts, the Balance Sheet as at 31st March 2022, Income and Expenditure Account and Receipts and Payments Account for the year ended on that date, together with the Schedules and Notes on Accounts annexed therewith give a true and fair view of the state of affairs of the Society.

For **K. Prahlada Rao & Co.**
Chartered Accountants

K. Pra...

K. PRAHLADA RAO & CO. Chartered Accountants FRN No: 002717S Hyderabad

(K. Prahlada Rao)
Partner
M.No.018477
FRN No: 002717S

Place : HYDERABAD
Date : 11.08.2022
UDIN : 22018477AOVCUX3889

BRANCH OFFICE : 47-3-28/19, FLAT NO. 2, II FLOOR, BHARAT TOWERS,
5th LINE, DWARAKA NAGAR, VISAKHAPATNAM - 530 016.

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES
(Ministry of Earth Sciences, Govt. of India)
"Ocean Valley", Pragathinagar(BO), Nizampet(SO), Hyderabad - 500 090

BALANCE SHEET AS AT 31st MARCH 2022

Particulars	Schedules	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
CAPITAL & LIABILITIES			
Corpus fund	1	72,87,96,337	11,83,97,544
Earmarked funds	2	28,79,92,685	10,69,28,671
Current liabilities & Provisions	3	19,98,03,489	23,75,29,115
Total		**1,21,65,92,512**	**46,28,55,330**
ASSETS			
Fixed Assets	4	58,36,38,518	1,96,39,484
Current Assets, Loans & Advances	5	63,29,53,994	44,32,15,845
Total		**1,21,65,92,512**	**46,28,55,330**
Notes forming part of Accounts	11	-	-

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. Prahlada Rao & Co. Chartered Accountants FRN No: 002717S Hyderabad

K. Prahlada Rao
Partner
M. No. 018477
FRN No: 002717S

Place : Hyderabad
Date : 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer

S. Nageswara Rao
Senior Accounts Officer

INCOIS

(Dr. T. Srinivasa Kumar)
Director, INCOIS

Dr. T. Srinivasa Kumar
Director, INCOIS

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(Ministry of Earth Sciences, Govt. of India)

"Ocean Valley", Pragathinagar(BO), Nizampet(SO), Hyderabad - 500 090

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH 2022

Particulars	Schedules	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
INCOME			
Income from Sales / Other Income	6	3,13,64,875	53,42,066
Interest Earned on Investments	7	25,33,461	26,38,425
Recurring Grants	8	22,78,00,000	22,60,00,000
TOTAL - A		**26,16,98,336**	**23,39,80,491**
EXPENDITURE			
Establishment Expenditure	9	13,26,78,122	15,94,94,491
Other Administrative Expenses	10	7,74,13,285	11,48,48,687
Depreciation	4	6,85,47,225	81,93,654
TOTAL - B		**27,86,38,632**	**28,25,36,832**
Excess of Income over expenditure (A-B)	1	**-1,69,40,296**	**-4,85,56,340**
Add / Less: Prior Period Items		51,69,349	-
Balance being net income / deficit transferred to Corpus Fund		**-2,21,09,645**	**-4,85,56,340**
Notes forming part of Accounts	11	-	-

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. PRAHLADA RAO & CO. Chartered Accountants FRN No: 002717S Hyderabad

K. Prahlada Rao
Partner
M. No. 018477
FRN No: 002717S

Place : Hyderabad
Date : 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer
S. Nageswara Rao
Senior Accounts Officer

INCOIS

(Dr. T. Srinivasa Kumar)
Director, INCOIS
Dr. T. Srinivasa Kumar
Director, INCOIS

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(Ministry of Earth Sciences, Govt. of India)

"Ocean Valley", Pragathinagar(BO), Nizampet(SO), Hyderabad - 500 090

RECEIPTS AND PAYMENTS ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2022

RECEIPTS	CURRENT YEAR 2021-22 ₹		PAYMENTS	CURRENT YEAR 2021-22 ₹	
Opening Balance			**Establishment Expenses**		
INCOIS Current A/c-SBI-HAL Campus Branch	2,66,07,263		Pay, Leave Salary Allowance	11,78,50,162	
UBI Savings A/c	1,21,20,837		NPS & CPF	1,01,24,367	
UBI Consultancy A/c	97,47,238		Staff Welfare (Medical IP & OP)	21,29,821	
Short Term Deposits with SBI, HAL Campus	35,64,00,000		Leave Travel Concession Expenses	6,09,097	**13,07,13,447**
INCOIS IOGOOS Secretariat- Local	8,74,905				
INCOIS IOGOOS Secretariat- Foreign	25,33,262				
INCOIS- CPF Account	1,48,40,399				
INCOIS- IDBPS Account	1,18,676		**Administrative Expenses**		
Short Term Deposits with SBI, CPF Account	-		EL encashment during LTC	48,077	
INCOIS SBI GeM POOL A/C	-	**42,32,42,580**	Children Education Allowance	19,16,598	
			Travel Expenses - Inland	-	
			Foreign	-	
Margin Money TDR Received			Others	-	
Margin Money Reversal	2,72,92,765	**2,72,92,765**	Telephone & Fax Expenditure	4,35,252	
			Postage & Telegraphs	44,793	
			Printing & Stationery	9,87,686	
Earmarked Funds			Honorarium to External Experts	46,000	
Ocean Information and Advisory Services (OASIS)	23,50,00,000		Advertisement & Publicity	6,16,973	
Ocean Observation Systems (OOS)	12,50,00,000		Audit Fee	25,370	
International Training Centre (ITCOocean)	5,45,00,000		Office Expenses	1,10,32,700	
O-MASCOT	2,00,00,000		General Expenses	11,73,169	

Deep Ocean Mission (DOM)	15,53,00,000	**58,98,00,000**	International Interface	8,63,991	**1,71,90,609**
Recurring Grants	22,78,00,000	**22,78,00,000**			
			Operation & Maintenance		
			Vehicle Hiring	5,41,922	
Other Receipts:			House Keeping, Plumbing & Garden Expenses	79,89,119	
Consultancy Projects:			Security Expenses	1,58,39,414	
Cowi India Pvt Ltd	21,600		Water Expenses	37,74,726	
AFCONS INFRA	10,83,240		Civil Services	1,40,378	
ONGC Consultancy for hiring of services	3,88,250	**14,93,090**	Electricity Expenditure	2,35,53,216	
			Pest Control Expenses	1,40,181	
			Maintenance & Repairs	50,16,682	
Other Receipts:			Material Consumable	29,85,246	
Interest on Short Term Deposits	2,08,38,838		HVAC & Electrical Operational & Maintenance Charges	22,00,312	
Interest on IOGOOS Foreign A/c	80,000		Bank charges	6,154	**6,21,87,351**
Interest on IOGOOS Local A/c	26,316				
Interest on UBI Savings A/c	3,88,061				
Interest on UBI Consultancy A/c	9,13,601				
Interest on SBI CPF A/c	3,87,370		PF transfer to Shri. BV Satyanarayana	20,00,000	
Interest on GeM Pool Account	93,463		PF transfer to Shri. KKV Chary	10,13,184	
Interest earned on ICD-TSSPDCL	2,83,284		PF transfer to Shri. M Nagaraja Kumar	13,50,000	
Interest on Vehicle Advance to Employees	60,000		PF transfer to Shri. V Subrahmaniyam	6,50,000	**50,13,184**
Earnest Money Deposit	9,04,000				
Security Deposit	6,33,363				
Closure of IDBPS Account	1,19,590				
Salary reimbursement from NCESS	49,66,353		**Payments Against Earmarked Funds**		
RTI Fees	50				
DR.Satya Prakasash - GSLIS Final Claim	8,14,074				
Refund of Travel charges by WHOI	62,06,546	**3,67,14,909**			

			Construction of New Building (Phase II)		
			Unspent Balance Refunded to CFI	3,76,342	**3,76,342**
DST Inspire fellowship HRA	9,213				
Refund of Registration Fee	2,45,999				
Refund of 36th IGC Fees	3,51,419				
Return IIOE2 DD from NIO	2,27,532	**8,34,163**	**OASIS**		
			Equipments	49,05,993	
			Hardware/Software	1,39,10,508	
IT Refund			Technical Support	3,89,15,546	
TDS Refund for Assement Year 2019-20	24,79,784	**24,79,784**	Administrative Expenses	4,98,33,173	
			Travel	2,09,300	
			Advance against subprojects	69,94,713	
Contribution received to CPF A/c			Advance for Purchase	24,49,109	
Amount received from NCPOR towards CPF Contribution of Dr M Ravichandran	3,34,548	**3,34,548**	Depository Work (APWD)	6,37,874	
			Interest Refunded to CFI	46,694	**11,79,02,910**
Fellowships received for Research Fellows:					
Science & Engineering Research Board (SERB)	79,254				
Inspire Fellowship	32,65,958				
Women Scientist Scheme	9,77,000		**Ocean Observation Networks - OON**		
Nation Post Doctoral Fellowship	8,77,800		Technical Support	1,92,50,678	
CSIR Fellowship	18,55,706	**70,55,718**	Administrative Expenses	84,85,933	
			Equipment	16,90,657	
			Travel	2,23,717	
Refund of Unspent Balances from PIs Sub-Projects			Consumable Material / Data	1,89,32,797	
Dr. Manas Ranjan Behara	5,39,585		Advance against subprojects	84,13,199	
Nansen Environmental	15,058		Advance for Purchase	1,51,66,960	

Dr A Saravanakumar	4,26,143		Interest Refunded to CFI	8,31,591	**7,29,95,532**
Dr.V Suneel NIO - Goa	3,86,801				
Dr.V. Vijith	2,13,546	**15,81,133**			
			Coastal Monitoring by INCOIS (CMI)		
			Administrative Expenses	20,04,187	
			Equipment	9,82,82,950	
			Advance against subprojects	61,18,489	
			Interest Refunded to CFI	87,25,391	**11,51,31,017**
			International Training Centre (ITCOocean)		
			Administrative Expenses	22,76,880	
			Travel	30,220	
			W.I.P	5,45,01,305	
			Depository Work (RITES)	30,00,000	
			Interest Refunded to CFI	16,87,879	
			Equipments	19,07,385	**6,34,03,669**
			O-MASCOT		
			Administrative expenses	47,45,780	
			Advance against subprojects	33,342	
			Equipments	18,90,000	
			Advance for Purchase	11,43,252	
			Interest Refunded to CFI	14,58,479	**92,70,853**
			Multi Hazard Vulnerability		
			Unspent Balance Refunded to CFI	9,66,704	**9,66,704**
			Monsoon Mission		
			Unspent Balance Refunded to CFI	2,56,70,026	**2,56,70,026**

			RIMES Afro Asian Region		
			Technical support	38,41,702	
			Interest Refunded to CFI	4,05,282	**42,46,984**
			IIOE2 & IIOSC		
			Administrative expenses	67,609	
			Interest Refunded to CFI	2,97,305	**3,64,914**
			Deep Ocean Mission (DOM)		
			Administrative expenses	1,19,662	
			Interest Refunded to CFI	15,56,930	**16,76,592**
			Expenditure on Fixed Assets		
			Computer / Peripheral	23,999	
			Other Fixed Assets	13,820	**37,819**
			Other Payments		
			Payment of GSLIS to (Late) Dr. Satya Prakash	8,14,074	
			Refund of Earnest Money Deposit	14,55,000	
			Security Deposits	23,83,874	
			Inspire Fellowship payments	21,59,134	
			LIC refund amount transferred to CFP	2,01,81,975	
			LIC refund amount transferred to Consultancy	2,39,14,136	
			Interest Deposit in Consolidated Fund of India (CFI)	2,29,80,766	
			Payment of Travel Expenses to Foreign Participants from UNESCO Fund	2,07,248	**7,40,96,207**

			Closing Balance		
			INCOIS Current A/c-SBI-HAL Campus Br.	4,57,43,580	
			UBI Savings A/c	76,81,217	
			UBI Consultancy A/c	44,15,574	
			Short Term Deposits with SBI, HAL Campus	47,52,00,000	
			INCOIS IOGOOS Secretariat- Local	9,01,151	
			INCOIS IOGOOS Secretariat- Foreign	27,27,836	
			INCOIS- CPF Account	1,08,169	
			Short Term Deposits with UBI (Consultancy)	3,00,00,000	
			Short Term Deposits with SBI, CPF Account	4,40,00,000	
			INCOIS SBI GeM POOL A/C	66,07,003	**61,73,84,530**
Total	**1,31,86,28,690**	**1,31,86,28,690**	**Total**	**1,31,86,28,690**	**1,31,86,28,690**

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. PRAHLADA RAO & CO. Chartered Accountants FRN No: 002717S Hyderabad

K. Prahlada Rao
Partner
M. No. 018477
FRN No: 002717S

Place : Hyderabad
Date : 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer
S. Nageswara Rao
Senior Accounts Officer

Indian National Centre for Ocean Information Services INCOIS Hyd.

(Dr. T. Srinivasa Kumar)
Director, INCOIS
Dr. T. Srinivasa Kumar
Director, INCOIS

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES
(Ministry of Earth Sciences, Govt. of India)
"Ocean Valley", Pragathinagar(BO), Nizampet(SO), Hyderabad - 500 090

SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31st MARCH 2022

SCHEDULE 1 – CORPUS FUND

Particulars	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
Corpus Fund at the beginning of the year	11,83,97,544	16,69,53,884
Add: Building fund balance amount capitalised	63,25,08,439	-
Add: Net income transferred from Income & Expenditure Account	-2,21,09,645	-4,85,56,340
BALANCE AS AT THE YEAR END	**72,87,96,337**	**11,83,97,544**

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. Prahlada Rao & Co. Chartered Accountants FRN No: 002717S Hyderabad

K. Prahlada Rao
Partner
M. No. 018477
FRN No: 002717S

Place : Hyderabad
Date : 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer
S. Nageswara Rao
Senior Accounts Officer

INCOIS

(Dr. T. Srinivasa Kumar)
Director, INCOIS
Dr. T. Srinivasa Kumar
Director, INCOIS

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE 2 - EARMARKED FUNDS

(Amount in ₹)

Particulars	FUND-WISE BREAK UP											TOTALS	
	Building Fund	OASIS	Ocean Observation Networks	Coastal Monitoring by INCOIS	ITCOO	O-MASCOT	MH Vulnerability	Monsoon Mission	RIMES	IIOE2 & IIOSC	Deep Ocean Mission	Current Year 2021-22	Previous Year 2020-21
a) Opening balance of the funds	3,76,342	(7,06,68,261)	(67,78,747)	13,69,08,636	89,06,189	(42,01,103)	9,66,704	2,24,00,468	45,07,878	39,91,305	1,05,19,259	10,69,28,671	22,62,76,901
b) Additions to the Funds:													
i. Grants	-	23,50,00,000	12,50,00,000	-	5,45,00,000	2,00 ,00,000	-	-	-	-	15,53,00,000	58,98,00,000	25,00,00,000
ii. Interest if any	-						-	-					1,91,29,226
a) Interest Apportioned during 2021-22	-	28,79,511	37,67,828	77,50,591	78,542	6,62,356	-	-	2,32,001	2,72,628	6,74,127	1,63,17,584	-
b) Interest credited Direct to projects 2021-22	-	97,102	95,663	-	-	-	-	-	-	-	-	1,92,765	-
iii. Advance for sub projects utilised/refund	-	23,49,357	-	-	-	1,23,918	-	-	-	-	-	24,73,275	5,20,78,687
iv. Advance for purchase Utilised	-	1,35,42,159	1,00,57,312	4,99,565	-		-	-		-	-	2,40,99,036	95,38,18,133
v. Margin Money Reversed	-	1,94,00,000	-	-	-	-	-	-	-	-	-	1,94,00,000	1,18,00,000
vi. Deposit Advance Utilized/refund	-	-	-	-	-	-	-	-	-	-	-	-	2,06,44,211
vii. Mobilization Advance Reversed	-	-	-	-	-	-	-	-	-	-	-	-	-
viii. Other Revenue	-	-	-	-	-	-	-	32,69,558	-	-	-	32,69,558	55,60,451
TOTAL (a+b) - A	**3,76,342**	**20,25,99,868**	**13,21,42,056**	**14,51,58,792**	**6,34,84,731**	**1,65,85,171**	**9,66,704**	**2,56,70,026**	**47,39,879**	**42,63,933**	**16,64,93,386**	**76,24,80,888**	**1,53,07,610**
c) Utilisation/Expenditure													
i. Capital Expenditure													
W.I.P	-	4,66,103	-	-	5,45,01,305	-	-	-	-	-	-	5,49,67,408	3,87,66,970
Architect fee	-	-	-	-	-	-	-	-	-	-	-	-	
Equipments	-	2,43,05,993	16,90,657	9,87,82,515	19,07,385	18,90,000	-	-	-	-	-	12,85,76,550	49,89,09,057
Computers / Software	-	2,93,35,719	-	-	-	-	-	-	-	-	-	2,93,35,719	16,42,56,257
Other Assets	-	-	-	-	-	-	-	-	-	-	-	-	5,33,718
Total	**-**	**5,41,07,815**	**16,90,657**	**9,87,82,515**	**5,64,08,690**	**18,90,000**	**-**	**-**	**-**	**-**	**-**	**21,28,79,677**	**70,24,66,002**
ii. Revenue Expenditure													
Technical support	-	3,90,48,661	1,92,50,678		-	-	-	-	38,41,702	-	-	6,21,41,041	20,15,64,147
Adminisrtrative expenses	-	4,97,00,260	84,85,933	20,04,187	22,76,880	47,45,780	-	-		67,609	1,19,662	6,74,00,311	11,32,07,406
Travel	-	2,09,300	2,23,717	-	30,220	-	-	-	-	-	-	4,63,237	41,31,577
Consumable Materials / Data	-		1,88,37,134	-		-	-	-	-	-	-	1,88,37,134	24,01,31,775
Total	**-**	**8,89,58,221**	**4,67,97,462**	**20,04,187**	**23,07,100**	**47,45,780**	**-**	**-**	**38,41,702**	**67,609**	**1,19,662**	**14,88,41,723**	**55,90,34,905**
iii. Others													
Advance against subprojects	-	69,94,713	84,13,199	61,18,489	-	1,57,260	-	-	-	-	-	2,16,83,661	6,55,68,553
Advance for Purchase	-	24,49,109	2,53,19,935	-	-	11,43,252	-	-	-	-	-	2,89,12,296	4,86,80,114
Deposit Works (APWD & RITES)	-	6,37,874	-	-	30,00,000	-	-	-	-	-	-	36,37,874	85,00,000
Margin Money against LC	-	-	-	-	-	-	-	-	-	-	-	-	1,94,00,000
Total	**-**	**1,00,81,696**	**3,37,33,134**	**61,18,489**	**30,00,000**	**13,00,512**	**-**	**-**	**-**	**-**	**-**	**5,42,33,831**	**14,21,48,667**
TOTAL (i+ii+iii) - B	**-**	**15,31,47,732**	**8,22,21,253**	**10,69,05,191**	**6,17,15,790**	**79,36,292**	**-**	**-**	**38,41,702**	**67,609**	**1,19,662**	**41,59,55,231**	**1,40,36,49,575**
Amount Refunded- C (Interest/Unspent Bal)	3,76,342	46,694	8,31,591	87,25,391	16,87,879	14,58,479	9,66,704	2,56,70,026	4,05,282	2,97,305	15,56,930	4,20,22,523	2,87,29,363
Interest to be refund - D (outstanding liability) as per 238 of GFR	-	29,76,613	38,63,491	77,50,591	78,542	6,62,356	-	-	2,32,001	2,72,628	6,74,127	1,65,10,349	
NET BALANCE AS AT THE PERIOD END {A -(B+C+D)}	**-**	**4,64,28,828**	**4,52,25,720.81**	**2,17,77,619**	**2,520.58**	**65,28,043.94**	**-**	**-**	**2,60,894**	**36,26,391**	**16,41,42,667**	**28,79,92,685**	**10,69,28,671**

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE - 3 CURRENT LIABILITIES & PROVISIONS

Particulars	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
A. CURRENT LIABILITIES		
Earnest Money Deposit	22,01,860	30,65,860
Security Deposit	63,98,512	72,16,243
Outstanding Expenses	2,12,35,913	2,03,53,274
Sundry Creditors	4,46,69,673	3,07,07,253
INSPIRE/DISHA/RTF-DCS Fellowship	40,38,736	10,32,645
Other bank Liability	2,43,07,601	8,49,79,897
Total – A	**10,28,52,295**	**14,73,55,172**
B. PROVISIONS		
Gratuity	4,36,70,909	4,43,24,793
Accumulated Leave Encashment	5,32,80,285	4,58,49,150
Total – B	**9,69,51,194**	**9,01,73,943**
Total (A+B)	**19,98,03,489**	**23,75,29,115**

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. Prahlada Rao
Partner
M. No. 018477
FRN No: 002717S

Place : Hyderabad
Date : 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer

S. Nageswara Rao
Senior Accounts Officer

(Dr. T. Srinivasa Kumar)
Director, INCOIS

Dr. T. Srinivasa Kumar
Director, INCOIS

SCHEDULE – 4 FIXED ASSETS

(Amount in ₹)

Description (% of Depreciation)	Gross Block			Depreciation			Net Block	
	As at 31.03.2021	Additions During the Year	As at 31.03.2022	As at 31.03.2021	For the Year 2021-22	As at 31.03.2022	As at 31.03.2022	As at 31.03.2021
1. Land (0%)	1,000	-	1,000	**-**	-	**-**	1,000	1,000
2. Plant, Machinery & Equipment (15%)	4,62,23,555	-	4,62,23,555	**4,52,11,425**	1,51,820	**4,53,63,244**	8,60,311	10,12,130
3. Furniture & Fixtures (10%)	1,72,67,084	-	1,72,67,084	**1,34,56,704**	3,81,038	**1,38,37,742**	34,29,342	38,10,380
4. Office Equipment (15%)	34,84,725	-	34,84,725	**29,77,163**	76,134	**30,53,297**	4,31,428	5,07,562
5. Computer / Peripheral (40%)	12,92,20,816	23,999	12,92,44,815	**12,59,50,264**	13,13,021	**12,72,63,284**	19,81,531	32,70,552
6. Electric Installations (10%)	20,98,406	-	20,98,406	**15,51,690**	54,672	**16,06,361**	4,92,045	5,46,716
7. Library Books (40%)	8,39,08,143	-	8,39,08,143	**7,69,32,332**	27,90,324	**7,97,22,656**	41,85,487	69,75,811
8. Other Fixed Assets (15%)	70,47,041	13,820	70,60,861	**50,00,588**	3,09,041	**53,09,629**	17,51,232	20,46,453
9. Vehicles (existing) (15%)	22,23,774	-	22,23,774	**7,54,896**	2,20,332	**9,75,228**	12,48,546	14,68,878
10. Building (10%)	-	63,25,08,439	63,25,08,439	**-**	6,32,50,844	**6,32,50,844**	56,92,57,595	-
Total	**29,14,74,544**	**63,25,46,258**	**92,40,20,802**	**27,18,35,061**	**6,85,47,225**	**34,03,82,286**	**58,36,38,516**	**1,96,39,483**
Previous Year	29,11,78,722	2,95,822	29,14,74,544	26,36,41,406	81,93,655	27,18,35,061	1,96,39,483	2,75,37,316

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE - 4A -EARMARKED FIXED ASSETS

(Amount in ₹)

	Description of the Assets	Gross Block					Depreciation					Net Block	
Sl. No	Name of the Fund/ Project	As on 01-04-2021	Additions 2021-22	Transfers to Fixed Assets based on prior approval of MoES	Grant Utilized/ Received till 31-03-2022 (G/A -Gen/Capital)	Total Amount as on 31-03-2022	As on 31.03.2021	For the Year 2021-22	Diff. of Previous Years Dep.	Total Depreciation for the year	As at 31.03.2022	As at 31.03.2022	As at 31. 03. 2021
i)	Building Fund	63,25,08,439	-	63,25,08,439	-	-	-	-	-	-	-	-	-
ii)	MDC & Equipment Fund	6,59,21,618	-	-	-6,59,21,618	-	-	-	-	-	-	-	-
iii)	Ocean Information and Advisory Services (OASIS)	1,99,67,87,572	5,41,07,815	-	-2,05,08,95,387	-	-	-	-	-	-	-	-
iv)	Computational Facilities	15,28,06,467	-	-	-15,28,06,467	-	-	-	-	-	-	-	-
v)	INDOMOD & SATCORE Projects	42,72,64,846	9,87,82,515	-	-52,60,47,361	-	-	-	-	-	-	-	-
vi)	Ocean Observation Networks	81,86,47,592	16,90,657	-	-82,03,38,249	-	-	-	-	-	-	-	-
vii)	International Training Center- ITCOocean	65,26,27,194	5,64,08,690	-	-70,90,35,884	-	-	-	-	-	-	-	-
viii)	O-MASCOT (HROOFS)	6,35,29,251	18,90,000	-	-6,54,19,251	-	-	-	-	-	-	-	-
ix)	IT & E Governance Fund	5,88,34,380	-	-	-5,88,34,380	-	-	-	-	-	-	-	-
x)	HPC Systems - Others	1,33,61,57,396	-	-	-1,33,61,57,396	-	-	-	-	-	-	-	-
xi)	CSS	14,37,371	-	-	-14,37,371	-	-	-	-	-	-	-	-
xii)	V SAT Node	17,44,71,627	-	-	-17,44,71,627	-	-	-	-	-	-	-	-
xiii)	Ernet India	72,00,000	-	-	-72,00,000	-	-	-	-	-	-	-	-
iv)	IOAS	51,25,986	-	-	-51,25,986	-	-	-	-	-	-	-	-
xv)	MH Vulnerability	28,30,738	-	-	-28,30,738	-	-	-	-	-	-	-	-
xvi)	Monsoon Mission	16,59,62,545	-	-	-16,59,62,545	-	-	-	-	-	-	-	-
xvii)	RIMES	4,85,36,951	-	-	-4,85,36,951	-	-	-	-	-	-	-	-
xviii)	Coastal Monitoring (CMI/SATCORE)	1,80,60,121	-	-	-1,80,60,121	-	-	-	-	-	-	-	-
xix)	NCS	13,73,259	-	-	-13,73,259	-	-	-	-	-	-	-	-
	Total	**6,63,00,83,353**	**21,28,79,677**	**63,25,08,439**	**-6,21,04,54,591**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Previous year	**5,92,76,17,351**	**70,24,66,002**	**-**	**-6,63,00,83,353**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	GRAND TOTAL	**6,92,15,57,897**	**84,54,25,935**	**63,25,08,439**	**-5,28,64,33,789**	**-54,672**	**-27,18,35,061**	**-6,85,47,225**	**-34,03,82,286**	**-54,672**	**-58,36,38,516**	**-1,96,39,483**	**-**
	GRAND TOTAL (PREVIOUS YEAR)	**6,21,87,96,073**	**70,27,61,824**	**-**	**-6,63,86,08,809**	**-60,746**	**-26,36,41,406**	**-81,93,654**	**-27,18,35,061**	**-**	**-1,96,39,483**	**-2,75,37,316**	**-**

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE - 5 CURRENT ASSETS, LOANS & ADVANCES

Particulars	Current Year (2021 - 22) ₹		Previous Year (2020 - 21) ₹	
A. CURRENT ASSETS				
1. Inventories (Valued at cost)	15,05,621	15,05,621	7,78,348	7,78,348
2. Cash & Bank Balance:				
a) With Scheduled Banks – Current Account				
State Bank of India HAL CAMPUS A/c	4,37,63,197		2,65,84,224	
Union Bank Pragathinagar SAVINGS A/c	73,65,178		1,21,21,630	
Union Bank Pragathinagar-Consultancy A/c	44,15,039		97,46,703	
State Bank of Indian - CPF Savings A/c	1,08,169		1,48,40,399	
State Bank of India - IDBPS Savings A/c	-		1,18,676	
State Bank of India - GeM Pool Account (GPA)	66,07,003	6,22,58,586		6,34,11,632
b) Short Term Deposits with SBI	47,52,00,000	54,92,00,000	35,64,00,000	35,64,00,000
c) Short Term Deposits with CPF	4,40,00,000			
d) Short Term Deposits with Union Bank Consultancy	3,00,00,000			
3. Sundry Debtors	11,64,660	11,64,660		-
TOTAL A:		**61,41,28,867**		**42,05,89,979**
B. LOANS, ADVANCES & OTHER ASSETS				
1. Deposits				
a) Telephone	1,73,186		1,73,186	
b) Electricity	70,16,374		70,16,374	
c) Gas	13,100		13,100	
d) Petrol/Diesel	-	72,02,660	1,01,400	73,04,060
2. Advances & other amounts recoverable in cash or in kind or for value to be received				
a) Interest Accrued	6,50,702		43,25,504	
b) Other Advances	-		62,668	
c) Tour Advance	65,246		9,000	

d) LTC Advance		-		1,56,400	
e) TDS					
Opening Balance -	Rs. 73,55,069	74,93,354	82,09,302	73,55,069	1,19,08,641
Less: Refund received for the year 2019-20	Rs. 23,48,410				
Add: Current year accumulation	Rs. 14,94,160				
Add: TDS Adjustment Entry	Rs. 9,92,535				
i) Margin Money against Bank Guarantee			34,13,165		34,13,165
TOTAL B: (1+2)			**1,88,25,127**		**2,26,25,866**
GRAND TOTAL (A + B)			**63,29,53,994**		**44,32,15,845**

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE 6 - INCOME FROM SALES / OTHER INCOME

Particulars	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
a) Other Receipts	60,07,516	17,44,269
b) Consultancy Services (Including Consultancy fee and interest received from LIC)	2,49,44,289	35,09,497
i. Transfer from IDBPS A/C to Consultancy Account - Rs. 2,39,14,136		
ii. Consultancy Revenue during 2021-22 - Rs. 10,30,153		
c) Income from staff quarters	4,13,070	88,300
TOTAL	**3,13,64,875**	**53,42,066**

SCHEDULE 7 - INTEREST EARNED

a) Interest on Deposits & Others	8,61,669	18,01,301
b) Bank Accounts	16,11,792	8,08,124
c) Staff Advances	-	29,000
d) Interest on Vehicle Advance	60,000	-
TOTAL	**25,33,461**	**26,38,425**

SCHEDULE 8 - IRRECOVERABLE GRANTS & SUBSIDIES RECEIVED

a) Central Government (Recurring Grant received from MoES)	22,78,00,000	22,60,00,000
TOTAL	**22,78,00,000**	**22,60,00,000**

SCHEDULE 9 - ESTABLISHMENT EXPENDITURE

a) Salaries, Wages & Allowances	11,97,66,760	14,75,28,432
b) Staff Welfare Expenses	21,29,821	8,75,680
c) Contributory Provident Fund	10,03,260	2,72,668
d) New Pension Scheme	91,21,107	78,32,148
f) Leave Travel Concession	6,57,174	29,85,563
TOTAL	**13,26,78,122**	**15,94,94,491**

INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

SCHEDULE 10 - OTHER ADMINISTRATIVE EXPENSES

Sl No.	Particulars	Current Year (2021-22) ₹	Previous Year (2020-21) ₹
1.	Electricity & Power Expenses	2,57,53,528	2,26,48,610
2.	Water Charges	37,74,726	32,98,309
3.	Operation & Maintenance expenses	50,16,682	1,20,40,791
4.	Garden Expenses	3,75,777	38,65,445
5.	Vehicle Hiring Expenses	5,41,922	4,06,668
6.	Postage, Fax & ISDN Charges	4,80,045	5,04,939
7.	Printing & Stationery	9,87,686	9,20,148
8.	Travelling Expenses:		
	Inland	-	-
	Foreign	-	-
	Others	-	46,710
9.	General Expenses	1,13,21,659	1,53,85,002
10.	Audit Fee	25,370	23,600
11.	House Keeping & Plumbing	78,93,902	2,89,90,142
12.	Security Expenses	1,58,39,414	2,35,48,911
13.	Advertisement & Publicity	6,16,973	3,81,001
14.	Internet Expenses	8,90,364	4,45,182
15.	Legal Expenses	-	56,850
16.	Papers & Periodicals	-	4,331
17.	Material /Consumable	29,85,246	20,81,808
18.	International Interface	8,63,991	88,240
19.	Others	46,000	1,12,000
	TOTAL	**7,74,13,285**	**11,48,48,687**

SCHEDULE NO.11

NOTES FORMING PART OF ACCOUNTS:

1. **Significant Accounting Policies:**

   a) **Basis of Accounting:**

   The Society follows the mercantile system of accounting and recognizes Income and Expenditure on accrual basis. The accounts were prepared on the basis as a going concern.

   b) **Income Recognition:**

   The Grant-in-aid was received by the Society from Ministry of Earth Sciences in the form of recurring grant and ear-marked funds.

   The Grant-in-aid received from Ministry of Earth Sciences for the purpose of meeting revenue expenditure is treated as Income to the Society and to the extent utilized for capital expenditure is added to the Corpus Fund. During the year 2021-22, the Society received Rs.22.78 Crores towards Recurring Grant as shown in the Schedule-8.

   The remaining Grant-in-aid of Rs.58.98 Crores received from Ministry of Earth Sciences is being utilized for specific purposes for which they were intended to and are disclosed under the Earmarked Funds- Schedule-2.

   c) **Fixed Assets and Depreciation:**

      i. Fixed Assets Register maintained by the Society.

      ii. The management verified the assets physically by appointing a committee.

      iii. The additions to the fixed assets during the period of audit were stated at cost.

      iv. Depreciation on Fixed Assets was provided on written down value, as per the rates prescribed under the Income Tax Rules.

   d) **Inventories:**

   Inventory of stores, stationery items and other material of significant value are valued at cost, and the same are taken as certified by the management.

   e) **Building:**

   As per the guidelines provided to the Central Autonomous Bodies, the Funds inflow and outflow relating to the building are initially shown under Building Fund in the Earmarked Funds under Schedule–2 and on completion and on approval of MoES, the value of building is transferred to the Society Fixed Assets schedule and shown in the Balance Sheet.

   f) **Employee Benefits:**

      i) **Gratuity:**

      The present value of the INCOIS obligations under Gratuity is recognized on the basis of an actuarial valuation given by the LIC of India Ltd., as on March 15, 2022.

      ii) Periodical contributions made towards Contributory Provident Fund (CPF) and New Pension Scheme (NPS) are charged to revenue.

      An amount of Rs.51,69,349/- was paid towards enhanced Employer Contribution to NPS effective from 01.04.2019 upon receipt of approval of MoES was accounted as prior period expenditure

      iii) **Leave encashment:**

      The present value of the INCOIS obligations under Leave encashment is recognized on the basis of an actuarial valuation made by the LIC of India Ltd., as on March 15, 2022.

a) The IDBPS (INCOIS Defined Benefit Pension Scheme) is managed by a separate trust and employers' contributions towards pension for the employees joined prior to 01-01-2004, was transferred by INCOIS to LIC of India Ltd up to August 31, 2015 only.

b) Based on the MoES letters, INCOIS requested all the 11 employees, who are under INCOIS-IDBPS, to exercise the option either to continue in the Contributory Provident Fund or to join the New Pension Scheme as the IDBPS is being discontinued in INCOIS. The funds transfer to LIC of India Limited towards contribution of INCOIS for the IDBPS is deferred with effect from September 2015 onwards.

c) As per the directives of the GC, INCOIS has sent a letter dated March 19, 2015 to Joint Secretary (Establishment), MoES requesting for post-facto approval for the Defined Benefit Pension Scheme (DBPS) which has been implemented since May 2010 for its employees joined service prior to 1.1.2004.

d) MoES vide its reply letter dated August 13, 2015 informed that the issue has been examined in consultation with IFD, MoES and it has not been found possible to accede to consider INCOIS proposal for ex-post-facto approval for the Defined Benefit Pension Scheme (DBPS) which has been implemented since May 2010 for its employees joined service prior to 1.1.2004.

e) The letter further informs that the demand for pension in respect of INCOIS employees who joined prior to 1.1.2004 may please be regulated in terms of guidelines issued vide letter No.MoES/01/Dir(F)/2015 dated May 26, 2015.

f) All 11 employees in the scheme contested the exercising the option given by the INCOIS and filed a legal case with Central Administrative Tribunal, Hyderabad on November 12, 2015. The hearings are going on. The court has issued status-quo orders on February 24, 2016.

g) Subsequently, all the 11 employees sought permission of the Central Administrative Tribunal (CAT) to withdraw the O.A. Now the CAT, Hyderabad Bench vide order dated 21.5.2020 has dismissed the OA No.21/1525/2015. The Trust has also resolved and requested the LIC for closure of the Master Policy of Defined Benefit Pension Scheme, LIC considered the request and close the Master Policy and refunded an amount of Rs.6,70,76,877/-.

h) Management obtained the necessary approvals for rejoining in CPF and distribution of the funds received from LIC of India Limited in the current financial year.

i. Total funds received from LIC of India Limited	Rs.6,70,76,877/-
ii. Less-Amount transferred to CPF	Rs.2,01,81,975/-
iii. Less-Amount transferred to Consultancy accounted as current year income	Rs.2,39,14,136/-
iv. Balance refunded to MoES for depositing in consolidated Fund of India	**Rs.2,29,80,766/-**

g) Interest on Deposits:

The Society invested surplus funds from time to time in Short Term Deposits in Nationalized Banks. For the year 2021-22, an amount of Rs.1,72,40,798 was earned as interest on the Short Term Deposits in the bank. Since, the interest received on Short Term Deposits, relate to the grants accruing to the various projects and recurring grants received by INCOIS, the management decided to spread the interest on Short Term Deposits to such projects and INCOIS Society.

a.	Interest transferred to Ear-marked Funds	-	Rs.1,63,17,584.00
b.	Interest transferred to various other funds (Such as DST-DPWS, DST-NPDF and SERB)	-	Rs. 3,38,388.00
c.	Interest transferred to Society	-	Rs. 5,84,826.00
	Total		**Rs.1,72,40,798.00**

In addition to the apportioned interest amount of Rs.1,63,17,584/- for various earmarked funds in Schedule 2, the funds earned interest directly also credited to the relevant funds and such amount is worked out to Rs.1,92,765/-. As the interest refund is to be deposited to the Consolidated Fund of India (CFI), under the compliance of Rule-230(8) of GFR-2017, a liability was created in the FY 2021-22 and the same will be deposited in the CFI.

However, interest is not being charged on excess utilized funds (funds that are in negative balance) used for the Earmarked funds to the respective grants. The programmes those were closed and interest and unspent balances were refunded for compliance of GFR were also not apportioned the interest.

The details are furnished below: -

(Amount in Rs.)

a.	Interest earned on regular STDRS closed FY 2021-22 - SBI	2,08,38,838.00
b.	Add: Net Interest accrued GEM Pool A/c FY 2021 -22	93,463.00
c.	Add: Net Interest accrued in UBI SB A/c FY 2021-22	3,88,061.00
d.	Add: Net Accrued Interest for the F.Y 2021-22 on SBI	1,13,664.00
e.	Add: TDS on closed and accrued TDRs on SBI as per 26 AS 2021-22	14,94,160.00
f.	Less: Transfer of outstanding Accrued Interest for the FY 2020-21	56,87,388.00
	Total Interest earned for the FY 2021-22	**1,72,40,798.00**

2. Notes on Accounts:

b) EARMARKED FUNDS:

The Society during the year 2021-22, received Rs.58,98,00,000/- Crores as Grant-in-aid towards Earmarked Funds from the Ministry of Earth Sciences (MoES) and other institutions in the form of Recurring and Non-Recurring grants as specified under Schedule -2.

The amounts advanced to various Earmarked Funds under Schedule-2, shall initially be shown as Advances to Sub Projects under "Others" category in the Earmarked Funds Schedule, and, on receipt of Utilisation Certificates from the respective project heads, the utilized amounts are transferred to either Capital expenditure or Revenue expenditure based on the nature of utilization.

INCOIS is making payments for the acquisition of equipment for the various projects classified under Earmarked Funds of Schedule-2. These payments are initially shown as 'advance for purchase' under Schedule-2, and later, on completion commissioning of the equipment and contractual/warranty obligations, the total value of equipment is transferred to equipments under the same Schedule. An amount of Rs.4.27Cr of advances was adjusted and the value of "Advance for Purchase" as on 31-03-2022 was only Rs.10.32 Crores.

The accumulated value of the capital expenditure as on 31-03-2022 (excluding advances to sub-projects and advances for purchases), incurred in each year and specified in the Earmarked Funds under Schedule - 2, are stated below. A separate schedule has been added at Schedule 4A.

Sl No.	Name of the Fund/ Project	As on 01-04-2021 Rs.	Capital Expenditure incurred during 2021-22 Rs.	Transfers to Fixed Assets based on prior approval of MoES	Total Amount as on 31-03-2022 Rs.
i)	Building Fund	63,25,08,439	0	63,25,08,439	0
ii)	MDC & Equipment Fund	6,59,21,618	0	0	6,59,21,618
iii)	Ocean Information and Advisory Services (OASIS)	1,99,67,87,572	5,41,07,815	0	2,05,08,95,387
iv)	Computational Facilities	15,28,06,467	0	0	15,28,06,467
v)	INDOMOD & SATCORE Projects	42,72,64,846	9,87,82,515	0	52,60,47,361
vi)	Ocean Observation Networks	81,86,47,592	16,90,657	0	82,03,38,249
vii)	International Training Center-ITCOocean	65,26,27,194	5,64,08,690	0	70,90,35,883
viii)	O-MASCOT (HROOFS)	6,35,29,251	18,90,000	0	6,54,19,251
ix)	IT & E Governance Fund	5,88,34,380	0	0	5,88,34,380
x)	HPC Systems – Others	1,33,61,57,396	0	0	1,33,61,57,396
xi)	CSS	14,37,371	0	0	14,37,371
xii)	V SAT Node	17,44,71,627	0	0	17,44,71,627
xiii)	Ernet India	72,00,000	0	0	72,00,000
xiv)	IOAS	51,25,986	0	0	51,25,986
xv)	MH Vulnerability	28,30,738	0	0	28,30,738
xvi)	Monsoon Mission	16,59,62,545	0	0	16,59,62,545
xvii)	RIMES	4,85,36,951	0	0	4,85,36,951
xviii)	Coastal Monitoring (CMI/SATCORE)	1,80,60,121	0	0	1,80,60,121
xix)	NCS	13,73,259	0	0	13,73,259
	TOTAL	**6,63,00,83,353**	**21,28,79,677**	**63,25,08,439**	**6,21,04,54,591**

c) **PROJECTS AND UTILISATION CERTIFICATES:**

The Committees comprising the heads of respective projects and other technical/scientific experts are monitoring the status of the various projects, including the financial budgets etc.

The recommendations of the committee are being reviewed from time to time by the competent authority.

The various assets of the projects and sub projects purchased either by the INCOIS or by the respective sub projects, are located at such projects and sub projects. The confirmations of the assets held by them are being submitted from time to time.

The respective project heads submitted the utilization certificates for the year ending 31st March of each financial year and these certificates are received by the INCOIS during the subsequent financial year. Hence, the management had decided to pass the entries relating to the Utilisation Certificates actually received upto 31st March of each financial year.

d) Contingent Liabilities:

i. Contingent liabilities not provided for:

a. In view of the non-fulfillment of the contractual obligation for Rs.9,50,000/- of Bank Guarantee submitted by M/s Gaian (FY2018-19) was encashed. Depending upon the satisfactory fulfillment, amount will be refunded in future.

ii. Estimated amount of Contracts remaining to be executed on capital account-NIL

iii. Claims against the company not acknowledged as debts-NIL

e) The Society had placed an order with M/s. Victory Genset Pvt. Ltd. for purchase of two 600 KVS DG sets in the year 2009 and released 90% payment by irrecoverable LC as per terms agreed. But, M/s. Victory Genset Pvt. Ltd. had supplied only one DG set. The society claims that the documents were fabricated by supplier as if two DG sets have been supplied and hence, filed a criminal and civil suit in 2009 against the supplier.

The III Additional Chief Judge of City Civil Court, Hyderabad, had passed a decree for Rs. 64,89,747/- plus damages Rs. 5,00,000/- with future interest till the date of payment by the firm vide their Order OS No. 69 of 2010, dated 18-04-2012. During the proceedings of the case, an amount of Rs. 18,50,907.98 was blocked through injection petition in the current account of M/s. Victory Genset Pvt. Ltd. Maintained at SBI, Versova Branch, Mumbai.

Upon grant of decree by Hon'ble court, the society on the advice of legal advisor had requested SBI, Versova Branch, Mumbai to transfer the available amount to INCOIS and to provide the details of assets of M/s. Victory Genset Pvt. Ltd. to file the petition to recover the balance amount. As SBI, Versova Branch refused to honour the court decree; the society had written letters to Governor, Reserve Bank of India & Secretary, Ministry of Finance, Govt. of India complaining against the SBI, Versova Branch for not adhering to the court decree. No response is received from the above.

Society now filed a Executive petition at III Additional Chief Judge of City Civil Court, Hyderabad for recovery of the amount available in the bank account of M/s. Victory Genset Pvt. Ltd at SBI, Versova branch and also to take steps by seizing his properties available in the Mumbai for recovering the decreed amount. As per the orders of the above Hon'ble court, the case has been transferred to the City Civil Court, Mumbai at Dindoshi (Borivali Division), Goregaon Mumbai. The case is in progress.

INCOIS filed criminal complaint against M/s Victory Genset Pvt. Ltd. at Dundigal Police Station, Hyderabad on October 5, 2009 and Police filed a Charge Sheet vide 173 of Cr: PC (Section 420 IPC) at VI Metropolitan Magistrate Court, Medchal, Hyderabad against the firm.

INCOIS has provided all the relevant documents related to the case to the concerned police officials. After final arguments and actual records available by the court, the Hon'ble Judge on 31.08.2018 had declared that Mr. Nanda Kumar is convicted in the case and issued Non Bailable Warrant as he has not attended to the court in spite of clear-cut instructions / orders issued by the Hon'ble Judge.

f) Input Tax Credit of GST

INCOIS is being a Scientific Organization mandated with providing ocean data, information and advisory services to the society, industry, the Government and Scientific Community. There is an imbalance of payment of GST against the Purchases made and services obtained against input tax credit claimed. The matter is discussed with GST Department. Since Input GST is not agreed by the GST Department as credit allowable, GST is treated as part of expenditure and GST collected as output GST, is treated as Income in the books of Accounts whereas while filing GST return, we claim ITC and set off against Output GST.

INCOIS has received notice from GST Authority under section 73 in connection with Input Tax credit. Accordingly, all replies have been uploaded online and case has been presented to GST authorities. Subsequently, GST authorities have suggested INCOIS to nullify Input tax credit balance during GST reconciliation for respective financial years. In compliance to the suggestion of GST Authorities, INCOIS has filed the DRC-03 to nullify its ITC credit balance.

g) Figures have been regrouped/rearranged wherever necessary.

h) Paise had been rounded off to the nearest rupee.

As per our report of even date
For K. Prahlada Rao & Co.
Chartered Accountants

K. Prahlada Rao & Co. Chartered Accountants FRN No: 002717S Hyderabad

(K. Prahlada Rao)
Partner
M.No. 018477
FRN No. 002717S

Place: Hyderabad
Date: 11.08.2022

For and on behalf of
INDIAN NATIONAL CENTRE FOR OCEAN INFORMATION SERVICES

(S. Nageswara Rao)
Senior Accounts Officer
S. Nageswara Rao
Senior Accounts Officer

(Dr.T.Srinivasa Kumar)
Director, INCOIS
Dr. T. Srinivasa Kumar
Director, INCOIS

Indian National Centre for Ocean Information Services INCOIS Hyd.

Indian National Centre for Ocean Information Services

(An autonomous body under the Ministry of Earth Sciences, Govt. of India)

"Ocean Valley", Pragathi Nagar (B.O.), Nizampet (S.O.), Hyderabad-500 090. Telangana, INDIA

Tel: +91-40-23895000, Fax: +91-40-23895001; E mail: director@incois.gov.in

Website: www.incois.gov.in