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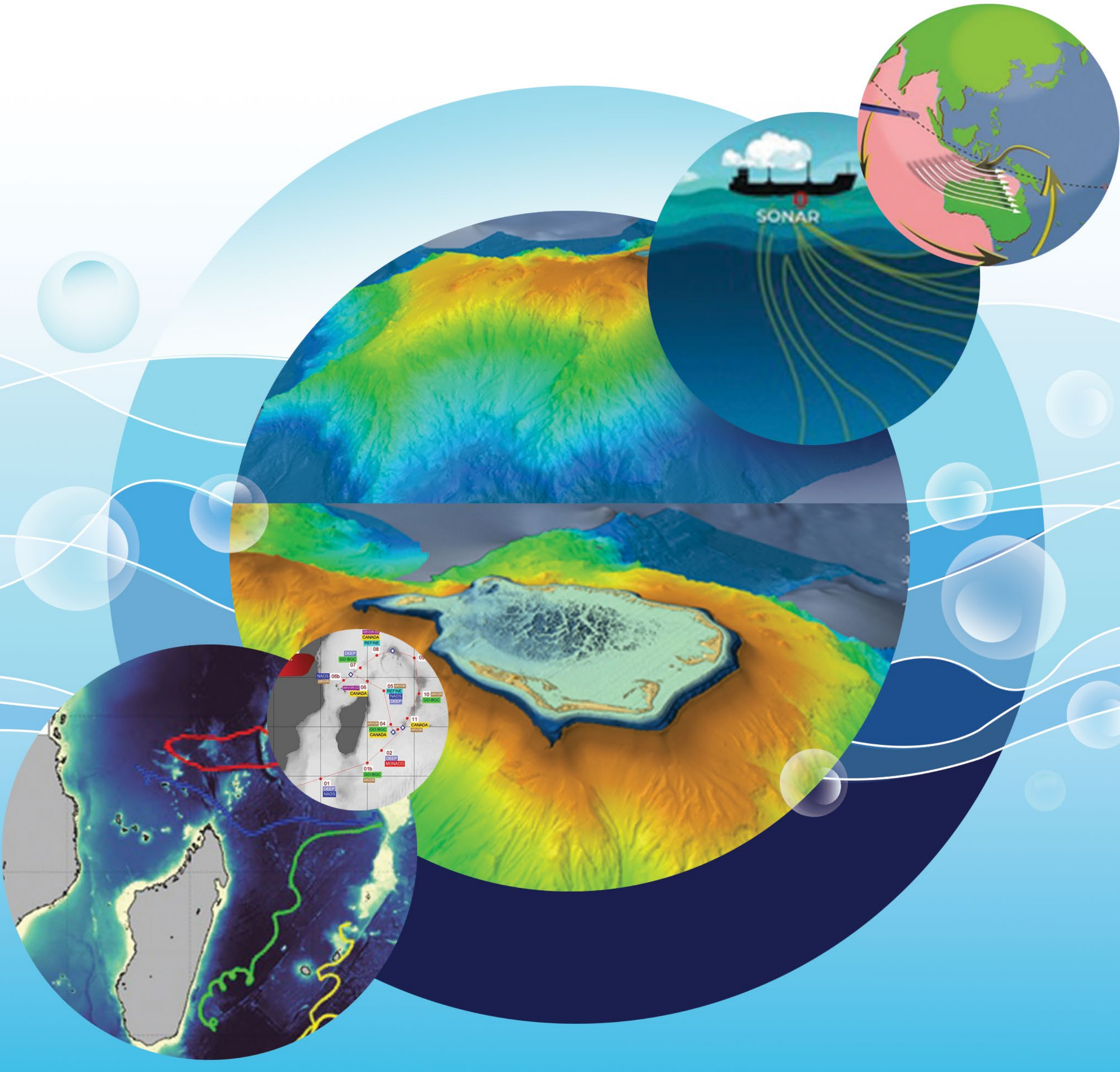
The Indian Ocean Bubble 2



Editorial

Dear IIOE-2 member,

Greetings from the Indian Ocean region!

Buoyed by the positive feedback and encouragement from all the quarters, we are presenting herewith to you a fresh issue of the IO-Bubble.

In this issue, we cover India Ocean research topics wide ranging from ecosystem and biodiversity to ocean exploration and even planetary axis wobble! We also report two major events one each national and international.

The national event is the biennial conference by the Ocean Society of India, hosted by INCOIS (home of IIOE-2 PO). The international event is the formal inaugural of the UN Ocean Decade Collaborative Centre for the Indian Ocean Region (DCC-IOR), also hosted at INCOIS. You would be excited to know that the IIOE-2 Early Career Scientists Network (ECSN) has also bagged Ocean Decade endorsement of their initiative called DECCaD-IO which stands for Devising Early-Career Capacity Development in the Indian Ocean region. First of the DECCaD-IO event has been hosted by ITCOocean in September 2023. In future, more regional initiatives under this are envisaged.

We strongly believe that these initiatives will synergize and flourish during the Ocean Decade under various frameworks, paving way for better Indian Ocean science.

On behalf of the IIOE-2 PO team,
N. Kiran Kumar, Nimit Kumar, and
Aneesh Lotliker

IN THIS ISSUE

Ecosystem and Biodiversity

Unravelling the Mysteries of the Indian Ocean: A Statistical Approach for Generating Gap-free Ecosystem Indices with Uncertainty Quantification

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The Earth's oceans, as captivating and diverse ecosystems, are perpetually evolving and driven by complex biogeochemical cycles. Satellite technology has significantly enhanced our understanding of these dynamic processes[1]. However, missing data in remotely-sensed ocean color observations can make it difficult for scientists to delve deeper into ocean dynamics. This is especially true for the tropical Indian Ocean, where seasonal cloud cover from the southwest summer monsoon results in a high percentage of missing values in chlorophyll data (Figure 1).

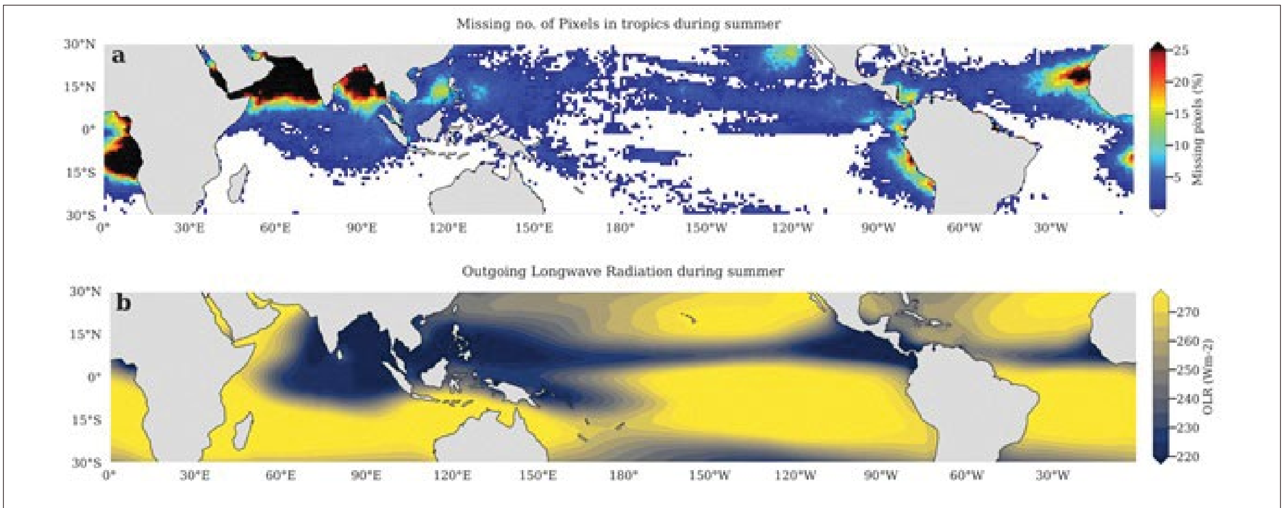

Figure 1: Missing values in ESA chlorophyll and mean OLR in the tropics during boreal summer. (a) Percentage of missing pixels in 8-day composites of ESA OC-CCI chlorophyll data from 1998-2019 over the tropical oceans during boreal summer (June-September). Gap-free pixels are indicated in white. Pixels with more than 25% of missing values are shown in black; (b) Climatological map of OLR (in W/m2) during summer (June-September) for the tropical oceans for the period 1998-2019. Regions in dark blue are associated with weaker convection, and those represented in yellow indicate strong convection.

Fear not, oceanographers. A team of scientists at IITM Pune and IIT Mumbai came up with a novel solution to this problem to fill the missing values in ocean color data. The solution comprises of a two-step gap-filling algorithm that combines optimal linear interpolation with Monte-Carlo methods. It has been developed to generate gap-free ecosystem indices with uncertainty quantification[2]. The algorithm fills in gaps sequentially along the three dimensions of longitude, latitude, and time. However, some gaps remain even after optimal linear interpolation, which is where the Monte-Carlo method comes in, filling in the remaining gaps with plausible values instead of a single value, enabling probabilistic solutions (Figure 2).

To address gaps in the Indian Ocean chlorophyll data, the team utilized the Ocean-Color Climate Change Initiative (OC-CCI) by the European Space Agency (ESA). This initiative merges ocean color observations from various satellite missions, applies quality corrections, and creates a high-quality, long-term chlorophyll dataset spanning over two decades, enabling the production of gap-free datasets of ocean color variables. Before implementing the gap-filling algorithm, the daily chlorophyll time series was processed into 8-day composites and re-gridded from a 4 km x 4 km resolution to a 1° × 1° resolution using conservative binning. Parametric distributions were employed to identify the best-fit probability density function (PDF) of the chlorophyll fields. The Kolmogorov-Smirnov test was used to confirm the best fit. If none of the applied parametric distributions fit the data, the Kernel Density Estimate (KDE) was employed to estimate the PDF. With the PDF identified, the team generated 10,000 instances using Monte-Carlo methods, offering a range of estimates and uncertainty quantification.

The gap-filling algorithm generated multiple gap-free datasets to determine ecosystem indices with uncertainty values, as seen in Figure 3. We validated these datasets using satellite data and available in-situ bio-Argo observations, finding that the Monte-Carlo filling did not alter the spatial and temporal characteristics of phytoplankton biomass. Generating multiple ensembles for filling missing values also allowed for addressing the critical issue of uncertainty quantification associated with missing data[3,4]. This innovative study provides a comprehensive approach for generating high-quality, gap-free datasets of ocean color variables, which can facilitate timely extraction of information on the phenology of the ocean ecosystem, ocean-cyclone interactions, and other biophysical interactions with higher temporal frequency. This dataset can prove beneficial for ecological forecasting applications, which is presently a limitation in many earth system models.

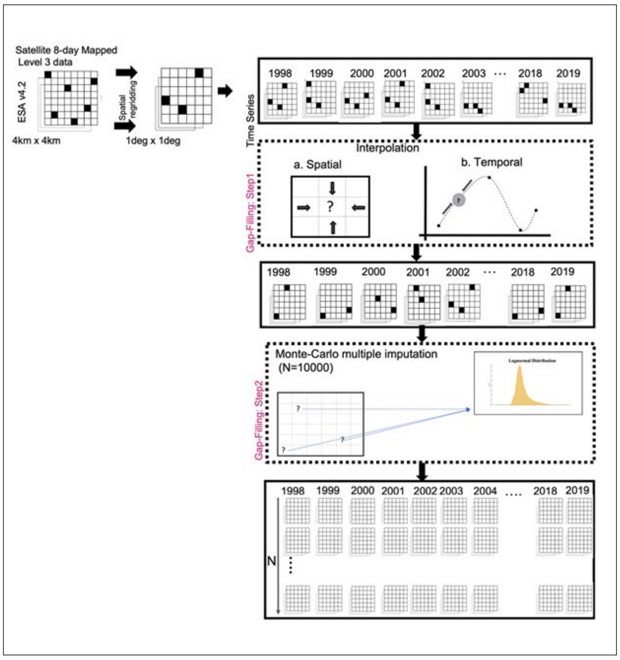

Figure 2: Schematic of the gap-filling algorithm for missing chlorophyll concentrations. The daily chlorophyll fields are available at a spatial scale of 4km x 4km for the period 1998-2019 by ESA OC-CCI. 8-day composites are prepared from the daily fields and re-gridded to 1 degree to reduce gaps. Gaps are filled in two steps: (a) Linear Interpolation; (b) Monte-Carlo Multiple Imputation.

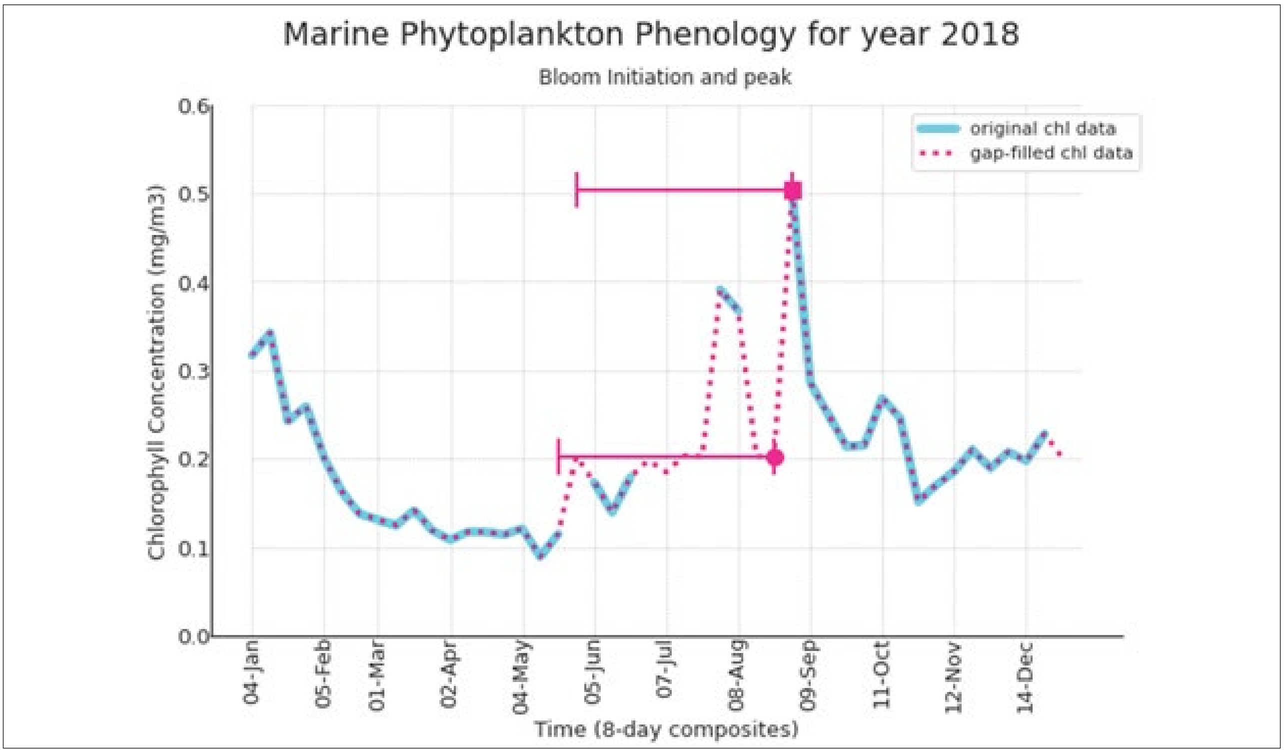

Figure 3: Phenological Indicators (Bloom initiation and bloom peak) estimated for the 8-day composites of chlorophyll for the period 2018 in the Arabian Sea [64°E, 11°N]. The light blue line represents the ESA v4.2 satellite chlorophyll (original data), while the pink line represents the mean of gap-filled chlorophyll (reconstructed data). Solid circles indicate bloom initiation, and solid squares indicate bloom peak in the same color as the data. The horizontal solid pink line represents the range of bloom initiation and peak timings derived from our gap-filled datasets. Bloom onset and peak are computed using the 5% threshold over the yearly median value.

The 22 year chlorophyll dataset generated through this study is available for public access in GitHub repository (https://github.com/aditimodi/Gap_Free_Ocean_Color.git), promoting collaboration and the advancement of oceanographic research. By making this dataset accessible to the wider scientific community, the researchers hope to encourage further exploration and understanding of ocean ecosystems, promoting a better appreciation of the intricate biogeochemical cycles that underpin our planet's health. Overall, this novel gap-filling algorithm and high-quality chlorophyll dataset facilitate the generation of high-quality, gap-free datasets of ocean color variables, promoting a better understanding of ocean ecosystems and advancing our knowledge of the biogeochemical cycles that impact our planet's health.

For more details on the dataset,please contact ***aditi.modi@tropmet.res.in***.

So let's dive in and unlock the mysteries of the Indian Ocean with this exciting new methodology!

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Reflections of a slippery but besieged trans-ecosystem sojourner

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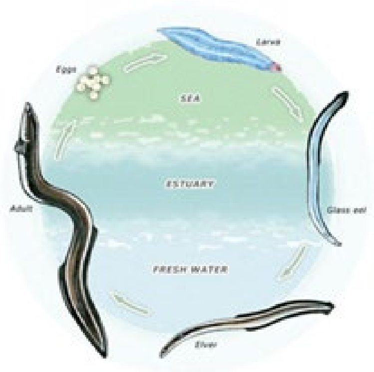
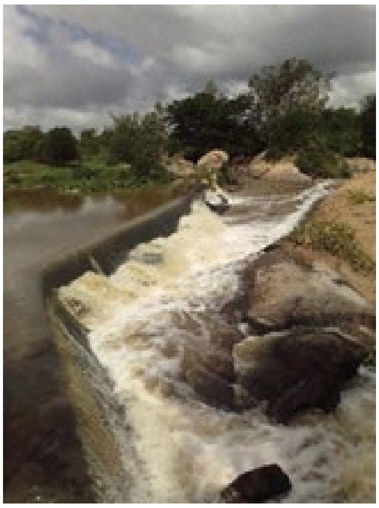
Esteemed pals, comrades and fellow earthly sojourners, greetings in all that is mighty and sacred. My name is Anguilla mossambica, a proud endemic anguillid of the east flowing rivers of the Western Indian Ocean (WIO). My fellow anguillids and I are renown aquatic straddlers, from the ocean deeps, our birthplace, to continental streams and runnels, where we mature. But not anymore, our current livelihood is a veritable nightmare. My present abode is beneath a boulder on the right orographic bank of the Athi river at Yeemwatu, Machakos county, Kenya, several hundred klicks south of headwater springs at Kerarapon, Ngong.

Born at the Mascarene submarine plateau, east of Madagascar in the Indian ocean, I would swear I am two to three decades old. Our Mascarene spawning ground is a marvel of nature, bearing traces of the ancient Gondwana, coupled with more recent seismic actions, rising majestically over 4000 m from the Indian ocean abyssal deeps. This spawning ground is a melting pot of adult anguillids from all over the western Indian ocean, where mating, fertilization and subsequent parentage confounds serious interrogation. What is common knowledge, is, our natal parents from all WIO corners comingle, mate, lay eggs and expire, right here. Eggs hatch into leaflike leptocephali that enter the Indian ocean plankton, drifting with prevailing equatorial currents to wherever. After drifting over several months to years, albeit with no feeding excepting our dwindling yolk reserves, we eventually catch a whiff of the African continental landmass. At this juncture, our pelagic existence is merely threatened by climate change induced weakening of oceanic circulation and oceanic child-killers.



On approaching terra firma, we transform into slender elongated transparent glass eels, in readiness to storming the salt wedge of East flowing river estuaries and deltas. The tangy, ochre colored, cool and sweet waters disgorging at estuaries draw us inexorably, as strobe lights at midnight. To complete our transformation into river dwellers, we acquire pigmentation and are now called elvers, whose powerful sinusoidal undulation, is the secret to fording cataracts, rapids and waterfalls, not forgetting man-made weirs, dams and myriad other barriers, thrown across our riverscape.

Juvenile anguillids at the WIO estuaries and river deltas, consist of an admixture of glass eels and elvers of all four anguillid-kind; A. bengalensis, A. bicolor, A. marmorata and yours faithfully. This make our WIO rivers a key global eel biodiversity hotspot, that is however oft overlooked in the echelons of conservation. These lively eel fledglings, eventually populate downstream, midstream and upstream reaches of the WIO rivers. And the quest to reach and successfully colonize these ultimate river haunts, is the thrust of these rumblings.



After a long and arduous upstream journey, A. mossmbica and their ilk, colonize upstream reaches and transform into the yellow eels, residing in rivers, over several decades. My kith and kin have been known to foray into cold oxygen rich, but nutrient poor headwaters, several thousand klicks from our ocean birthplace. In our upstream hangouts, A. mossambica yellow eels are apex predators, only supplanted by introduced trout and the omnivorous catfish. These lively delightful, clear, fast flowing headwater streams we wax lyrical about, were a joy to behold less than a few eel life-terms ago. We nostalgically recall, wild clear bubbling streams, clothed with luxuriant riparian and upstream jungles, that kept the water-table throbbing. The bubbling streams enjoin cricking entomofauna, croaking anurans, tinkling songbirds, rumbling pachyderms, and roaring flesh-eaters, in a celestial symphony. But currently, such are the just mumblings of the ancients, who now sadly, number a fistful, and the majestic forests, bleed vast quantities of life threatening, human flotsam and jetsam. And now the rivers are defrocked and ashamedly silent.

Trout were introduced into upstream brooks and tributaries in the 1950's with the aim of providing choice prey for a burgeoning sport fishery. At this time, local participation in fishery was nonexistent and hence the initial government promotion of local fishery. This was a hard sell for the predominantly agropastrolist societies, most of whom regarded fish and especially eels, with abhorrence. In fact, their gigantic size, predatory nature, coupled with their scaleless, slippery, snakelike appearance, stirred communities to concoct remarkably similar but mesmerizing taboos and folklore. Such stories linked these enigmatic creatures not only to the rains (mukunga mbura), but also doom and foreboding. Among the Maa, the tale of how a whole community is decimated by the exploits of mukunga, a mythical water giant, keeps youngster quacking. But alas, today a thriving local fishery has ignored all this, and local fisher families relish a bowlful of eel.

The 1960's furor heralding the advent of post-colonial Africa, did not help much. These newly minted rulers, soon turned their appetite to the east flowing rivers and their resources. The hanker to tame, dam, barricade these streams and rivers to irrigate parched landscapes, provide electricity and potable water for the teeming masses, grew exponentially. Meanwhile, highland farms were carved from pristine jungle, in the backdrop of the thrum and rumble of logging juggernauts and power-tools. Sprouting smoke-stacked manufactories, with their chemical enriched effluents, blended with sewage from urban settlements, disgorge into struggling streams. To add insult to injury, runoff from the entrepreneurial farms exporting coffee, tea, flowers and other cash crops, is liberally tinted with pesticides, hormones and other agrochemicals from Armageddon.

As if that is not enough, every landless, jobless, broke villager residing a walking pace from the river, now calls himself a fisher. While we can't begrudge these villager's need to eat or be eaten, some middle ground has to be charted, in the ubuntu spirit of live and let live. As I muse, am contemplating the looming return downstream spawning run, since am now turning into a silver eel. My raging hormones tell me that from Sabaki, I can shoot for the Mascarene and meet this dream girl that keeps me awake on frigid nights. Nonetheless, am reliably informed that the multi-billion Thwake grand multipurpose dam in Kitui, is almost complete, and I have little chance of seeing Sabaki estuary, once more. I bid you all adieu and will my epitaph to read 'I bestrode the WIO'. I remain A. mossambica, in the year of our maker, 2023.

Planetary Matters

Madden-Julian Oscillation induced Indo-Pacific Seesaw and its influence on the polar motion of the Earth

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When the wind blows over the ocean, it can either disturb the entire water column uniformly (barotropic) or the upper layers of the water in a different way compared to the rest of it (baroclinic). The spatial extent and the periodicity of the wind determine how the vertical extent of the ocean will get disturbed. Theoretical investigations have shown that at intraseasonal timescales, winds with spatial scales greater than 100 km can impart energy that can disturb the entire water column up to the ocean bottom, triggering barotropic responses (Willebrand et al., 1980). These responses cause changes in oceanic mass. However, in the case of wind with a lesser spatial extent, the intraseasonal response is baroclinic, and the energy imparted is trapped in the top layer of the ocean.

At intraseasonal timescale, though large-scale wind-driven barotropic variabilities were observed in the extratropics (Fu et al., 2003), they were believed to be insignificant in the tropics in spite of the existence of large-scale wind anomalies like Madden Julian Oscillation (MJO, Madden and Julian, 1971 & 1972), El Nino Southern Oscillation, Indian Ocean Dipole, Monsoon, etc. One of the reasons for such belief could be the lack of observations from the tropics that could reveal such barotropic variabilities. One of the ways to observe such variability is the measurement of ocean bottom pressure, which is indicative of the changes in the entire water column (or oceanic mass). Since the occurrence of the devastating tsunami in the Indian Ocean in 2004, the Ministry of Earth Sciences, India, has deployed several such sensors to measure the changes in the bottom pressure, which would indicate the tsunami waves passing over that in the open ocean.

The analysis of bottom pressure data by Rohith et al. (2019) revealed evidence for a significant intraseasonal (30-80 days) barotropic sea level (BSL) variability in the tropical Indian Ocean (TIO) during boreal winters (December to April). The data from the bottom pressure recorders and numerical models were used to investigate the origin of such variabilities and their dynamics. The data showed that the BSL in the TIO rises and falls by as much as 4-6 cm every 30-80 days. This variability in the BSL accounts for ~ 30-60% of the total intraseasonal sea level variability in the TIO; hence, it cannot be neglected. Further, they showed that the variability in BSL at intraseasonal frequency is triggered by the winds associated wit h boreal winter MJO, which are stronger in the gap region between the Indonesian Islands and Australia (the Maritime Continent). They found that the MJO winds over the Maritime Continent drove out several types of waves at varying speeds. One among them is the Rossby Wave that quickly spreads over the entire Indian Ocean (north of 30°S), inducing basin-wide oscillation in the TIO at intraseasonal frequency. Since such oscillations necessitated the rise and fall of the sea level in TIO, the water from the adjacent Pacific was drawn into the Indian Ocean during the rising sea level and driven out during the falling sea level, thus setting a seesaw of oceanic water between the Indian and Pacific Oceans at intraseasonal frequency (Figure 1). Interestingly, the BSL in the Pacific Ocean rises and falls by ~ 2–3 cm, which is about half of the variability observed in the TIO (~ 4-6 cm) and accounts for ~ 15 % of the total intraseasonal sea level variability in the tropical Pacific Ocean.

It is intriguing that the boreal winter MJO wind over the Maritime Continent (dotted green box in Figure 2), which covers only 4% of the surface of the Earth, is causing such synchronous large-scale BSL fluctuations in the Indo-Pacific basin, whose spatial scales encompass more than 65% of the Earth's surface. The large-scale MJO winds generate sufficient vorticity to disrupt the whole water column in the Maritime Continent, thus commencing the barotropic response of the ocean. A part of this barotropic response propagates westward in the form of Rossby waves and invades the entire TIO in a few days. The other part traverses the Indonesian throughflow (ITF) as coastal barotropic waves. Once this wave reaches the western equatorial Pacific, the barotropic signal is transmitted across the Pacific through a combination of equatorial Kelvin waves, poleward propagating coastal waves, and westward propagating Rossby waves (Figure 2). These fast-moving barotropic waves originating from the Maritime Continent propagate throughout the Indo-Pacific basin in ~ 6 to 7 days.

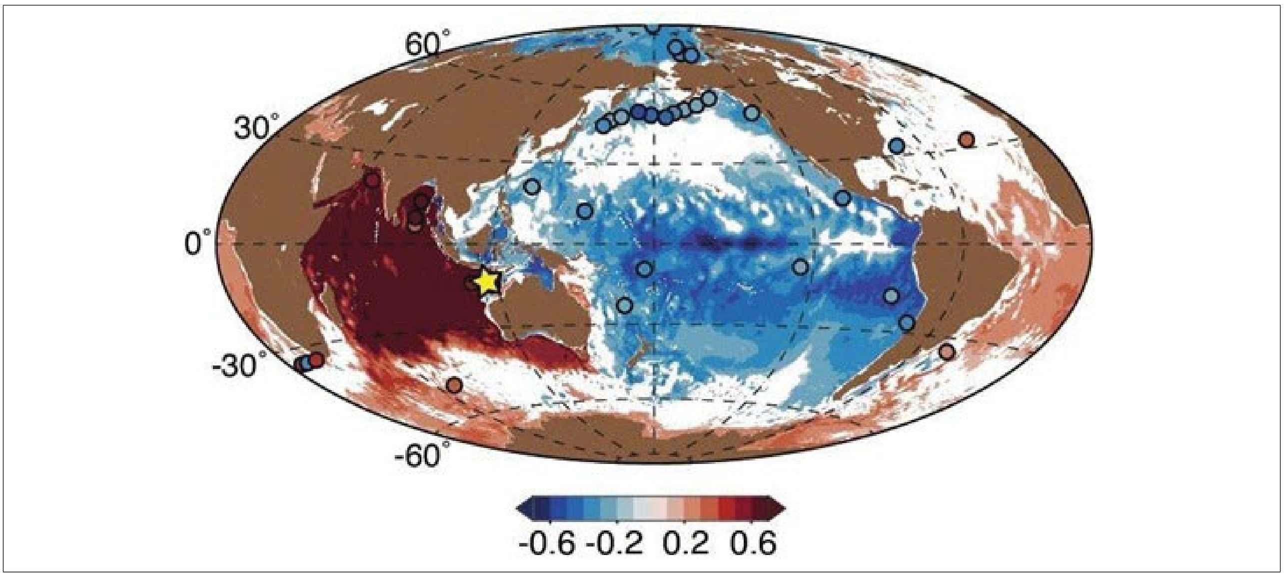

Figure 1: Seesaw in the Indo-pacific Oceanic mass. The plot of correlation (>90% significance) of intraseasonal BSL over the Maritime Continent at 117.94°E, 15.02°S (yellow star) with respect to the intraseasonal BSL at all grid locations. The colored circles overlaid are the same correlation analysis performed on BPRs.threshold over the yearly median value.

The above observations and accompanying dynamics challenge our previous understanding of the variabilities in tropical oceans. For example, due to the slow baroclinic dynamics, the sea level in the eastern Pacific Ocean was believed to take months to respond to MJO winds over the Maritime Continent. In contrast, the fast-moving barotropic waves perturb the eastern Pacific within a span of a week. The seesaw events were strongest during the 2011-12 and 2012-13 boreal winters owing to strong MJO.

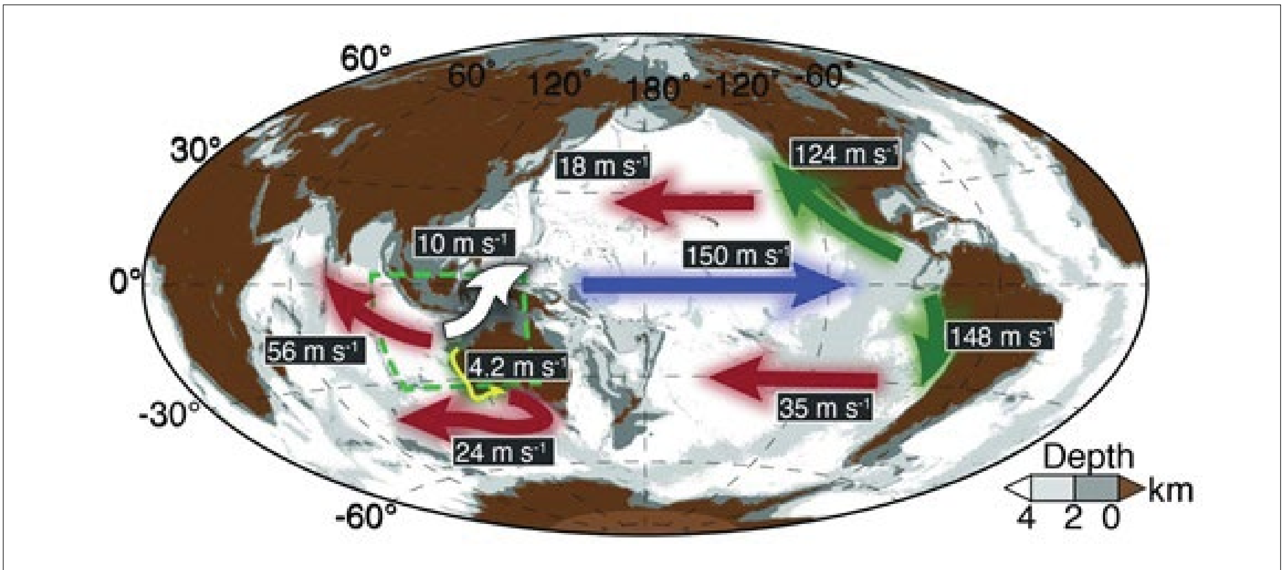

Figure 2: Wave dynamics in the Indo-Pacific Ocean. Schematic diagram of the barotropic waves in the Indo-Pacific basin due to MJO winds over the Maritime Continent. The dotted green box represents the Maritime Continent region. The red arrows represent the Rossby wave; blue represents the equatorial Kelvin wave; green represents coastal Kelvin waves; yellow represents the shelf wave; white represents the wave through Indonesian Throughflow. The number beside each arrow denotes the corresponding phase speed. Gray shades represent bathymetry.

The sensitivity experiments conducted using a numerical model revealed that the ITF is the crucial pathway that facilitates the mass exchange necessary to sustain the seesaw. The ITF transports ~ 8 Sv (Sverdrup, Sv $=10^6$ m^3s^{-1}) of water between the Indian and Pacific oceans during a peak seesaw event, accounting for 60-80% of total ITF transport across all time scales in the range of 9-15 Sv, reported by Creswell et al. (1993) and Gordon et al. (1999). Among the major ITF straits, transport through the narrow Lombok and Ombai straits dominates the ITF transport associated with the seesaw compared to the wider Timor passage. The positive MJO wind stress curl over the Maritime Continent triggers the Indian Ocean to draw water from the Pacific via multiple circulation pathways in the Indonesian Seas. Once the flow reaches the Indian basin, it forms a large-scale anticlockwise barotropic circulation that moves ~ 2 Sv of water on average in the southern Indian Ocean (Figure 3). The eastern arm of this anticlockwise circulation flows along the east coast of Australia. Concurrently, a bifurcation from this flow along Australia's east coast happens around the equatorial region to the eastern coast of the Pacific. This flow forms a large-scale clockwise circulation in the South Pacific Ocean. This circulation pattern then reverses in the Indian and Pacific basins when there is a negative MJO wind stress curl over the Maritime Continent.

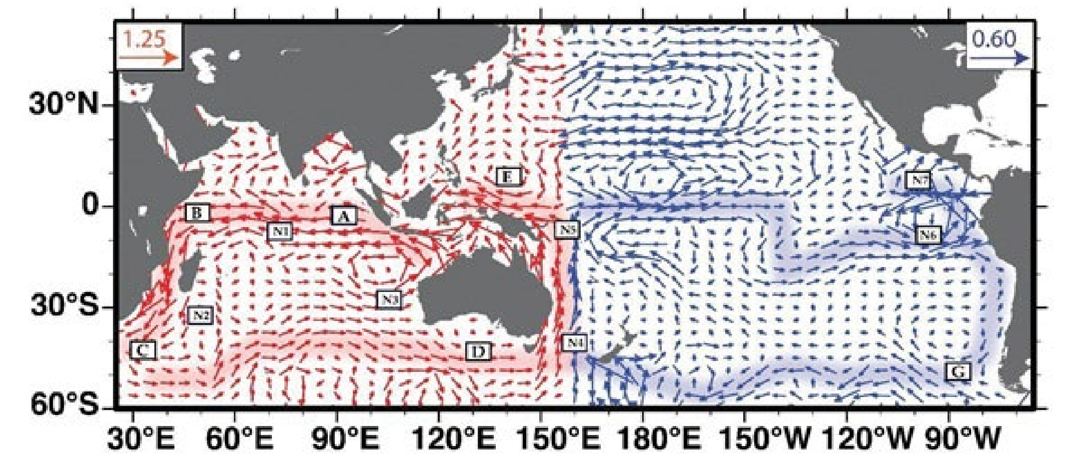

Figure 3: Barotropic circulation (unit: mm/s) computed from the composite average of barotropic components of currents during the positive phase (or positive MJO wind stress curl) of the seesaw index for the period 2009 to 2019 during boreal winters, December-April.

The significance of this barotropic process is multipronged. The barotropic phenomena observed here carry significant energy and will play an important role in the ocean's energy and momentum budget. The large-scale mass redistribution associated with the seesaw and the barotropic currents associated with that significantly influence the ocean angular momentum and, thus, the angular momentum of the Earth. As a consequence, the Earth's wobble of the polar axis (or polar motion) gets affected because the total angular momentum of the solid Earth, atmosphere, and ocean is approximately conserved at intraseasonal timescales. Afroosa et al. (2023) showed that the strong 2012-13 seesaw, associated with the strong MJO, has a detectable signature on the polar motion of the solid Earth about the y-axis (Figure 4). The polar motion of the Earth is generally described in terms of polar motion excitation functions. It has been shown that

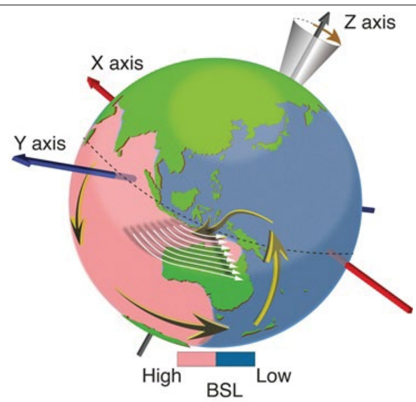

Figure 4: Schematic illustration of a positive cycle of the seesaw in the oceanic mass in the Indo–Pacific basin due to boreal winter MJO winds over the Maritime Continent and its subsequent manifestation in the wobbling of the Earth at intraseasonal timescales. The green colour represents landmasses. The colour bar signifies intraseasonal BSL anomaly. The white colour arrows over the Maritime Continent depict zonal wind patterns due to MJO. The increasing southward arrow length of the wind vector signifies a positive vertical component of the wind stress curl and, consequently, a negative source term for barotropic dynamics. The anticlockwise barotropic circulation around the Australian continent is denoted by the curly yellow arrows. The three axes of the solid Earth are represented by the red (x-axis), blue (y-axis), and black (z-axis) arrows. The wobbling of the z-axis is represented by the brown arrow. The black dashed line represents the Equator. The wind and the circulation reverse direction during the negative cycle of the see-saw.

the polar motion oceanic excitation is comparable in magnitude but out of phase with the polar motion excitation caused by the atmosphere during 2012-13. That means the ocean stabilizes the polar motion changes induced by the atmosphere. The mass redistribution occurring in the Southern Indian Ocean was found to be the dominant contributor to oceanic contribution to the polar motion changes about the y-axis during the 2012-13 boreal winter. Since the MJOs are intensifying and getting erratic with each passing year (Arnold et al., 2015, Haertel, 2020), more such instances of strong seesaw events in the Indo-Pacific basin and their influence on the polar motion of Earth cannot be ruled out in the future.

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CO_2 fluxes in the Indian Ocean: A comparison of hindcast and atmospheric inversion models with Observation-based surface CO_2

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The Indian Ocean is one of the undersampled regions with reference to surface ocean pCO_2 and its fluxes in the global ocean. Hence, we need to depend on the model estimates to examine CO_2 fluxes at the air-sea interface. In order to examine how models are performing with reference to observational climatology, $_{CO2}$ fluxes derived between 1985 and 2018 by 14 hindcast, 2 atmospheric and 12 empirical models were compared as a part of the Regional Carbon Cycle Assessment and Processes-2 (RECCAP2) project.

The simulated mean annual CO_2 sea–air fluxes by different models varied between -0.27 and -0.13 PgC yr-1 for the Indian Ocean (north of 30°S), with a relatively lower sink estimated by empirical models (-0.13±0.04 PgC yr-1) than hindcast (-0.21±0.10 PgC yr-1) and atmospheric inversion models (-0.27±0.16 PgC yr-1) (Fig. 1). Both hindcast and atmospheric inversion models overestimated the sink of CO_2 by 3 times that of climatology (-0.07±0.14 PgC yr-1) whereas empirical models are close to the observations. The observational pattern of CO_2 flux shows that the South Indian Ocean (SIO) is a dominant sink whereas the Arabian Sea is a strong source while the equatorial Indian Ocean (EIO) and the Bay of Bengal (BoB) are weak sources of atmospheric CO_2. All models simulated similar patterns of spatial variations of the CO_2 fluxes that are in agreement with observations, but the magnitudes of fluxes are different. For instance, the modelled CO_2 fluxes were spread around the climatological values with relative overestimation of the sink in the south of 22°S, whereas, underestimation of the source was noticed by all models in the north of 22°S in the Indian Ocean. In contrast, the regional hindcast models reproduced CO_2 fluxes well in comparison with the climatology. Similarly, the simulated CO_2 fluxes by empirical models are in good agreement with the climatology. In the case of the atmospheric inversions, a higher CO_2 sink to the south of 15°S whereas sources of CO_2 to the north of 15°S than the observational climatology was observed. The CO_2 fluxes by all models are in near perfect agreement with each other for the entire Indian Ocean within the standard deviation of the estimates, however, they are different on the regional subdivisions such as the Arabian Sea, Bay of Bengal, EIO and SIO.

All hindcast models failed to simulate seasonality in pCO_2 levels. For instance, higher pCO_2 levels were observed during July to September in the observations whereas maximum was observed during April to May in the models in the Arabian Sea. Similarly, models showed a few months' lags in the other basins of the Indian Ocean. The difference in pCO_2 levels between mean hindcast models and observations varied between 15 and 50 µatm whereas it was <20 µatm in the case of empirical models and this difference may be caused by weaker mixing in the models in the Indian Ocean. All models captured observed spatial patterns of high pCO_2 levels in the Somalia/Oman upwelling region, and EIO and sink in the SIO and BoB. However, the magnitude of fluxes are either under or over-estimated. All models suggested the strengthening of the sink over the period between 1985 and 2018 by 0.02 PgC yr-1 decade-1.

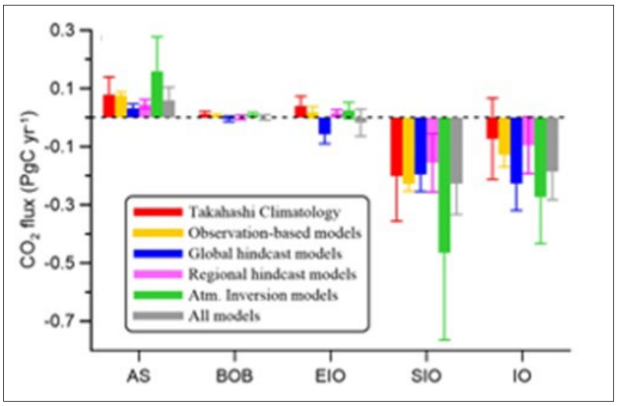

Figure 1: Annual mean uptake from climatology, hindcast, empirical and atmospheric inversion models (PgC yr-1) for the reference year of 2002. The error bars represent the standard deviation. The negative values represent fluxes into the ocean and positive to the atmosphere.

Unless the monsoon mixing is represented well in the models, it will remain difficult to confidently project the future changes in CO_2 fluxes in the Indian Ocean. The lack of seasonal data in most parts of the Indian Ocean is another serious problem to validate the models. Significant improvement in model performance was not noticed since the RECCAP1 comparison between models and observations due to the lack of addition of new data in this region. Therefore, intensive ocean observations of pCO_2 and atmospheric tower observations are required for further improvements of the models.

Full-text reference:

VVSS Sarma, B. Sridevi, N. Metzl, P. K. Patra, Z. Lachkar, Kunal Chakraborty, C. Goyet, M. Levy, M. Mehari, N. Chandra. 2023. Air-Sea fluxes of CO2 in the Indian Ocean between 1985 and 2018: A synthesis based on Observation-based surface CO2, hindcast and atmospheric inversion models. Global Biogeochemical Cycles, doi.org/10.1029/2023GB007694

Ocean Exploration

The Monaco Explorations research voyage in the South-western Indian Ocean

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Monaco Explorations (ME) organized a 2-month expedition in the South-western Indian Ocean, in October and November 2022, to evaluate the state and functioning of the marine ecosystems of the Seychelles and Mauritian waters, with a focus on Saya de Malha Bank, the largest submerged plateau worldwide (Fig. 1). For this purpose, ME chartered the South African S.A. Agulhas II, one of the largest oceanographic vessels in service. The ship left Cape Town (South Africa) on 3 October 2022 and made a first stop in Mauritius, before undertaking a circumnavigation of the region passing through Reunion Island, Aldabra and Mahé in Seychelles, the Saya de Malha Bank, Saint Brandon, before returning to Mauritius where almost the entire scientific team disembarked. The ship then returned to Cape Town, which she reached on 30 November, thus completing a journey of 10,000 nautical miles (18,500 km). The expedition mobilized 150 participants of 20 different nationalities: scientists, young researchers and students, filmmakers and photographers, artists and communicators

Fig. 1 - Outline of the Monaco Explorations Voyage IIOE-2 EP49 I the South-western Indian Ocean

The Expedition programme was developed in liaison with the authorities of Mauritius and Seychelles, based on the responses to a call for proposals and guided by an Advisory Committee of fourteen international experts, established in February 2021.

Authorisations to conduct Marine Scientific Research were granted by the Governments of France, Mauritius, and Seychelles for the work in their EEZ, and by the Designated Authority of the Joint Management Area of the Continental Shelf for the work on the Saya de Malha Bank.

The Indian Ocean Expedition is the first element of the Decade Action submitted by Monaco Explorations in response to the first Call for Decade Actions of the "UN Decade of Ocean Science for Sustainable Development" issued on 15 October 2020. The Monaco Explorations project was endorsed as Decade Action No. 202 in June 2021. The Expedition itself was endorsed as Cruise No. EP49 by the 2nd International Indian Ocean Expedition (IIOE-2) in October 2022.

A diversity of projects

During the cruise, routine underway observations were recorded through the onboard scientific data system. This included ADCP current profiles, sea surface temperature and conductivity, depth (single beam SIMRAD sounders at four frequencies: 18, 38, 120 and 200 kHz) and sub-bottom profile (Kongsberg TOPAS PS 18 profiler).

The Expedition was composed of nine distinct projects:

- Multidisciplinary study of the Saya de Malha Bank ecosystem (the main project). To complement the existing scientific information on the marine environment of the shallow areas of the Saya de Malha Bank and its slopes; and to undertake an inventory of the benthic biodiversity, to assess the species richness and possible endemism, in order to map the sensitive habitats that may require specific conservation measures (PI: Francis Marsac, IRD);
- Microplastics and coral pathogens (MADCAPS). To collect (with a manta net) and characterize plastic debris transported by currents, and assess their role as inert vectors of coral pathogenic micro-organisms (PI: Margot Thibault, University of Reunion);
- Conservation of marine turtles (GECOS). To complement the genetic map of the Indian Ocean turtles and infer their genetic structure, and assess the contaminant and stress level of these populations(PI: Jerôme Bourjea, Ifremer);
- Climate impacts on tropical coral habitats using novel instruments (4SEA). To compare the rate of change in the physical and biological environment between pristine ecosystems and those under human stress, with surface and aerial drones fitted with multibeam sounders and hyperspectral cameras (PI: Sylvain Bonhommeau, Ifremer & Julien Barde, IRD);
- Extension of the BGC-Argo monitoring programme to the area explored by the expedition, which is one of the less observed regions in the global ocean, with the deployment of 29 floats (Fig. 2). It was also the opportunity to test a new generation of robots and contribute to the "Adopt a float" ocean literacy project (PI: Herve Claustre, CNRS)
- Sea surface circulation, using lagrangian floats: 4 SVP buoys and 18 "low-cost" SSD drifters developed by the University of Western Australia (PI: Nick D'Adamo, UWA, & Jean-François Ternon, IRD) (Fig. 3)

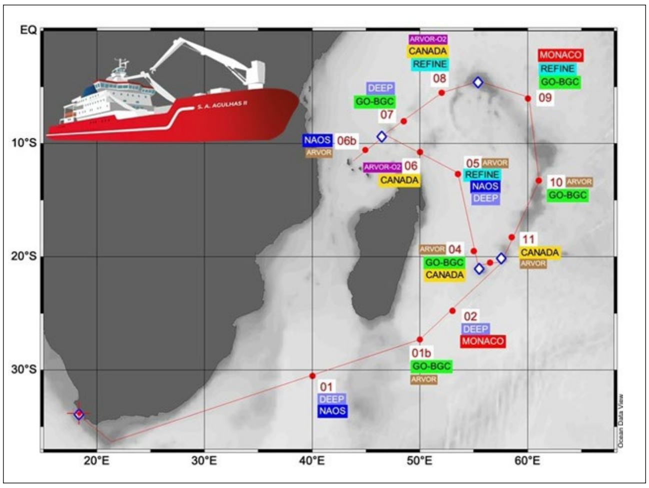


Fig.2 - Deployment of 29 BGC-Argo floats at 12 sites along the cruise track.

- Collection of live coral colonies (58) from Aldabra to contribute to the World Coral Conservatory being set up between several large aquariums in the world (PI: Didier Zoccola, CSM & Olivier Brunel, IO);
- Coral connectivity and associated invertebrate biodiversity. To collect samples of three widespread coral species, complete reef mapping and eDNA sampling at four sites in Aldabra, and at two sites in Saint Brandon (PI: Heather Koldewey, Zoological Society of London);
- Phyto-physiology study of photosynthetic invertebrates to assess their resilience to thermal stress (PI: Ranjeet Bhagooli, University of Mauritius)

The Expedition also included training and outreach components. During the first part of the Expedition

(Reunion to Seychelles), an onboard school was organised, with twenty MSc students and three teachers from Sorbonne University (Paris) and the European International Master of Science in Marine Biological Resources, complemented by ten students and early-career scientists from Seychelles and Mauritius. The students participated in at-sea operations and developed their mini research project. During the second part of the Expedition, the participants from Mauritius and Seychelles benefited from training sessions led by IRD scientists on processing and analysis of CTD data, use of NetCDF files for handling multidimensional scientific data, and international law of the sea and its relations with marine science. In relation to the third theme, a network of researchers working on "national or international seamounts, banks, and submarine structures" was established.

Press tours, animations and visits for officials, school and civil society groups were organized during each stopover, involving about 500 visitors. In addition, eight interactive sessions were set up to discuss the scientific and artistic activities onboard with schools in France (Paris, Reunion), Monaco and Seychelles.

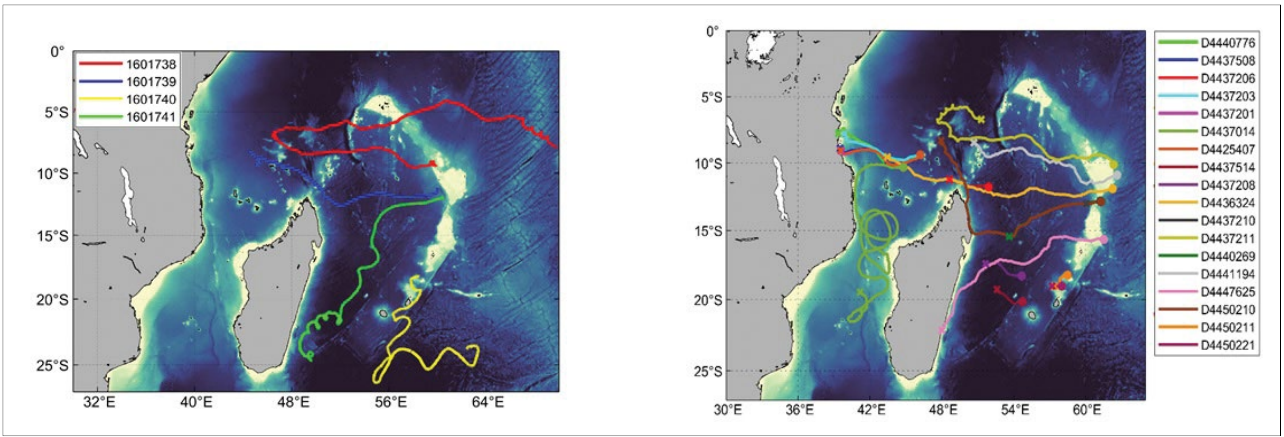


Fig 3– Trajectories of the 4 SVP (top panel) and 18 SSD lagrangian drifters released during the ME voyage

Focus on the Saya de Malha Bank ecosystem study

The Saya de Malha Bank (SMB), an area of 40,000 km^2, was selected to perform a holistic study of its ecosystem with a particular emphasis on the benthic biodiversity in invertebrates, sponges and plants. The SMB forms part of a joint management area of 400,000 km^2 created in 2012 by Mauritius and Seychelles in the framework of the extension of the continental shelf of these two States. This legal status, provided for in the United Nations Convention on the Law of the Sea, gives the two States full sovereignty over the seabed, the subsoil and attached resources. Complements on existing scientific data are required to inform the marine spatial planning that is underway for SMB, and this part of the ME campaign was designed with a "Science for Governance" objective.

The Saya de Malha project took place over 2 weeks (2-17 November 2022). Measurements of the physico-chemical and biological properties of the water column with a 24-bottle rosette and a SeaBird CTDO probe (25 hydrological and plankton sampling stations) and collections of benthic fauna and flora were conducted on the shelf, along its slopes and in the deep sea (Fig. 4). Sampling of benthic biodiversity was carried out through 11 dives by professional divers, 46 trawls and other bottom operations by towed gears (from 70 to 1500 m depth), and 7 dives by a remotely operated vehicle (ROV).

Promising preliminary results

The results are promising, with the collection of 300 to 400 species of molluscs, 250 species of crustaceans and about 100 species of plants. The taxonomic inventory is in progress, but already, on board, three specimens were confirmed new to science (i.e. undescribed species): an Ethusidae crab, a Stenopidae shrimp and a Lamellarinae gastropod. Given the richness of the collection, the potential is high for the discovery of other undescribed species.

The endemism concerning molluscs could reach 20% on the SMB. There, a characteristic of the benthic fauna is the very small size of the organisms that dominate the collections, often molluscs less than 2 mm. Species described in the early 20th century or in the late 1980s have been "re-discovered", such as Conus primus and the clam Tridacna rosewaterii.

The identification of the collected specimens will take several years. However, as early as September 2023, a workshop gathering the best world taxonomic experts will take place in France, and we can expect significant progress towards a better appreciation of the benthic biodiversity of the SMB.

Data processing is underway. The surface current pattern on the SMB indicates the well-established westward propagating South Equatorial Current (SEC). At the eastern slope, the SEC diverges into north-westward and south-westward directions. Current velocities vary from less than 30 cm s-1 over the bank up to 63 cm s-1 along the slopes.

Provisional results in primary productivity indicate an average total chlorophyll-a concentration ranging from 0.02 ± 0.004 mg.m^{-3} in deeper waters to 0.51 ± 0.04 mg.m^{-3} at the maximum fluorescence level of 60–80m. Some spatial differences in the relative abundance of pico-, nano- and micro-plankton are observed, especially between shallow and deeper areas of the SMB. The long-term satellite imagery gives evidence of higher rates of productivity in the western edge of the SMB whereas the eastern edge is oligotrophic.

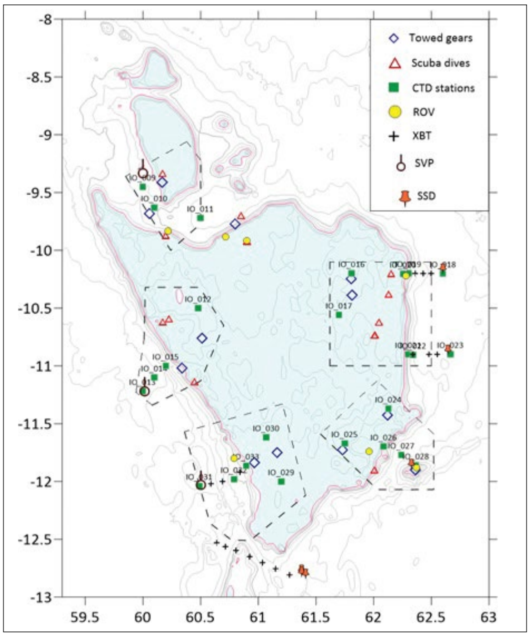


Fig. 4 – Location of the operations by category, conducted on the SMB and neighbour deep sea

Strengthening links between regional scientists

Finally, this campaign was an extraordinary training opportunity for students and young researchers of the region. It strengthened the bond between Seychellois and Mauritian scientists. The expedition contributed to the establishment of a regional team ready to be active on other expeditions, especially those concerning the joint management area between the two States.

The Saab Seaeye Cougar XT ROV used during the cruise (credit Francis Marsac)

S.A Agulhas II (LOA 134 m, width 22 m, draft 7.7 m) © Nicolas Mathys - Zeppelin / Monaco Explorations

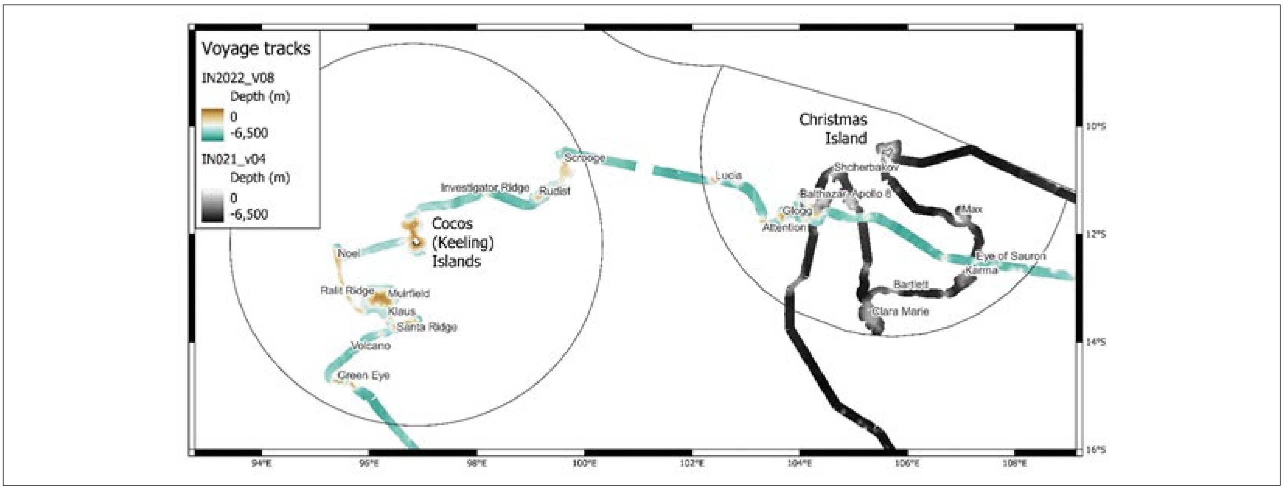
Investigating Australia's Indian Ocean Territories

Tim O'Hara

Museums Victoria, Australia

The eastern Indian Ocean is an under-explored marine environment that contains numerous seamounts, oceanic ridges, fracture zones and deep abyssal plains. The seamounts are the remains of ancient (120-40 mya) volcanos that have now mostly subsided hundreds of meters below sea-level. The few exceptions include Christmas Island, the Cocos (Keeling) atolls, and the Muirfield seamount that peaks at only 17 m below sea level. In 2021, the Australian Government recognised the unique biodiversity around these islands by proclaiming two new large marine parks, which together protect an area of 744,069 km^2.

Australia's ocean research vessel Investigator conducted a 21-day biodiversity survey of the Christmas and Cocos (Keeling) Island Marine Parks (MP) of the eastern Indian Ocean in October 2022. This followed a 2021 voyage (IN2021_V04) that surveyed the central Christmas Island MP. Both surveys were led by Museums Victoria from Melbourne Australia, collaborating with CSIRO (Australia's main research agency), the Australian Museum (Sydney), and the Western Australian Museum (Perth). The voyages were funded through CSIRO's Marine National Facility, Parks Australia and the Department of Environment's BushBlitz program.



S.A Agulhas II (LOA 134 m, width 22 m, draft 7.7 m) © Nicolas Mathys - Zeppelin / Monaco Explorations

The 2022_V08 survey started in the west of the Christmas Is MP and then traversed towards the centre and then south of the Cocos (Keeling) MP. The voyage successfully mapped and surveyed a series of seamounts, including the 'Balthazar' complex, 'Glögg', 'Attention', 'Lucia' in the Christmas Island MP, and 'Scrooge', the 'Rudist' complex, the seamount underlying the Cocos (Keeling) Islands, 'Noel', Raitt Ridge, Muirfield, 'Klaus', and 'Santa Ridge', and the 'Green-eye' and 'Carcharocles' seamounts to the south-west of the Cocos (Keeling) Islands MP. In particular, we mapped the massive Muirfield Seamount in its entirely.

As a consequence of the survey, we have a better understanding of the composition and distribution of seafloor fauna in the proposed Christmas Island and Cocos (Keeling) Island Marine Parks through sampling with 40 beam trawls, 6 epibenthic sleds, and 6 video tows. We have mapped significant areas of seafloor with multibeam sonar. In all our voyage track extended over 5594.7 n mi. We obtained oceanographic data and eDNA water samples from 44 CTD casts to the seafloor. We were the focus of well over 1400 media items and there was also considerable social media output from voyage participants. Finally, we conducted outreach activities with 27 primary and high schools throughout Australia and its territories via a partnership with Australia's BushBlitz program. This included primary and high schools on Cocos (Keeling) Islands via live video feeds from the vessel and social media. Local engagement with Cocos Islanders included two live crosses to the shire council and the Cocos Marine Care group.

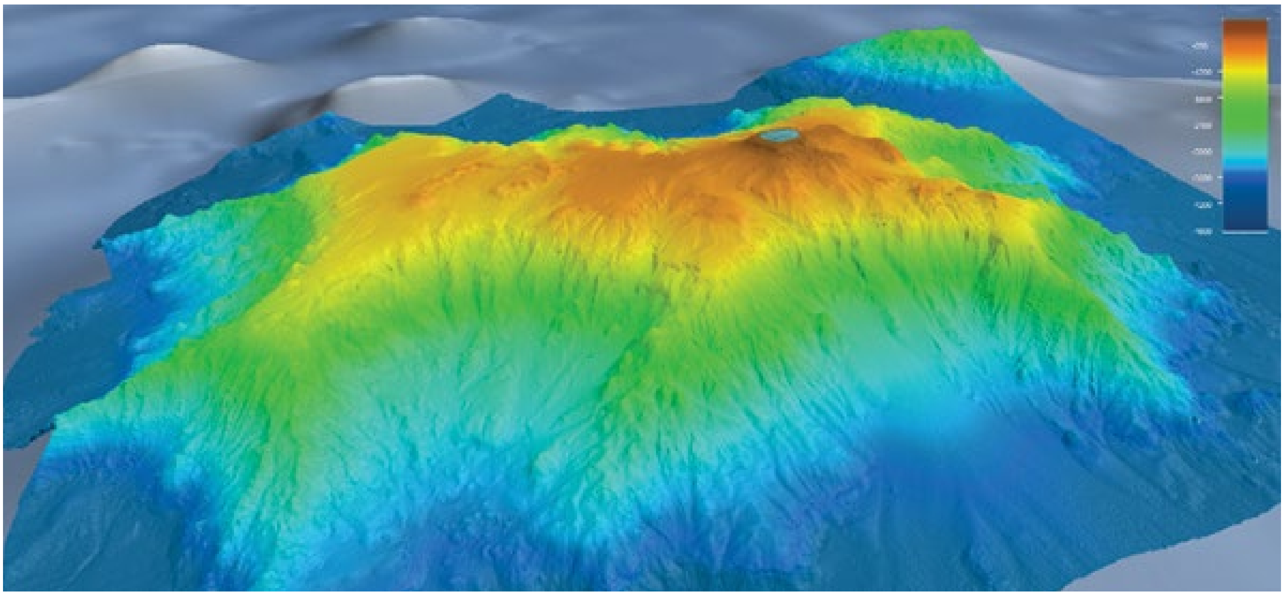


Fig.: 3D bathymetric image of Muirfield Seamount from a NE direction. CSIRO/GSM

The specimens collected by the expedition have been distributed to partner organisations and taxonomic identification of the animals collected has commenced. However, already taxonomists have identified a series of new species of fish, crabs, seastars, brittle stars, black corals and worms. We are collaborating with a CSIRO program (the National Biodiversity DNA Library) to build up a reference database of whole mitochondrial genome sequences from up to 1000 voucher samples. This will greatly assist future eDNA studies by linking DNA sequences found in water or sediment samples to accurate species identifications.

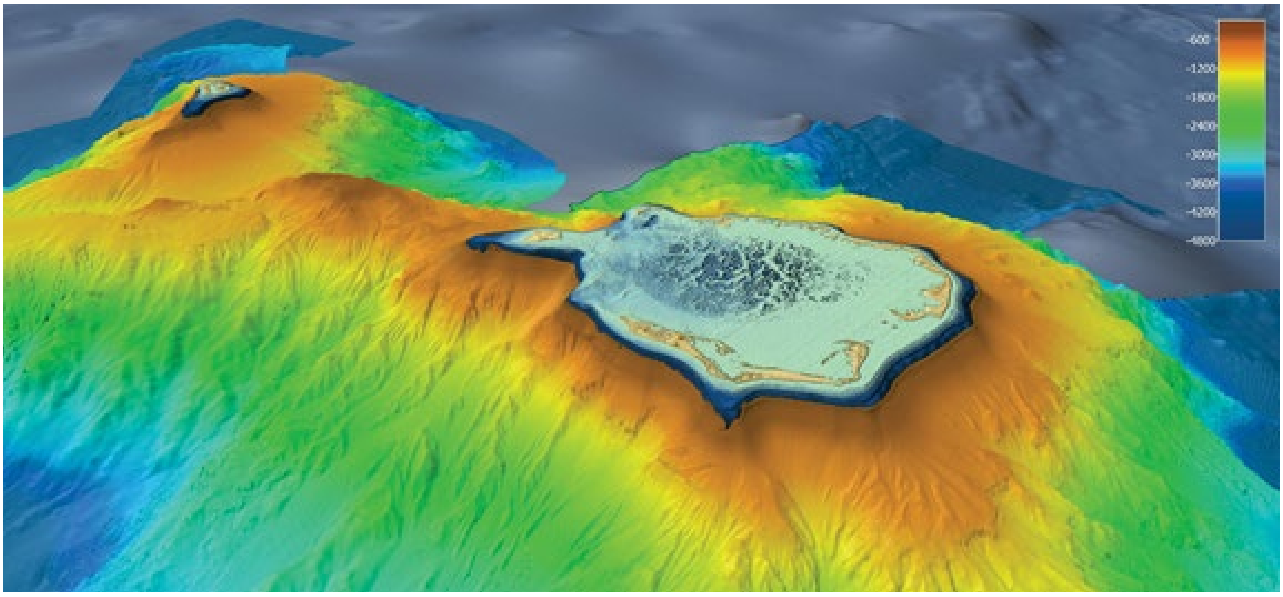


Fig.: 3D bathymetric image of the Cocos (Keeling) islands and seamount from the SE direction. CSIRO/GSM

Sound of the Ocean

Machine Learning approach for effective prediction of Sonic Layer Depth

Pavan Kumar Jonnakuti, Jyothi Agarwal, T.V.S Udaya Bhaskar, E Pattabhi Rama Rao

Indian National Centre for Ocean Information Services, MoES, Govt of India.

Abstract

Sonic Layer Depth (SLD) is a significant acoustical parameter in the upper ocean which indicates the potential to trap the sound energy in the surface duct. The SLD variability plays an important role in naval operations by identifying the shadow zones for submarine safe parking. Traditionally, SLD is estimated using the Sound Velocity Profiles (SVP), which are in-turn derived using temperature and salinity profiles or from direct measurement through veloci meters. As close relationship between the sound speed and the temperature is observed and due to the availability of abundant temperature profiles and limited salinity profiles in the sea, an alternative way to estimate SLD using Artificial Neural Networks (ANN) is proposed. This work is illustrated by using temperature data obtained from Argo floats over the Bay of Bengal region. The ANN estimated SLD was observed to be having a Mean Squared Error (MSE) of 0.20 meters and Correlation Coefficient of 0.70 indicating that the SLD estimated from temperature profiles using ANN is found to be reasonably good. The estimates can be further improved using more and more temperature data from all possible sources.

Keywords: Sonic Layer Depth, Depth Inversion, Regression, ANN

1. Introduction

Water is an excellent conductor of sound, considerably better than air. Sound travels more rapidly and with much less attenuation of energy through water than air. This property of sound in water resulted in rapid development of underwater acoustics and has immense importance in naval operations. Sonic Layer Depth (SLD) is a near surface depth where the first maxima of sound speed occur [1]. SLD plays an important role in refraction of sound waves travelling in the ocean. This helps in estimation of shadow zones for the safe parking of underwater vessels like submarines. Submarines transmit sound waves in the ocean which get reflected back to the surface when hit by underwater objects, thus disclosing their presence of submarines as shown in (Figure 1).

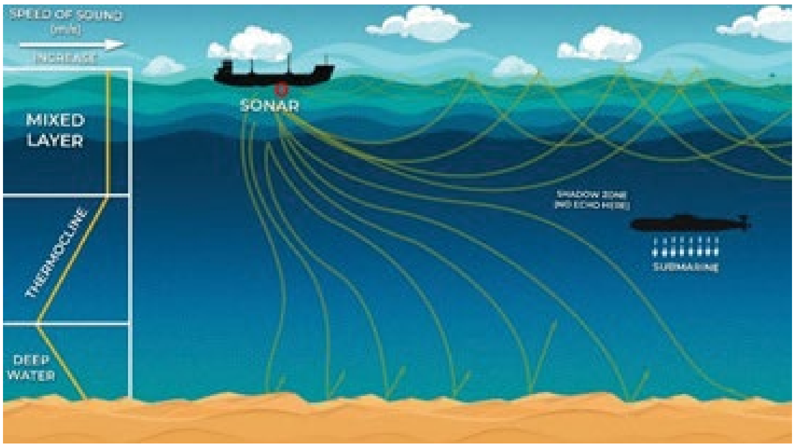


Figure 1. The presence of shadow zone in the ocean

An inversion in temperature profile is a deviation from the normal change of an oceanic property with depth. Temperature Inversion (TI) is an increase in temperature with depth. Figure 2 depicts the relationship between TI and SLD. With the increase in depth, one can see that both Depth vs Temperature curve and Depth vs Sound Velocity curve trace similar path. Although there are other factors like salinity and pressure that influence the sound velocity and the sonic layer, the SLD is more sensitive to temperature.

Temperature is one of the oldest measured parameters of the global ocean. Consequently, the number of data sets pertaining to temperature are more than the salinity. The measurements of the parameters like salinity and temperature

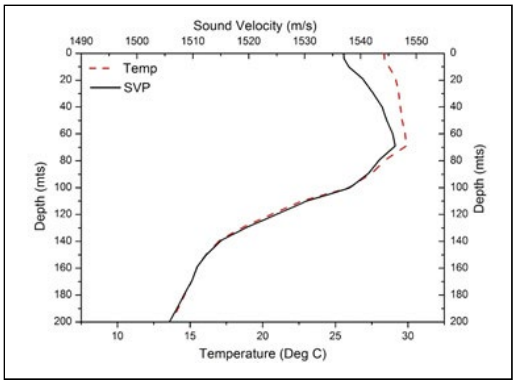


Figure 2. Relationship between sound velocity and temperature

combined are recorded using instruments like CTD which requires the vessels to remain stationary and takes around few hours of time to record whereas the Expendable Bathythermograph (XBT) gives the temperature reading in a short period of time without the constraint for vessels to remain stationary. Considering all these factors, a model was proposed to predict the SLD using ANN by utilizing all the available temperature profiles.

Machine Learning is a branch of Artificial Intelligence which is primarily based on the idea that machines can learn, identify the patterns and make decisions with minimal human intervention. It is categorized into supervised learning and unsupervised learning. Unsupervised learning intends to discover patterns from unlabelled data and they generally include tasks like clustering whereas supervised learning infers to a function from labelled training data i.e. learning a function that maps an input to an output based on input - output pairs. Supervised learning typically includes tasks such as classification and regression. Classification is same as categorizing i.e. it is the task of identifying the category to which an observation belongs whereas Regression is a supervised learning based algorithm which is used to determine the relationship between one dependent variable and one or more independent variables. Regression techniques differ based on the number of independent variables and type of relation between the dependent and independent variables. Based on independent variables, regression is of two types, Linear Regression where one independent variable is used to predict the target variable and Multiple linear regression where two or more independent variables are used to predict the dependent variable. Machine Learning further has a sub branch, Deep Learning which can be used for a variety of complex tasks like Artificial Neural Networks (ANN) for classification and regression. Artificial Neural Network (ANN) is popularly defined as information processing paradigm, which is inspired from the biological nervous system of humans. It is composed of large number of neurons which are highly interconnected, working together to solve a problem. The beauty of ANN is its capability to deal with non-linear data. Over the years, deep learning algorithms have gained popularity and have proved to be a popular tool for analysing oceanographic data in an efficient way. In [2], the authors have implemented ANN for prediction of outgoing long wave radiation over Bay of Bengal using non-linear atmospheric data. Similarly, the authors of [3] implemented an ANN to predict the Mixed Layer Depth using surface parameters. Our aim is to implement an ANN to predict the SLD using the data of the Bay of Bengal Region.

Many authors have used the machine learning techniques for estimating various oceanographic parameters. Sarika Jain et al. [4] implemented an ANN to predict the SLD using surface parameters. The data used in their study was from central Arabian sea mooring. Their estimated SLD had root mean square error of 11.83 and the coefficient of correlation was 0.84. Further, they presented a comparative study between the accuracy of ANN and Multiple Regression technique. Udaya bhaskar et al., [5] proposed a method to utilize the XBT measurements and World Atlas climatological salinities to compute sound velocity profiles (SVP) and then extract SLD owing to the limited availability of salinity data in comparison to temperatures. This approach was demonstrated by using T/S data from Argo floats in the Arabian sea. They successfully obtained the results wherein more than 90% of the cases, the SLD matched exactly with root mean square deviation ranging from 3-12m with an average of 7m. In [6], an ANN was presented by Aparna and et al. to predict the sea surface temperatures (SST) in north eastern Arabian sea with an aim predicting SST one day in advance using current day's SST. The results showed that more than 75% of the times, the model error was less than or equal to 0.5°C. It was found that model's performance was dependent on the availability of previous data. Janati et al. [7] demonstrated a method for the management of oil slick transport in the marine environments where they provided a powerful tool for prediction of oil slick trajectory ANN. In [8], Nielson et al. presented a study where they had implemented ANN to generate multi-parameter input models to estimate the power predictions of the wind turbine. The model improved the energy production forecasting error to 0.4%.

2. Data & Methodology

The subsurface data used were temperature profiles from Argo floats in Bay of Bengal (Fig.3). Profiles spanning years 2002 - 2020, comprising of 6697 observations were used in this study. Argo profiling floats provide T/S measurements from surface to about 2 km depth every 5/10 days (ArgoScience Team 2001). The data was made available after real time quality control checks.

In this study, we applied ANN to predict the SLD using temperature inversion profiles. The figure 4 shows a single layer neural network also known as Perceptron. One can see that, x0,x1,x2,x3,…..,xn represent the various inputs of single observation and each of these inputs is multiplied by weights which are represented as w0,w1,w2,w3,….,wn. A bias value b is added to shift the activation function up or down.

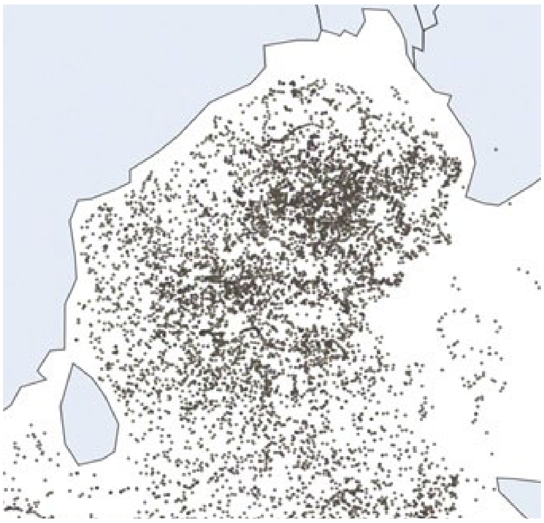


Figure 3: Area of study: Bay of Bengal

The products x0w0,x1w1,x2w2,x3w3….xnwn are summed along with bias 'b' in the simplest network. Then, the activation function is applied to the sum. Mathematically, it is represented as ***y = Φ(x0w0 + x1w1 + x2w2 + x3w3 +..…. xnwn + b)*** where, Φ is the activation function and y is the output.The activation function decides whether a neuron should be activated or not by calculation of the weighted sum and further adding it to the bias. This introduces a non - linearity into the output of the neuron. There are several types of activation functions like - Threshold Activation function, Sigmoid Activation function, Hyperbolic Tangent Activation function, Rectified Linear units. An ANN can be broadly classified based on the number of layers into two categories - 1. Single hidden layer, 2. Multiple hidden layers. In the present analysis we used an ANN with 2 hidden layers. The architecture as shown in figure 6 consists of one input layer, 2 hidden layers and one output layer. First hidden layer consists of 10 neurons and the second hidden layers consists of 5 neurons.

Generally, the data which is retrieved from external or internal sources is in the raw form and is not fit for the model. Therefore, several pre-processing steps are applied to transform the raw data in a useful and efficient format. In the pre-processing stage, there are several steps involved, the first one being Data Cleaning where all the incomplete, noisy and inconsistent data are handled. In our analysis, we first eliminated all the noisy and inconsistent values. Further, we had detected a few outliers in the data which were removed as outliers have a string effect on variance and standard deviation of the data distribution.

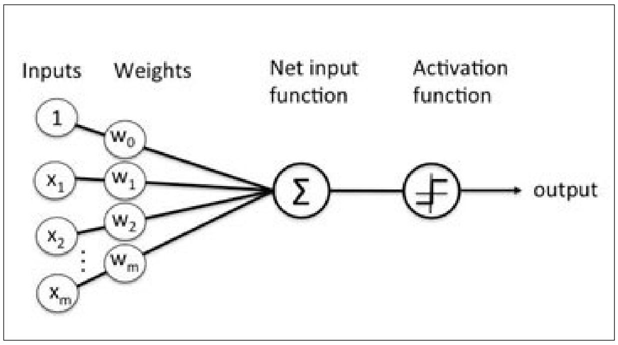


Figure 4. Representation of a Perceptron

Sometimes, the data might have irrelevant features which might decrease the accuracy of the models. Therefore a technique called feature selection (a.k.a variable selection, attribute selection or variable subset selection) is applied to select the features which are important or contribute the most to the prediction variable or output. Here, we select 5 important features [Inversion depth, Temperature at Inversion Depth, Latitude, Longitude, Temperature at surface depth] which contribute most to the prediction variable. In machine learning process, the entire dataset is split into 3 parts - 1. Training, 2. Validation, 3. Testing. In our analysis, we sub-divide the dataset where out of 6697 observations, we randomly considered, 80% (5358) for training, 20% (1339) for validation and testing.

The three parts of the dataset are scaled as this would normalize the values and sometimes help in speeding the algorithm. Finally, we implemented the ANN using the pre-processed data. The table below represents the parameters of the ANN which yielded the best results.

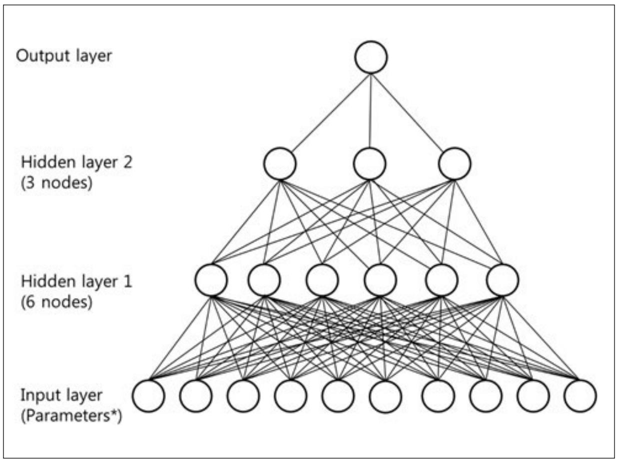


Figure 5: The Artificial Neural Network Architecture

Table 1

Parameters	Properties
Number of neurons in input layer	5
Number of hidden layers	2
Number of neurons in hidden layer 1	10
Number of neurons in hidden layer 2	5
Number of neurons in output layer	1
Learning rate	0.1
Optimizer	RMSprop

3. Results

The performance of ANN for regression is generally examined by considering the mean squared error, root mean squared error and correlation coefficient. Upon implementation of ANN, the mean squared error for training set was observed to be 0.20 and the correlation, 0.71. Figures 6 to 8 show the relation between the training set and the predicted values obtained from the ANN model.

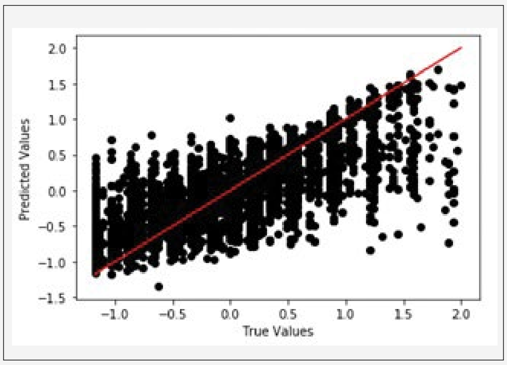


Figure 6: The Regression graph of Training set

For the validation set, the mean squared error was observed to be 0.21 and the correlation coefficient is 0.71.

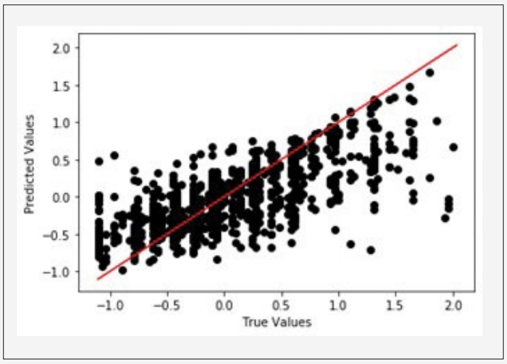


Figure 7: The Regression graph of Validation set

For the testing set, the mean squared error as 0.19 with correlation coefficient of 0.77 and the regression line for the set is depicted through the figure below.

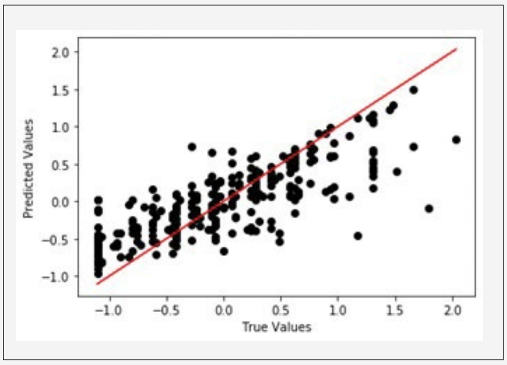


Figure 8: The Regression graph of Testing set

4. Conclusion

Sonic Layer Depth (SLD) is a significant acoustical parameter in the upper ocean which indicates the potential to trap the sound energy in the surface duct. The SLD variability plays an important role in naval operations i.e. identifying the shadow zones for safe submarine parking. The measurements of salinity and temperature using instruments like CTD are sparse in comparison to the data from the Expendable Bathythermograph (XBT). Considering these factors, a model was proposed to predict the SLD using ANN using only the temperature profiles. The studies present a quintessential method of estimating the sonic layer depth using Temperature inversion profile instead of temperature salinity (T/S) profiles. The estimated SLD mean squared error (MSE) was 0.20 and correlation was 0.70 indicating that the SLD estimated from temperature profiles using ANN is found to be reasonably good.

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OSICON-23

Indian National Centre for Ocean Information Services,

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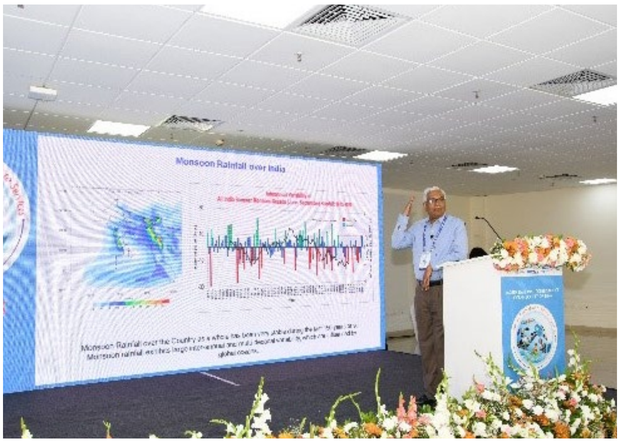
Summary of the Eighth Biennial Conference of Ocean Society of India (OSICON-23)

Indian National Centre for Ocean Information Services (INCOIS) hosted the 8th Biennial National Conference of the Ocean Society of India (OSI), OSICON-2023 during 23-25th August 2023 in INCOIS campus, Hyderabad. The theme of this edition of the conference was "Operational Oceanography- Science to Services". Dr. T. Srinivasa Kumar, Director, INCOIS welcomed the dignitaries and participants to the 3-day conference. In his welcome address, Dr. Srinivasa Kumar expressed sincere thanks to the Ocean Society of India for allowing INCOIS to host the OSICON-23 in the Silvar Jubilee year of INCOIS. Dr. M. Ravichandran, Secretary to Govt. of India, Ministry of Earth Sciences, inaugurated the conference on 23rd August. In his inaugural address, Dr. Ravichandran highlighted the importance of concerted R&D efforts in ocean science and technology for achieving the goals of 'Blue Economy' policy of the country, particularly in the energy, food, fresh water and health sectors in the backdrop of the climate change. He also stressed the need to harness the resources from oceans in a sustainable way. In the inaugural lecture, Prof. Harsh K. Gupta, Former Secretary, Department of Ocean Development, Govt. of India talked about the conceptualization and the evolution of the Indian Ocean Tsunami Warning Centre and the scientific and technological considerations while designing the tsunami warning centre. The first ever Dr. N. K. Panikkar Memorial Lecture of OSI was delivered by Dr. Shailesh Nayak, Former Secretary, MoES during the OSICON-23. In his talk, he brought out the current trends in the ocean science and services and provided a clear vision on how the oceanographic community should gear up to address the challenges in operational oceanography.

The conference was very rich in terms of participation and scientific deliberations. Over 500 delegates attended the conference and 343 research papers, spread across 13 sub-themes, were presented in the conference. This included 77 posters and 266 oral presentations. The overarching theme of the presentations was the application of oceanographic knowledge and technological advancements in the service to society and hence to support the Blue Economy. A large number of presentations in the 'Ocean Information and Advisory Services' sub-theme were focused on the operational services provided by INCOIS. Oceanographic data collected through remote sensing and in situ observations, algorithms for retrieving the satellite-based observations, validation of remote sensing data etc. were discussed in the 'Ocean Observations' sub-theme. While many presentations in the 'Ocean Modelling and Data Assimilation', 'Coastal and Open Ocean Processes', 'Air-sea Interaction' and 'Biogeochemistry of Oceans' sub-themes described the observed variability in the physical and biogeochemical properties of the Indian oceans, some of the presentations discussed their representations in the numerical models and the processes responsible for these variabilities. "Ocean and Climate Change' was a sub-theme in which several papers were presented on the observed long-term changes in the climate indicators such as sea level, marine heat waves, coral bleaching, extreme waves etc. and their representations in CMIP models. In addition, there were presentations in "Ocean Engineering and Technology", Marine Geology and Geophysics", "Polar Sciences and Cryosphere Studies", "Blue Economy" and "Marine Resource Management" as well. While there is a good amount oceanographic data available within the country, its utilization is not very satisfactory, and this is identified as one of the gap areas in the conference. A general recommendation was to make quality controlled oceanographic data easily accessible to the academic and research community. Utilization of the AI/ML techniques in different aspects of oceanographic research and services is found to be an emerging trend and this will increase the demand for easier access of such data in future.



In addition to the contributory presentations, there were three plenary talks by Dr. P. S. Goel, Dr. M. Rajeevan, former secretaries of Ministry of Earth Sciences and Dr. S. S. C. Shenoi, former Director of INCOIS) respectively during the conference. Dr. D. Srinivasan Endowment award instituted by OSI was awarded to Professor A D Rao. Dr. P. V. Joseph was conferred with the OSI Honorary Fellowship award and Dr. Satheesh Shenoi was conferred with OSI Fellowship award.

The event also marked with the inauguration of the UN Decade Collaborative Centre for the Indian Ocean Region (DCC-IOR), inauguration of Regional Specialized Meteorological Centre (RSMC) for Numerical Ocean Wave Prediction and Global Numerical Ocean Prediction at INCOIS as well as special sessions by Federation of Indian Geophysical Association (FIGA), Early Career Ocean Professionals (ECOP) and Indian Meteorological Society (IMS) also. Six PG dissertation awards and best oral-poster awards in all the sessions were also distributed during the valedictory function. A one-day pre-conference tutorial was held in connection with the conference.

The OSICON-23 concluded with a panel discussion chaired by Dr. Srinivasa Kumar, Director INCOIS during 1600-1700 hrs on 25th August 2023. Session chairs summarized the major outcomes of each session, including the major gap areas and recommendations to bridge them during the panel discussion. The meeting ended with vote of thanks proposed by Dr. P. G. Remya, Co- Convenor, OSICON-23.

UN Ocean Decade

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

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United Nations General Assembly proclaimed in 2017 the "UN Decade (2021-2030) of Ocean Science for Sustainable Development". The Ocean Decade seeks to stimulate ocean science and knowledge generation to reverse the decline of the state of the ocean system and catalyse new opportunities for sustainable development of this massive ecosystem. The vision of the Ocean Decade is 'the science we need for the "ocean we want:" A clean ocean, A healthy and resilient ocean, A productive ocean, A predicted ocean, A safe ocean, An accessible ocean and An inspiring and engaging ocean.

Governance and coordination framework for the Decade is through a Decade Coordination Unit of IOC Secretariat with a decentralized Coordination Structure that includes Decade Collaborative Centres (DCC) and National Decade Committees (NDC). An assessment of India's proposal to establish a Decade Collaborative Centre for the Indian Ocean Region (DCC-IOR) was carried out on May 13, 2022 and the proposal was approved by the IOC Decade Coordination Office. IOC endorsed the proposal on 19 October 2022 and a formal letter of exchanges to acknowledge and formalize the DCC-IOR was accomplished during the IOC Assembly session in June 2023.

Meanwhile, INCOIS contributed by participating in the bi-monthly meetings conducted by the IOC Decade Coordination Office with all the National Decade Coordination Committees (NDCC) focal points to update and review the progress of national activities under UN Decade of Ocean Science for Sustainable Development, to discuss on the contributions of NDCs to the success of the decade, Global Stakeholder forum, etc. DCC-IOR team participated in the initiation networking meeting with the Ocean Observing Co-Design Tropical Cyclone (TC) Exemplar Steering team on 24 Apr 2023.

Director, INCOIS Dr. Srinivasa Kumar has been invited to be a Member of the Working Group on Ocean Cities and also to be the Co-Chair of the Working Group on Ocean Resilience. The DCC-IOR team participated in a bilateral online meeting on 24 May 2023 with the Coastal Resilience DCC (DCC-CR, University of Bologna) on Vision 2030 WG 6 – 'Increase community resilience to ocean hazards', co-chaired by the Heads of both DCCs.

INCOIS, India partnered with the UN Decade Collaborative Centre on Ocean Prediction and actively participated in its Kick-off meeting held through online platform during Jan 11-12, 2023. INCOIS is playing major role in formulating and coordinating the formation of Indian Seas Regional Team for Ocean Prediction. On 3 May, 2023, DCC-IOR hosted the First Indian Seas Regional Team online meeting of Mercator Ocean's UN Ocean Decade-endorsed Ocean Prediction-DCC programme.

Dr, Nimit Kumar, INCOIS, delivered a NANO Webinar 'Your first dive into the UN Ocean Decade' on 10 Feb 2023, as a part of Ocean Decade activity, (www.youtube.com/watch?v=y9go75vGV-8). A project proposal by IIOE-2 Early Career Scientist' Network (ECSN) titled "Devising Early-Career Capacity Development in the Indian Ocean region" (DECCaD-IO) has been endorsed as an Ocean Decade action under ECOPs programme in March, 2023.

Dr. Abhishek Chatterjee, Dr. Mahendra R S and Dr Baliarsingh S K participated to Third Phase of the RCSTT-IORA Workshop Series on 'Effects of Climate Change on the Indian Ocean Marine Environment' during 20-22 Feb 2023 at RCOWA, Tehran, Islamic Republic of Iran as an ocean decade activity in collaboration with DCC-IOR. Similarly, Dr. Nimit Kumar, Scientist, INCOIS served as faculty to NF-POGO Regional Training Programme on 'Sustainable Marine Resource Management' organized by SUST, Sylhet, Bangladesh, from 12-23 Mar, 2023, and held in collaboration with DCC-IOR as an Ocean Decade activity.

NF-POGO Regional Training Programme at Sylhet, Bangladesh Mar, 2023.

A dedicated session to mark the formal inauguration of the DCC-IOR was convened during the 8th edition of the Biennial National Conference of the Ocean Society of India (OSICON-23), held at INCOIS, Hyderabad, India, from August 23-25, 2023.

Call for Contributions

Informal articles are invited for the next issue. Contributions referring Indian Ocean studies, cruises, conferences, workshops, tributes to other oceanographers etc. are welcome. Articles may be up to 1500 words in length (MS-Word) accompanied by suitable figures, photos (separate .jpeg files).

Deadline: **15th November 2023**

Send Your Contributions as usual to to **iioe-2@incois.gov.in**

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