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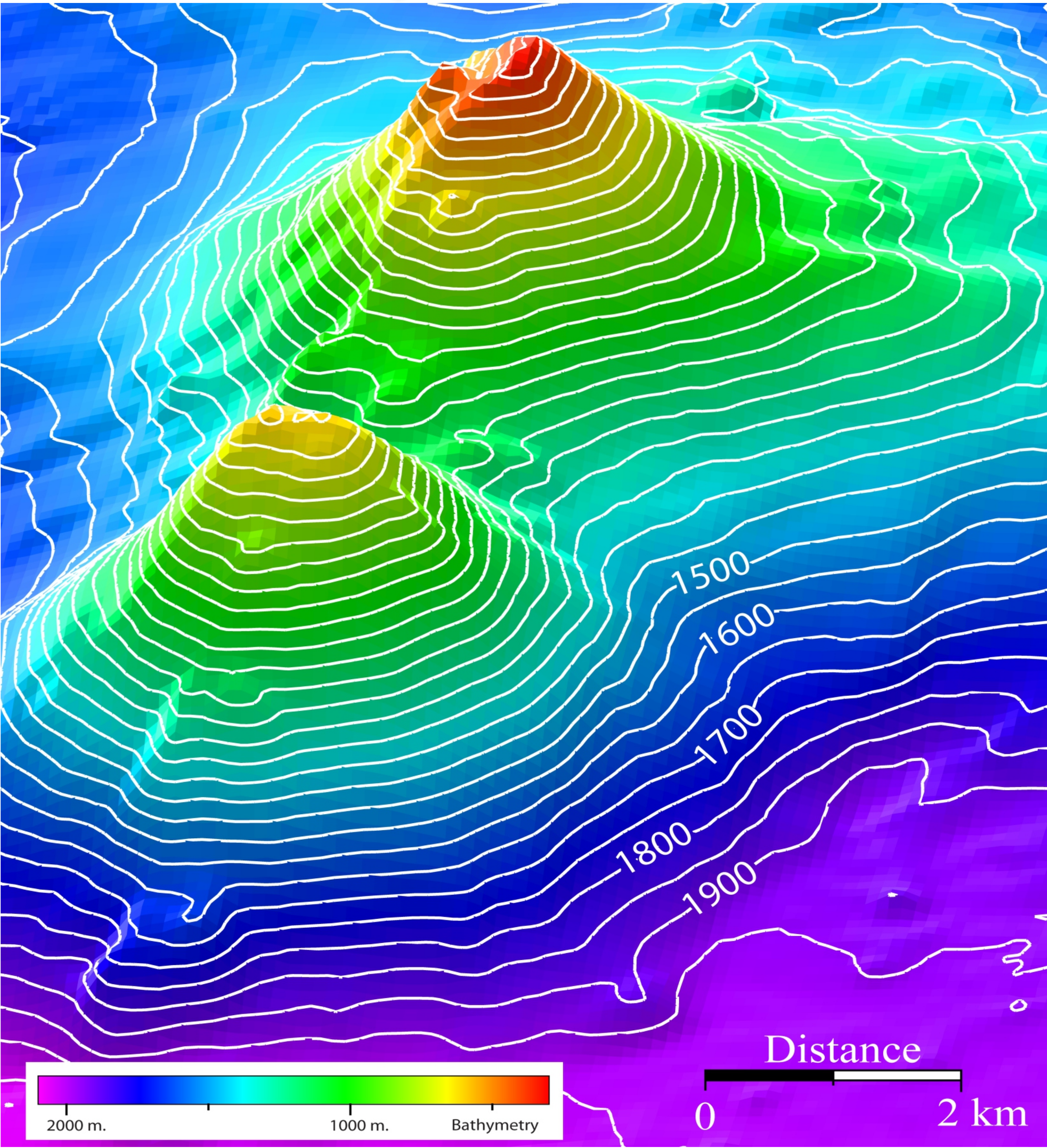

Development and Qualification of shallow water spherical pressure hull for the manned submersible

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Under Deep Ocean Mission program, National Institute of Ocean Technology (NIOT) (Ministry of Earth Sciences, GoI) is developing a 6000 m depth rated manned submersible – first of its kind for India to aid human direct investigation for deep sea research. As an overall application, the manned submersible shall have direct bearing for ocean resource explorations and scientific observations in deep waters apart from technology support and capacity building in the country for the development of human rated deep water vehicles.

Manned submersible under development shall carry three human beings to the depth of 6000 m water depth. The manned submersible is designed with an endurance of 12 hours in normal conditions and 96 hours in case of emergency. The descent and ascent of the vehicle are through a ballast mechanism with a maximum bottom time of 4 -5 hours for deep sea observation with 3 knots speed of the vehicle. The shape of the manned submersible is carefully studied to minimize the energy requirements and it plays an important role in energy utilization and endurance. The sub-systems are arranged in such a way that the centre of buoyancy (CB) is above the centre of gravity (CG) and it meets the minimum requirement defined by DNV rules which is an international body for Certification and Classification of the design and realization. The optimized shape of the manned submersible is shown in Figure 1.

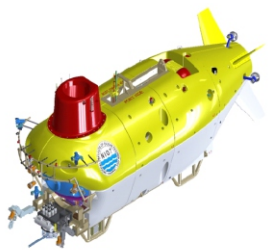

Figure 1. Optimised shape of the manned submersible – MATSYA6000

Figure 2. Deployment view of spherical pressure hull from ORV Sagar Nidhi in Bay of Bengal and the graph shows depth vs time

One of the critical components of manned submersible is the Personnel Sphere (Spherical Hull) which carries three human beings to the designated depth and designed to maintain one atmosphere pressure inside by withstanding external pressure. A shallow water spherical pressure hull rated for 500 m has been designed and developed by NIOT in parallel to the realization of the 6000 m depth rated spherical hull. The internal diameter of the pressure hull is 2.1 m to carry three human beings along with operation controls and life support system devices. The pressure hull shall facilitate to mount three acrylic view ports for seeing outside from spherical hull, two penetrator assemblies for external subcomponents interface and hatch for human entry and exit at the surface. To ensure the safety and reliability, design and manufacturing of pressure hull have been carried out using DNV and ASME PVHO-1 rules. The linear and nonlinear buckling pressure analysis has been carried out to understand the collapse pressure of the spherical pressure hull. By considering the material and manufacturing facility available, SA516 Grade 70 steel has been chosen as the pressure hull material.

The manufacturing process in petal and crown construction was followed for a design thickness of 25 mm as per the approved quality assurance procedure. The post-weld heat treatment has been carried out after welding the viewport flanges, entry hatch, and penetrator plates with the formed spherical shell. The material selection, fabrication, and qualification are witnessed by the DNV-GL. The spherical hull assembly developed was tested for an internal pressure of 1.3 bar (g) and a vacuum test for 0.23 bar (g). Open ocean test was carried out in Bay of Bengal to validate the depth integrity during October 2021.

As per the validation requirements, the pressure hull was deployed using deep sea winch of Sagar Nidhi up to a test diving depth of 600 m (1.2 times of Nominal Diving Depth 500 m) as shown in Figure 2. Figure 2 also gives the depth sensor data with respect to time. The open ocean test was conducted twice for assurance of repeatable test results for the strain gauges installed on the critical welded joints (to ensure that the structure remains well within the elastic region). After the test, it was observed that there was no physical damage and no leakage. Non-destructive examinations were carried out before and after the external pressure test to understand the integrity of the pressure hull. Optical laser scanning was conducted to get the complete profile of the real manufactured spherical hull in 3D CAD model. This 3D real CAD model was used for measuring thickness, out-of roundness, local imperfection, weld offset, and to carry out finite element analysis. The strains measured at the critical locations are compared with real 3D model finite element analysis and the results are within the stress limit.

Design, analysis, fabrication and test data including the results obtained from successful Open Ocean trials of the first-time indigenous development of such large diameter (2.1 m) pressure hull for external pressure in India have been submitted to DNV and it is certified by DNV for man rated usage upto 500 m water depth. Further, this shall be used for habitability of human being with life support system for long endurance operation in an enclosed space of 4.8 m^3. Further subcomponent realisation for manned submersible is under progress towards realization of the manned submersible.

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Research Highlights

Observational evidence on the coastal upwelling along the northwest coast of India during summer monsoon





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This article is based on the following paper:
Narayanan Nampoothiri S, V., Ramu, C., Rasheed, K., Sarma, Y. V. B., & Gupta, G. V. M. (2022). Observational evidence on the coastal upwelling along the northwest coast of India during summer monsoon. Environmental monitoring and assessment, 194(1), 1-16.

The lesser-known coastal upwelling in the North Eastern Arabian Sea (NEAS) during summer monsoon, its associated dynamics and forcing mechanisms is elucidated for the first-time using basin scale monthly time-series in-situ and satellite data. The presence of cool upwelled waters along northwest coast of India from July to early October with an associated increase in productivity was evident in both data. The low level Findlater jet blows towards west coast of India with high wind magnitude (10-12 m/s) during summer monsoon generates strong Ekman transport (1416 kg/m/s) at offshore and Ekman pumping velocity (1.349 m/s) at coastal region initiates upwelling. It was identified that the currents and remote forcing also regulates upwelling along the region. Although upwelling seem to exist along the northwest coast, it was weaker (25.5°C) compared to the southwest coast where the SST dropped to 24°C. The upwelling was observed in the south during June as a surface process, while it was observed along the northwest coast of India by the end of August. Even though the onset of upwelling in the NEAS and South Eastern Arabian Sea (SEAS) had a lag of two months, the recession of upwelling happened during late and early September respectively. The cause for the lag in the onset and cessation of upwelling between SEAS and NEAS is attributed to the propagation of Kelvin waves and southwest monsoon winds. Study also reveals that temperature and chlorophyll profiles shows bi-modal peaks of high and low associated with winter cooling (winter) and upwelling (summer).

Northern Arabian Sea is landlocked and is connected to two marginal seas, the Persian Gulf and the Red Sea which makes it much saltier. The continental shelf is narrow along the study region and has high velocity tidal fluctuations (Wagle 1979). During the winter monsoon, winds are north easterly (Kantha et al. 2008) and during the summer monsoon, warm, moist air prevails and a strong southwesterly wind jet runs diagonally across the Arabian Sea (Findlater 1969).This general wind pattern associated with the monsoons results in the upper layer circulation. The coastal current driven by the pressure gradient (McCreary et al. 1993) is northward during winter monsoon and is southward during summer monsoon which are termed as the West India coastal current (WICC) (Shetye et al. 1990). Winter cooling is observed in the NEAS due to cold and dry north-easterly winds in the region during winter with subsequent convective mixing thereby deepening the mixed layer and increasing the chlorophyll concentration (Madhupratap et al. 1996; Prasanna Kumar et al. 2004; Shankar et al. 2016). Excess evaporation and turbulent heat loss cool the surface waters during winter leads to formation of Arabian Sea High Saline Watermass (ASHSW) in the study area (Kumar and Prasad 1999). The weak northerly winds and increased solar insolation during the inter-monsoon period leads to high SST and shallow mixed layer (Kumar and Prasad 1996). Location map and sampling points along the northwest coast of India is shown in Figure 1.

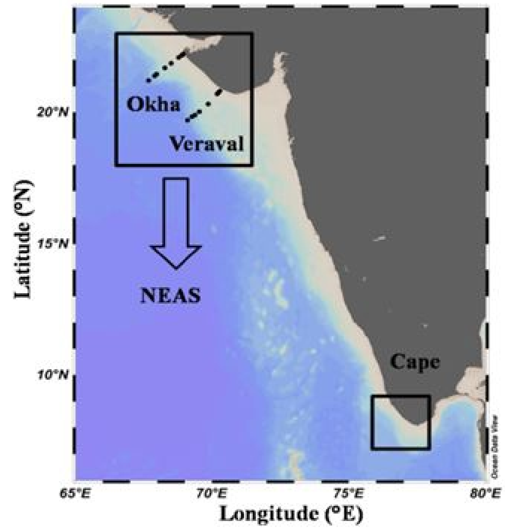

Figure 1. Location map of study area along the northwest coast of India. This study focus on the Okha and Veraval transects in the NEAS (shown in box).

The vertical sections of temperature along the Okha transect showed colder waters (<24°C) throughout the water column at coastal location (30m depth) during winter (December to February). From March or early April temperature increases until July which is interrupted by a cooling due to upwelling during August-September when the temperature dropped to 25.5°C (Figure 2). By the end of September, the temperature increased with warmer conditions (28°C) extending from surface to bottom and later the effects of winter cooling dominates from mid-November with a gradual fall of temperature (<24°C). Salinity and density profiles also display significant shallowing during August-September from 30m to surface. During the period of upwelling, the salinity was dropped (0.5psu) and denser waters were uplifted, when compared to pre-monsoon and post-monsoon periods. The signature of coastal upwelling was stronger in the subsurface (below 20m) compared to its surface expression. This indicates that upwelling process was weak at the northwest coast. Temperature profiles and the uplift of D24 and D26 isotherms confirm the presence of coastal upwelling observed during the summer monsoon period along the northwest coast. Time-series vertical variation of temperature at shelf location (100m depth) also shows signals of winter cooling associated cooler temperature and summer monsoon upwelling associated shallowing of cooler waters. This is also evident from the salinity and density profiles. Time series satellite observations during 2012-2018 clearly reveal the decrease of SST during winter and mid-summer. The long-term observations during the 7-year period showed that during August-September (middle of summer monsoon)SST were comparatively high (26-27°C) when compared to the December-February (winter monsoon) where it was less than 24°C (Figure 3). Coastal region of NEAS remains productive throughout the year due to the combined effect of coastal upwelling during summer monsoon and winter cooling during winter monsoon. CMFRI (2019) annual report also mentioned off Gujarat coast with high marine fish landings compared to other coasts in India that supports this finding.

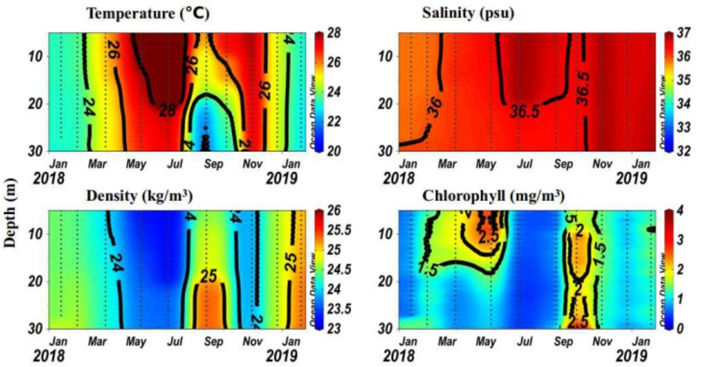

Figure 2. Time series distribution of hydrographical parameters (Temperature, Chlorophyll, Salinity and Density) along the coastal waters (30m) off Okha during Dec, 2017 to Jan, 2019.

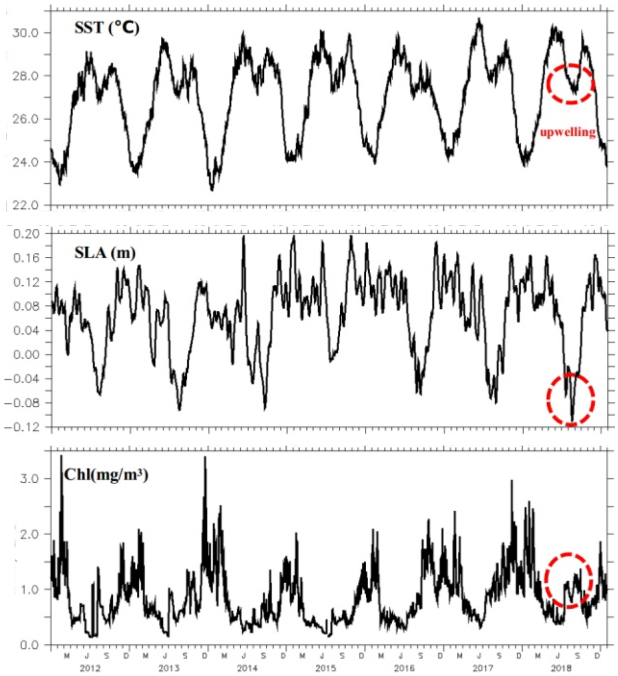

Figure 3. SST (°C), SLA (m) and Chl (mg/m3) along the northwest region (box averaged 68-70°E and 20-23°N) during 2012 to 2018 showing short term and recurring upwelling process. Red box confirms upwelling signals during 2018

Upwelling in the NEAS is observed to be recurring, but short-term during August-September. SST along NEAS is warmer (25.5°C) when compared to SEAS (24°C). It is apparent that the change in wind and current pattern is the major causative factor for the development of upwelling. In the northwest coast of India, coastal orientation also favours the change of wind pattern leading to coastal upwelling. Rise and fall observed in the wind stress and southward directing coastal current during southwest monsoon triggers uplift of isotherms along the northwest. Remote forcing also plays a major role in the upwelling/downwelling processes in this region. The upwelling mode of Kelvin wave formed due to strong tangential winds along the SriLanka coast propagates northward along the west coast which is initiated during May-June and propagates upto September and downwelling mode of Kelvin wave propagating from equatorial region through Bay of Bengal reaches west coast by October coinciding with the withdrawal of southwest monsoon. This upwelling/downwelling mode of Kelvin wave and southwest monsoon winds plays a major role in the late onset and cessation of upwelling along the NEAS compared to SEAS. Coastal region of NEAS remains productive throughout the year due to the combined effect of coastal upwelling during summer monsoon and winter cooling during winter monsoon. High chlorophyll along the NEAS occurs with a lag after the peak winter cooling and upwelling and this is due to sudden rise and fall in wind stress. There was a delay of about two month between the onset of upwelling in south and north in EAS as indicated by drop in SST. However, the cessation of upwelling occurred in a short span of time, as it appeared to commence during early September in SEAS compared to end of September or early October along the NEAS. Hence, it can concluded from this work and other previous studies related to upwelling that the entire EAS shows signals of coastal upwelling but with different forcing mechanisms and is not restricted to SEAS. But off Mumbai, it was weak and restricted to subsurface due to bathymetry/shelf break changes and also due to strong cross-shore winds which are perpendicular to the coast. This work brings a better understanding to the upwelling process along the EAS and to give a light to the description of the other ecosystem response/processes in the northwest coast of India.

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Research Highlights

Mesoscale eddies and the spring *Noctiluca* bloom connection in North Eastern Arabian Sea


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Smitha B R, Sanjeevan V N, Padmakumar K B, Midhun Shah Hussain, Salini T C and J.K. Lix. (2021). Role of mesoscale eddies in the sustenance of high biological productivity in North Eastern Arabian Sea during the winter-spring transition period. Science of the Total Environment, https: //doi.org/10.1016/j.scitotenv.2021.151173.

The upper layer oceans in general support high biological production as surface nutrient availability is maintained through dynamical processes that churn the water column, such as upwelling, convective mixing, horizontal advection, eddies/meanders etc. (Dugdale and Goering, 1967). Concurrent with the seasonal processes of strong convective mixing during winter, pockets of high production (Figure 1) and bloom formation appear in the oceanic regions of NEAS on a regular basis during winter-spring season. These pockets are most often associated with mesoscale eddies which occur persistently as evident from the Sea Surface Height Anomalies (SSHA) and Okubo-Weiss parameterization (Figure 2). Life span of these eddies varies from 2-6 months. The core is often dominant of eddy kinetic energy (EKE) over the available potential energy (APE). These disturbances are formed due to the baroclinic instabilities as evident in the larger diameter as compared to the Rossby radius.

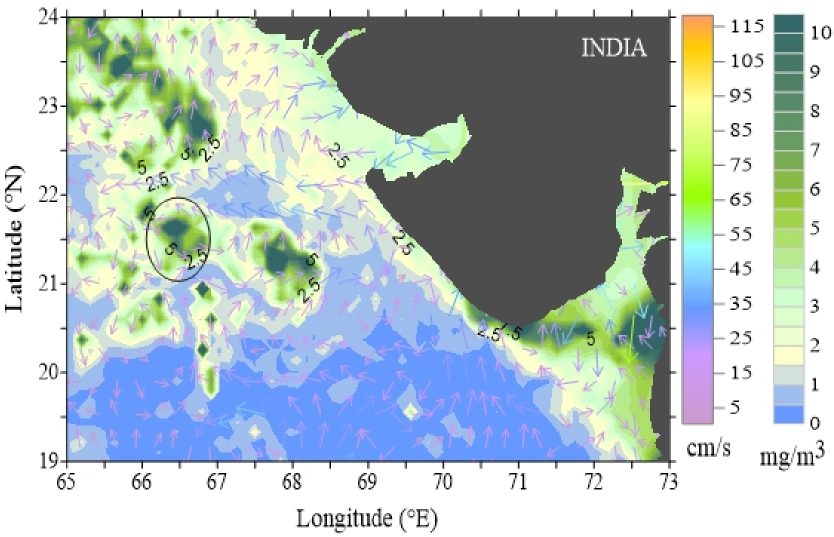

Figure 1. Chl- a (mg /m^3) imagery from MODIS AQUA showing Cold core eddy (circled area) overlaid with Jason II Altimetry derived geostrophic currents (cm/s) for 9th March 2013.

Active mixing and high nutrient concentration is most often associated with diatom dominance. However, when mixing slackens, surface waters become warmer (>27°C) and there is Silicate limitation, the dinoflagellate green *Noctiluca* dominate the biological community through mixotrophy supported by regenerated production. While Cold Core Eddies (CCEs) with uniform APE are observed as the sites of mixed algal blooms dominated by diatoms, CCEs with non-uniform APE promote intense

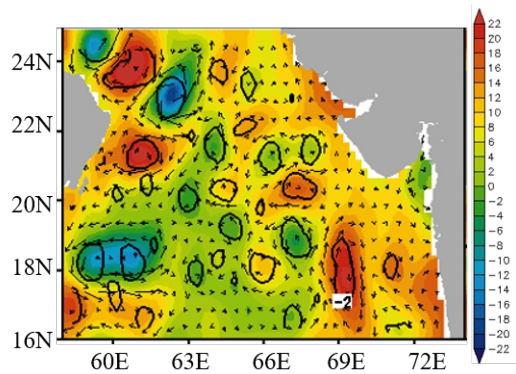

Figure 2. SSHA and Okubo-Weiss closed contour for the month of March. The NEAS is observed with number of cyclonic (cold core) and anticyclonic (warm core) eddies resulting in the formation of retention areas and high export flux in the region.

blooms of the green *Noctiluca scintillans* on its calm fronts (due to weak currents). With the onset of spring inter monsoon (SIM) season (mid -February), the mixed layer associated with warm core eddies (WCEs) begin to shallow (from ~85m to ~50m), become less turbulent and promote the proliferation and blooming of *N. scintillans* utilising the nutrients conserved inside the eddy (Figure 3). These blooms are sustained till April through regenerated production. From April the oligotrophic surface waters of NEAS are transported southward by the west India coastal current (WICC) where the SST is higher, and the surface waters contain more iron. Under these conditions, the cyanobacteria *Trichodesmium erythraeum* undertakes diazotrophy (Capone et al., 1998; Gomes et al., 2008a, b) and form extensive blooms as reported in the southern parts during April- May. Winter cooling and convective mixing in NEAS are reportedly showing an increasing trend from 2003 onwards, making the NEAS more productive. On the other hand, warming causes nutrient limitation due to strengthening in stratification which result in nutrient limitation and a consequent shift towards an assemblage dominated by small phytoplankton (Li et al., 2009; Moran et al., 2010) and/or the dominance of mixotrophic forms such as the green Noctiluca (Gomes et al., 2014).

Major data sets used for the study are in-situ data collected using CTD, ADCP, AWS and Chlorophyll/phytoplankton measurements onboard *FORV Sagar Sampada*. Wind fields from ASCAT Scatterometer, Surface net heat flux from ECMWF ORA-S3, Chl-a and SST for the identification of the eddy are retrieved from GSFC NASA and processed using SeaDAS. SSHA from Jason II as well as from the merged geophysical products from TOPEX/Poseidon and Jason I altimetry, WOA climatological values of Temperature and Salinity.

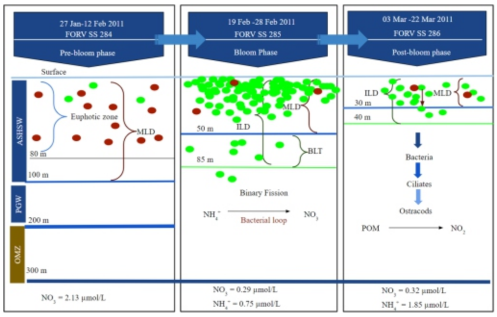

Figure 3. Schematic representation of the process associated with the blooming of *Noctiluca* in the NEAS during winter-spring season. The green circles represent *Noctiluca* cells. Red circles denote diatom cells. The representation is made based on the FORV Sagar Sampada observations during 2011, and the available secondary information.

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First Passive OBS Experiment in the Andaman Sea Reveals Reasons for Trembling Off Nicobar Region

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Aswini, K.K., Dewangan, P., Kamesh Raju, K.A., Yatheesh, V., Singha, P ., Arya, L., Reddy, T.R., 2020. Sub-surface magma movement inferred from low-frequency seismic events in the off-Nicobar region, Andaman Sea. Scientific Reports, 10:21219, . Supplementary information available at https ://doi.org/10.1038/s4159 8-020-78216 -2.

Frequent occurrence of major earthquake swarms in the Off Nicobar region have been noticed, these have become more prominent particularly after the 26 December 2004 megathrust event. The observed earthquake swarms are episodic, and preferentially occur in the region where the Andaman Nicobar Fault, West Andaman Fault, and the strands of Great Sumatra Fault meet (Figures 1), suggesting a strong influence of the fault systems. It was presumed that reactivation of these faults is one of the reasons for the occurrence of earthquake swarms.

What makes these faults to get agitated / excited / re-activated at frequent intervals? This question was addressed in a recent study based on passive Ocean Bottom Seismometer experiment (Aswini et al., 2020). Hints of subsurface magma movement are seen in the form of Very Long Period Earthquake Events (VLPEs) sensed by the OBS network. It is suggested that the subsurface magma movement initiated an upward surge of magma pulses which, in turn, re-activated the sliver fault system in the Off Nicobar region, resulting in the incidence of the earthquake swarms. This phenomenon is greatly influenced by the active sub-marine arc volcanism prevalent in the Andaman Sea region

All this action is taking place in an invisible submarine environment underneath a thick layer (1 to 3 kms) of water column.

Passive Ocean Bottom Seismometer experiment:

The OBS receivers sit on the ocean floor (these are rated to operate at depths up to 6000 m) and continuously sense earth motions with the help of a Geophone in an autonomous mode. Besides the Geophone they also have a hydrophone sensor, battery pack and the associated electronics, all housed in a pressure packed titanium containers.

The OBS units are dropped from the research ship at predetermined locations; they sink with the weight of the attached anchor that is coupled to the instrument unit with an acoustic link. Battery powered, they can remain on the ocean floor up to six months or more depending on the design. When it is time to pick, the scientists go to the location again, and activate the acoustic link to release the instrument package from the anchor weight. After getting released from the anchor weight, the instrument unit floats to the sea surface and will be retrieved by the research vessel.

The recorded data are downloaded after the retrieval. This passive (called passive, as it uses naturally occurring Earthquakes as source of seismic waves) OBS experiment was conducted for the first time in the Indian waters (with the EEZ of India) by an Indian group of researchers

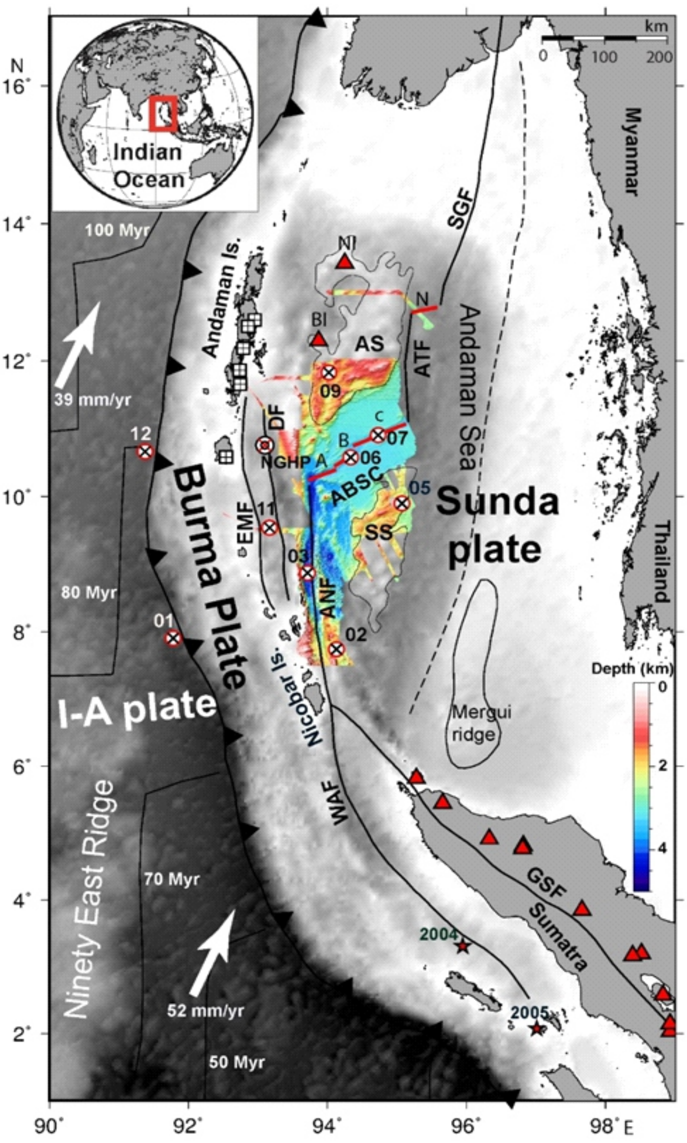

Figure 1. General tectonic framework of the Andaman Sea encompassing the Andaman Backarc Basin presented on a gray shaded bathymetric image with age contours and the plate motion directions (white arrows) Multibeam bathymetry coverage in the bacarc basin is depicted. Black squares with cross denote broad band seismic stations from the ISLANDS network red circle with black cross represents the Ocean Bottom Seismometer deployments. Black double circle with red cross represents NGHP deep drilling site. Great Sumatra Fault (GSF), West Andaman Fault (WAF), Eastern Margin Fault (EMF), Diligent Fault (DF), Andaman-Nicobar Fault (ANF), Andaman Backarc Spreading Centre (ABSC), Andaman Transform Fault (ATF), Sagaing Fault (SGF), Sewell Seamount (SS) and Alcock Seamount (AS) are marked. The dashed black lines represent the ocean-continent boundary. Red triangles represent volcanoes. Red star represents major earthquake events of 2004 and 2005. (See Kamesh Raju et al., 2020 for full caption with references).

belonging to the CSIR-NIO. Only few developed countries have the capability to make the OBS units that can operate up to depths of 6000 m. For the Andaman experiment OBS units were hired from a German company K.U.M. located at Kiel, Germany.

The Study:

Earthquake studies are one of the important tools for studying subsurface crustal activity. To understand the submarine volcanic arc and subduction-related processes in the Andaman Sea, CSIR-NIO deployed Ocean Bottom Seismometers (OBS) for four months (during Dec 2013-May 2014). This experiment was carried out using CSIR-NIO's research ship, RV Sindhu Sankalp and hired OBS units.

The deployed OBS Network sensed an earthquake event of 6.5 MW magnitude on 21st March 2014 in the off Nicobar region followed by an earthquake swarm that lasted for about 48 hours (two days). Analysis of this two-day earthquake data revealed for the first time, the occurrence of low-frequency (very long-period) earthquakes (VLPEs). These are typically identified based on the earthquake waveform characteristics (p-wave and s-wave). In our data we discovered an exceptionally long period signal having a maximum period of 600 s (10 minutes). This is very rare and also suggests that the origin of the waves are deep seated and located at depth in the subsurface (about 30 km below the seafloor). At this subsurface depth, we expect magma (molten mantle) and we attribute the observed VLPEs as indicators of magma movement. Most often VLPEs are associated with deep magma movement as also observed at other regions.

The volcanism associated with the volcanic arc and the magma movement discovered in the present study are interlinked. The study also opens up possibility of monitoring volcanism and volcanic eruptions. By deploying OBS units and also by making use of global seismographic network (GSN) data, it is possible to monitor volcanoes with remote observations.

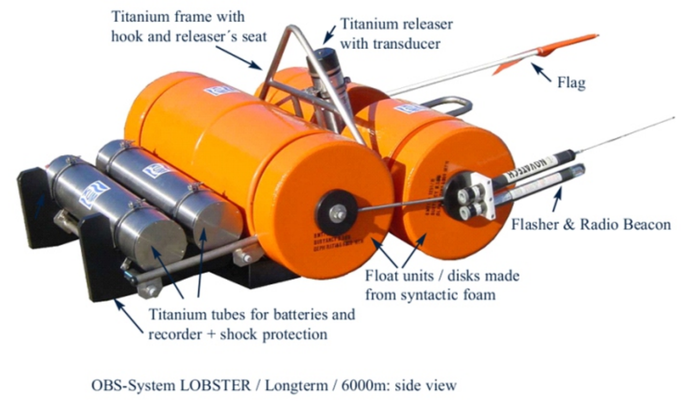

Figure 2. Ocean Bottom Seismometer – image courtesy K. U. M, Germany

Reference

Kamesh Raju, K.A., Aswini, K.K. and Yatheesh, V., 2020. Tectonics of the Andaman Backarc Basin – Present Understanding and Some Outstanding Questions. In: J. S. Ray and M. Radhakrishna (eds.), The Andaman Islands and Adjoining Offshore: Geology, Tectonics and Palaeoclimate, Society of Earth Scientists Series, Springer Nature Switzerland AG 2020. https://doi.org/10.1007/978-3-030-39843-9_12

OSI Webinar Series (October-December 2021)

October 2021

Topic: The significance of coastal processes in determining erosion control measures along India's northeast coast
Speaker: Dr. Subbareddy Bonthu, Scientist-'C', National Centre for Sustainable Coastal Management, Chennai

Date & Time: 25 October, 2021; 04:00 PM – 05:00 PM IST

YouTube Link: https://youtu.be/hp aen5dEMM

About the Talk:
The talk provided the fundamentals of coastal processes and their role in the identification of erosion hot spots and causes along the West Bengal coast. The second section discusses conceptually appropriate shore protection measures at eroding hotspot regions in order to maintain coastal stability with minimal consequences on nearby regions using numerical coastal process models. Finally, it addresses the preparation of shoreline management plan for the implementation of appropriate actions in West Bengal's coastal areas.

November 2021

Topic: Benchmark worst droughts in India (1901-2020)
Speaker: Dr. Vimal Mishra, Associate Professor, IIT Gandhinagar

Date & Time: 23 November, 2021; 04:00 PM – 05:00 PM IST

YouTube Link: youtu.be/Hfbunmg71jk

About the Talk:
During the summer monsoon (June-September) season, drought poses changes for agricultural activities and water availability in India. We develop a framework considering the timing, areal coverage, and severity of droughts that can be used for the assessment as the monsoon season progresses. We estimate the benchmark worst droughts within the monsoon season (June, July, August, and September) using the long-term (1901-2020) gridded rainfall. The benchmark worst droughts were identified considering the extent and severity of drought using the Drought Severity Coverage Index (DSCI). The worst meteorological droughts in June, July, August, and September occurred in 1923, 2002, 1937, and 1907 with a return period of 68, 200, 147, 188 years, respectively. The worst drought in the entire summer monsoon season occurred in 1918, which had a return period of 238 years. The benchmark droughts during June 1923, July 2002, and monsoon 1918 were associated with the warm SST over the equatorial Pacific Ocean.

December 2021

Topic: Understanding Circulation of the Bay of Bengal using Modern Observations and Models
Speaker: Dr. Sourav Sil, Assistant Professor, IIT Bhubaneswar

Date & Time: 16 December, 2021; 04:00 PM – 05:00 PM IST

YouTube Link: https://youtu.be/a9Ib1Wi_cOE

About the Talk:
This talk introduced the usefulness and importance of modern observations, and numerical models to study and investigate the multi-scale oceanic processes in the Bay of Bengal region. ARGOS observational platform has been providing valuable high-resolution observations for monitoring the sub-surface profiles since 2003. The Indian Coastal Radar Network (ICORN) installed and operated by NIOT, Ministry of Earth Sciences, Government of India provides high-resolution and high-frequency coastal surface currents since late 2009. OMNI buoys of NIOT and recent scatterometer ScatSat-I (ISRO) winds are useful for studying the oceanic processes in the basin.

Articles/research highlights of general interest to the oceanographic community are invited for the next issue of the Ocean Digest. Contributions may be emailed to osioceandigest@gmail.com

Cover image: *Colour-coded 3D bathymetric map depicting the seafloor morphology of two seamounts located off Nicobar Island in the Andaman Sea, discovered by CSIR - National Institute of Oceanography, Goa. The northern one is with a well-developed crater at the summit. The white lines with annotations represent bathymetric contours of the respective seafloor depths. Image courtesy: Dr. Yatheesh Vadakkeyakath, Principal Scientist, CSIR-National Institute of Oceanography, Dona Paula, Goa*