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INTERNATIONAL INDIAN OCEAN EXPEDITION

INTERNATIONAL INDIAN OCEAN EXPEDITION - II

The Indian Ocean Bubble 2

Bubble 2
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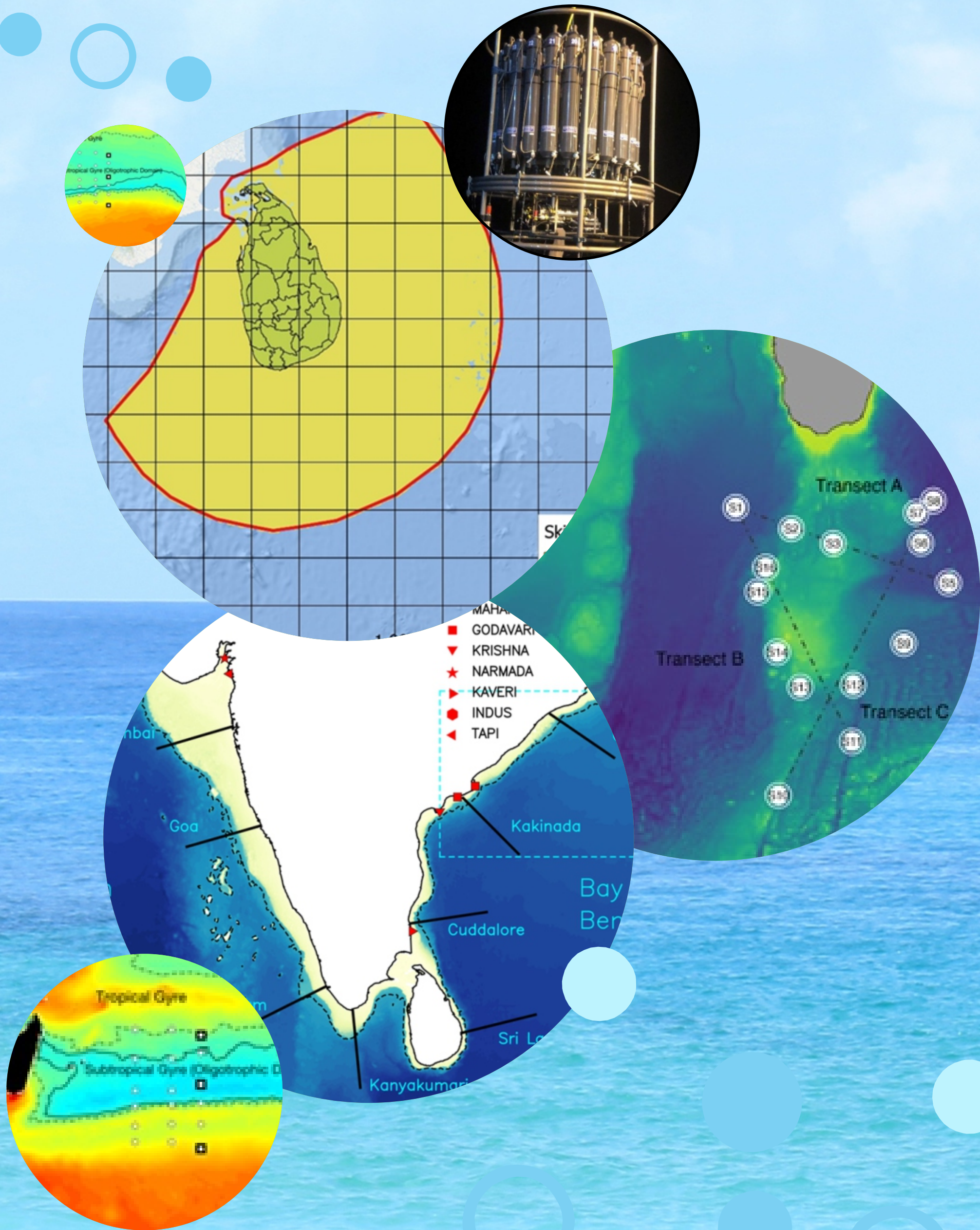

EDITORIAL

Dear IIOE-2 member,

Greetings from the Indian Ocean region!

Welcome to the latest issue of IO-Bubble. This edition explores Indian Ocean science, including ocean data, circulation, and fisheries. We also share an inspiring piece from an Early Career (EC) scientist.

Highlights include:

- Recycling of Recalcitrant Organic Matter in the Bathypelagic Indian Ocean (INDICOM)
- Numerical Modelling of Seasonal Volume, Freshwater, and Heat Transport
- Mapping Sustainable Skipjack Tuna Habitats in Sri Lanka
- Evaluating Sea Surface Temperature in the Southeastern Arabian Sea""Cruise SO308 South Indian Ocean GEOTRACES Gi07

We also cover the elevation of IOCINDIO to an IOC-UNESCO sub-commission, enabling wider collaboration.Lastly, explore details of the upcoming 7th International Conference on Ocean Engineering (ICOE 2025).We hope you enjoy this issue.

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

IN THIS ISSUE

Ocean Data

Composition, production, and recycling of recalcitrant organic matter in the bathypelagic Indian Ocean (INDICOM)

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During the SONNE expedition SO307, scientific work was carried out for the project INDICOM to investigate the origin and fate of dissolved and particulate organic matter (DOM and POM), including gel particles (i.e., carbohydrate-rich transparent exopolymer particles - TEP and protein-rich Coomassie stainable particles - CSP) in the deep sea. During the expedition, we conducted 34 individual CTD casts to a maximum depth of 5000 m and processed ~8 m^3 sea water. Experiments regarding the role of gel particles and freshly produced organic matter for deep sea bacteria were carried out on board and will be continued at GEOMAR.

The overall aims of INDICOM

INDICOM aims to investigate the biological and biogeochemical processes that affect the turnover of organic matter in the deep Indian Ocean, focusing on understanding how phytoplankton-derived organic carbon is processed from the surface to the deep ocean. While most freshly produced organic matter is remineralized within short timescales in the sunlit surface ocean, only a small fraction is exported to the dark ocean, where it undergoes much slower turnover, potentially resulting in long-term carbon sequestration as refractory dissolved organic carbon or insediment burial. However, knowledge about aggregation and disaggregation processes, changes in organic particle size distributions, bacterial colonization, and the dynamics of DOM in the deep ocean remains limited. Therefore, we specifically investigated these processes, emphasizing the role of heterotrophic bacteria in controlling organic carbon turnover and focusing on gel particles that bridge dissolved and particulate organic matter phases. Carbohydrate- and protein-rich gels (e.g., TEP and CSP) have been identified as abundant in the meso- and bathypelagic Indian Ocean. However, their role in deep-sea organic matter turnover is poorly understood. To address this, we conducted detailed chemical, micro(biological), and molecular analyses, including heterotrophic rate measurements (Table-1), and tested hypotheses about the factors controlling the bacterial reworking of organic matter. Experimental studies examined how the chemical composition of organic matter affects heterotrophic growth efficiency, whether deep-sea bacterial communities can respond to labile and semi-labile organic matter despite potentially dilute concentrations, and how enrichment of specific organic compounds can enhance bacterial consumption and remineralization. These efforts aim to better quantify carbon fluxes and unravel the mechanisms governing organic matter turnover in the deep ocean.

Table-1: Overview of sampled and analysed chemical and microbiological parameters.

Name	Parameter	Abbreviation
Total and Dissolved Biogeochemical Parameters (DOM)	Total and Dissolved Organic Carbon	T/DOC
	Total and Dissolved Organic Nitrogen	TDN
	Total and Dissolved Hydrolysable Amino Acids	T/DHAA
	Total and Dissolved Combined Carbohydrates	T/DCHO
	Chromophoric and Fluorescent Dissolved Organic Matter	CDOM/FDOM
	Dissolved Inorganic Carbon	DIC
	Nutrients (nitrate, nitrite, phosphate, silicate)	NUT
	Total Alkalinity	TA
Particulate Biogeochemical Parameters (POM)	**Transparent Exopolymer Particles (microscopic and colorimetric)**	TEP
	Coomassie Stainable Particles (microscopic and colorimetric)	CSP
	Confocal Laser Scanning Microscopy and Combinatorial Labeling and Spectral Imaging	CLSM CLASI-FISH
	Lipid analysis (Lipidomics)	LA
	Chlorophyll *a* concentration	Chl-*a*
Phytoplankton and microbiological parameters	**Bacterial abundance**	BA
	Picophytoplankton abundance	PA
	Viral abundance	VA
	Bacterial Biomass Production	BBP
	Total Extracellular Enzymatic activity	EEA
	Bacterioplankton community composition (16S - rRNA gene amplicon sequencing)	16S-rRNA
	Bacterioplankton functional potential (metagenomics)	metaG
	Bacterioplankton gene expression (metatranscriptomics)	metaT

Methods, Shipboard Procedure and Shore-based Analyses

Discrete Seawater Sampling with the CTD Rosette

A total of 15 CTD stations and 34 vertical profiles (casts) of conductivity (C), temperature (T), pressure (P), and oxygen (O) were recorded during So307 (Figure-1 and Table-2). In addition, a chlorophyll /turbidity sensor, a photosynthetically active radiation sensor (PAR), an altimeter system, and an underwater vision profiler (UVP) were attached to the CTD frame. The CTD profiles ranged from the surface to a maximum depth of 5000 m.

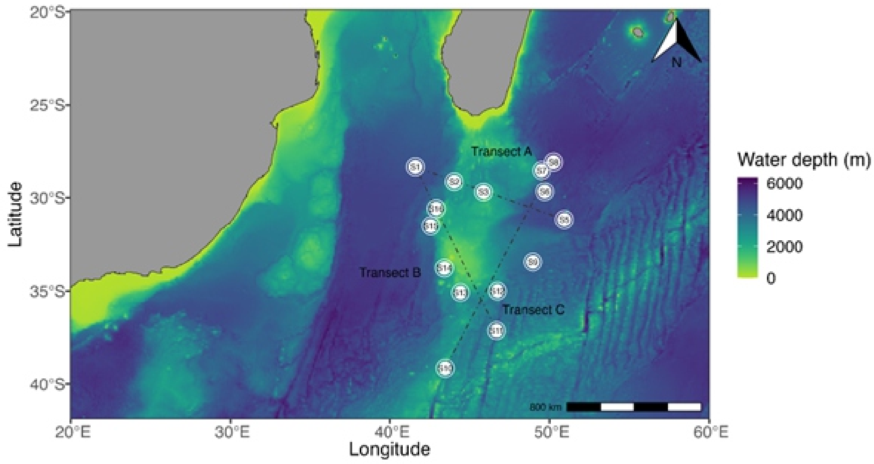

Figure-1: Overview of CTD/RO deployments (station numbers) and transects during SO307 (12. Sep. – 28. Oct. 2024) and the location of stations from where samples for biological and microbiological analyses were collected. For a detailed list of the individual CTD/RO deployments, see Table- 2.

Table-2: Overview of CTD/RO (including UVP5) deployments for the biogeochemical and microbiological work during So307.

Stn	Stn ID	Date	Time	Latitude	Longitude	Sampling depth	Water depth
Nr.	SONNE	2024	[UTC]	[°S]	[°E]	[m]	[m]
S1	SO307 1-1	09-14	23:30	28° 20,000'	041° 35,004'	744	4585
	SO307 2-1	09-15	01:49	28° 20,002'	041° 34,996'	4474	4585
	SO307 3-1	09-15	05:20	28° 19,970'	041° 35,001'	1978	4585
S2	SO307 8-1	09-16	13:40	29° 07,906'	044° 01,300'	1980	2436
	SO307 9-1	09-16	15:17	29° 07,908'	044° 01,296'	2000	2436
	SO307 10-1	09-16	16:48	29° 07,910'	044° 01,295'	1999	2436
	SO307 11-1	09-16	18:20	29° 07,909'	044° 01,299'	800	2436
S3	SO307 20-1	09-18	12:00	29° 41,253'	045° 51,472'	1900	2005
	SO307 21-1	09-18	13:47	29° 41,254'	045° 51,471'	800	2005

S7	SO307 39-1	09-22	11:56	28° 31,850'	049° 30,105'	1998	3876
	SO307 40-1	09-22	13:40	28°31,847'	049° 30,095'	800	3876
S8	SO307 41-1	09-22	20:10	28° 04,941'	050° 14,909'	5000	5405
	SO307 42-1	09-22	23:58	28° 04,942'	050° 14,915'	800	5405
S6	SO307 49-1	09-24	15:20	29° 39,934'	049° 41,918'	799	4245
	SO307 50-1	09-24	16:28	29°39,957'	049° 41,894'	2999	4245
S5	SO307 57-1	09-26	09:13	31° 10,078'	050° 54,956'	799	4818
	SO307 58-1	09-26	10:27	31° 10,076'	050° 54,974'	4000	4818
S9	SO307 59-1	09-27	06:06	33° 26,586'	048° 57,200'	799	4140
	SO307 60-1	09-27	07:13	33° 26,588'	048° 57,214'	3998	4140
	SO307 61-1	09-27	10:22	33° 26,586'	048° 57,204'	2002	4140
S11	SO307 66-1	09-29	05:05	37° 07,666'	046° 40,789'	800	3820
	SO307 67-1	09-29	06:10	37° 07,661'	046° 40,798'	3499	3820
S10	SO307 85-1	10-04	21:30	39° 08,982'	043° 27,631'	1999	2338
S12	SO307 105-1	10-09	15:16	34° 59,996'	046° 44,003'	802	4020
	SO307 106-1	10-09	16:22	35° 00,002'	046° 44,007'	3989	4020
	SO307 107-1	10-09	19:21	34° 59,996'	046° 44,006'	2002	4020
S13	SO307 119-2	10-12	19:02	35° 05,019'	044° 25,079'	2500	2646
S14	SO307 130-1	10-15	02:41	33° 46,185'	043° 24,408'	2502	2594
	SO307 131-1	10-15	05:00	33° 46,176'	043° 24,386'	2001	2594
S16	SO307 148-1	10-20	07:46	30° 35,014'	042° 54,008'	800	3924
	SO307 149-1	10-20	08:54	30° 35,016'	042° 54,012'	3891	3924
	SO307 150-1	10-20	11:58	30° 35,016'	042° 54,005'	2002	3924

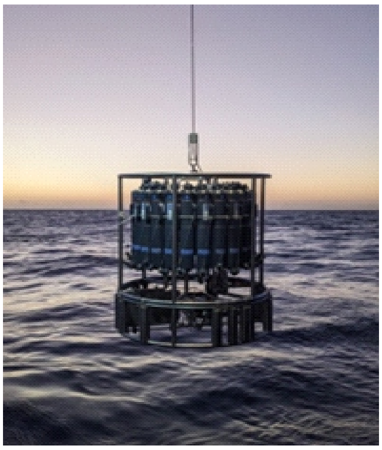

Photo: Conductivity, Temperature, and Depth (CTD) system attached to the water sampler rosette (RO) onboard R/V SONNE (© J. Karnatz).

We used the ship's CTD system attached to the water sampler rosette (Picture) and SBE Seasave software (version: 7.26.1.8) for processing the CTD data. Discrete water samples were collected during the cruise from vertical CTD/RO casts for later analysis on shore. Chemical and biological parameters associated with organic matter composition and microbial activity were sampled to investigate the processes affecting organic matter turnover in the deep Indian Ocean (Table-1)

Onboard Incubation Experiments with Deep-Sea Bacteria

POM is a key source of reactive substances for deep-sea microbes. Yet, the role of carbon-rich marine gels in the meso- and bathypelagic ocean is poorly understood. To explore this, onboard experiments tested whether gel particles, formed from naturally occurring DOM, could stimulate heterotrophic bacterial activity. Gel particles were generated by adding alginic acid to ultrafiltered surface water DOM (> 1kDa), with viruses removed via further filtration (< 30 kDa). The gel particles were resuspended in deep-ocean water (2000 m depth) containing natural bacterial communities for incubation at in situ (~2.5°C) and elevated (~6.5°C) temperatures to assess ocean warming effects.

Samples were collected periodically to analyse DOM composition, such as carbohydrate and amino acid content, microbial activity, nutrients, gel particle concentration, and bacterial colonization. Parallel experiments assessed microbial community composition, functional potential, and activity through metagenomics and metatranscriptomics (Table-1). Another experiment tested the effects of varying gel concentrations on microbial activity, simulating different POM/TEP export fluxes. Additional long-term seawater incubation studies at GEOMAR will examine the impact of organic matter source (surface vs. deep), lability, composition, and temperature on microbial turnover.

Preliminary Results

CTD transects

The CTD casts sampled various water masses in the southwestern Indian Ocean near the Madagascar ridge (Figure-1). The key water masses include Subtropical Surface Water (SSW) in the upper water column, Subantarctic Mode Water (SAMW) at 500-1000 m depth, Antarctic Intermediate Water (AAIW) at 1000-2000m, and the North Atlantic Deep Water (NADW) below 2000 m.

Transect A (S1: 28° 20.000' S, 041° 35.004' E to S5: 31° 10.078' S, 050° 54.956' E): Chlorophyll a (Chl-a) fluorescence, a proxy for phytoplankton biomass, ranged from 0.3 to 1.4 mg m^3 in the upper 100 m, peaking at ~35 m at station S2 (~44°E) (Figure-2A). Surface temperatures varied from 16.4°C to 23.4°C, dropping to ~2.6°C at 2000 m (Fig. 2B). Salinity peaked at 35.64 near the surface, reaching a low of 34.67 at depth (Figure-2C). Oxygen declined from 6.6–7.7 mg L^{-1} at the surface to 5.5 mg L^{-1} at 2000 m (Figure-2D).

Transect B (S11: 37° 07.661' S, 046° 40.798' E to S1): Chl-a peaked at S16, S13, and S11 (~1.2 mg m^{-3}), with the deep chlorophyll maximum (DCM) mostly above 50 m except at S15, where it extended to ~100 m (~1 mg m^{-3}) (Figure-2E). Surface temperatures decreased southward from 23.4°C to 16.6°C (Figure-2F). Surface salinity remained ~35.5, decreasing to 34.4 at 1200 m (Figure-2G). Oxygen levels increased from 6.6 mg L^{-1} at S1 to 7.6 mg L^{-1} at S11, inversely correlating with temperature (Figure- 2H).

Transect C (S8: 28° 04.941' S, 050° 14.909' E to S10: 39° 08.982' S, 043° 27.631' E): Chl-a ranged from 0.13 to 2.1 mg m^{-3}, peaking at 13 m at S10. Most high Chl-a values were above 50 m, except at S12 (~1 mg m^{-3} to 100 m) (Figure-2I). Surface temperatures decreased southward from 20.4°C to 10.7°C at S10 (Figure-2J). While surface salinity was stable (~35.59), it dropped to 34.37 at S10, accompanied by a pronounced halocline and increased oxygen levels (~8.9 mg L^{-1}) (Figure-2K, 2L). These findings suggest influence from a distinct water mass, likely AAIW, at S10 (~40°S), possibly through upwelling of deep water through eddies.

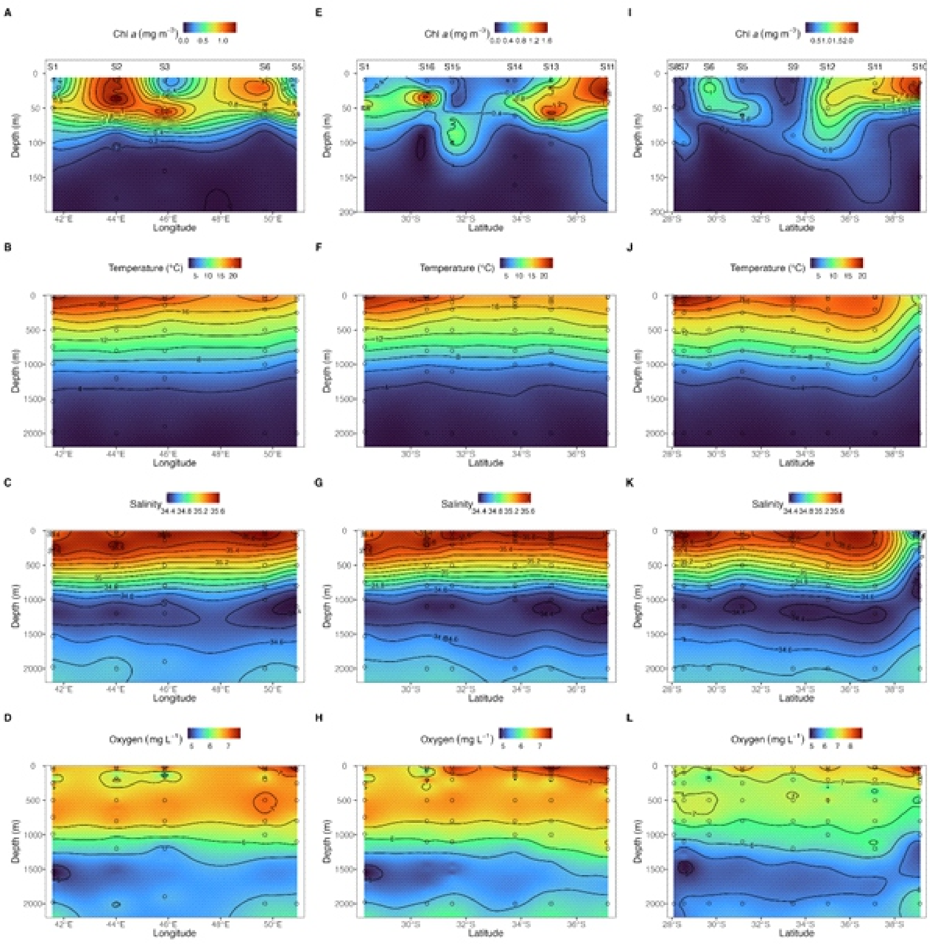

Figure-2: Longitudinal cross-section plots showing the hydrographic properties (i.e., chlorophyll-a concentration, seawater temperature, salinity, and oxygen concentration) of the water column down to 2000 m depth along transect A (Panels A-D), transect B (E-H), and transect C (I - L). The depths where discrete water samples were collected are indicated with open circles. Station names are shown above panels. Note the different y-axis ranges for chlorophyll a. An overview of all sampled CTD stations is shown in Figure-1 and Table-2.

Acknowledgement. The INDICOM project was funded by the German Federal Ministry for Education and Research (BMBF) under the grant number 03G0307C.

High-resolution numerical modelling of seasonal volume, freshwater, and heat transport along the Indian coast

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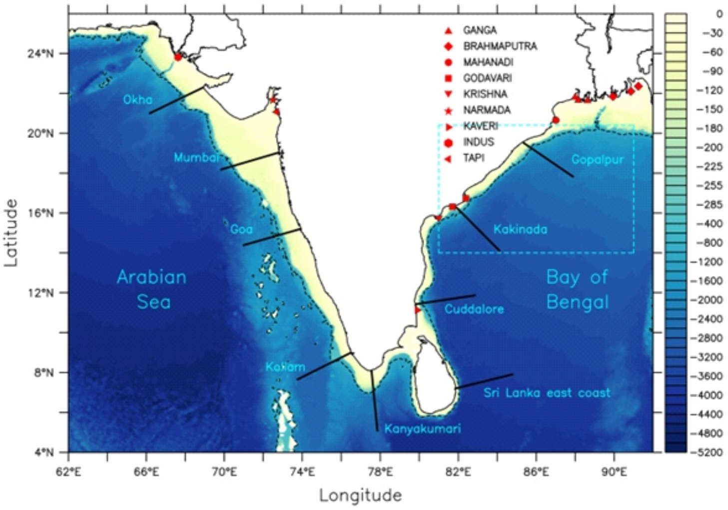


Figure-1: Study area depicting the bathymetry of the MITgcm domain in colour scale. The dashed black line represents the 1000m bathymetry contour. The red symbols represent the discharge points of major river systems in India. The dashed blue box represents the region considered for eddy-induced transports. All transects are 3° in length (solid black lines).

Introduction

The Indian coastline is bordered by the northern Indian Ocean (NIO), with the Arabian Sea (AS) to the west and the Bay of Bengal (BoB) to the east. The circulation in these basins is influenced by seasonal wind reversal and remote equatorial forcing, facilitating freshwater exchange and thermal ventilation. AS is a saline basin due to high evaporation and inflows from the Persian Gulf and the Red Sea, while BoB is fresher due to heavy precipitation and river discharge. The AS and BoB feature key coastal currents that regulate alongshore transport. The West Indian Coastal Current (WICC) in AS flows equatorward in summer and poleward in winter. At the same time, the BoB experiences a poleward Western Boundary Current (WBC) before the summer monsoon and an equatorward East Indian Coastal Current (EICC) in winter. Monsoon currents further contribute to inter-basin exchanges, transporting saltier AS water into BoB and freshwater in the reverse direction. Observational studies provide insights into these processes but are limited in subsurface coverage.

We employed the MITgcm to quantify heat and freshwater transport along the AS and BoB coasts. We simulated coastal circulation using a high-resolution (~5 km) setup (Figure-1) and validated the results against observational datasets. This setup helps analyse mesoscale dynamics, eddy-driven transport, and meridional heat distribution. Our model provides a robust alternative to sparse in situ data, offering valuable insights into coastal exchange processes in the NIO.

Results and Discussion

To analyse alongshore volume transport (AVT) and freshwater transport (AFT), nine transects were selected along the Indian and Sri Lankan coasts, capturing seasonal and intraseasonal variability of coastal currents. AVT was computed for surface (0–200 m) and subsurface (200–1200 m) layers. Along the eastern coast, transport is primarily seasonal, with poleward flow during MAM and equatorward flow during ON, driven by the EICC. In contrast, the western coast shows weaker seasonality, with the WICC flowing equatorward in summer. Southern locations like Kollam and Kanyakumari experience stronger remote forcing, leading to a mix of poleward and equatorward transport. MITgcm and INCOIS-HYCOM (INC-HYC) model comparisons show strong agreement except at Cuddalore and Kanyakumari (Figure-2).

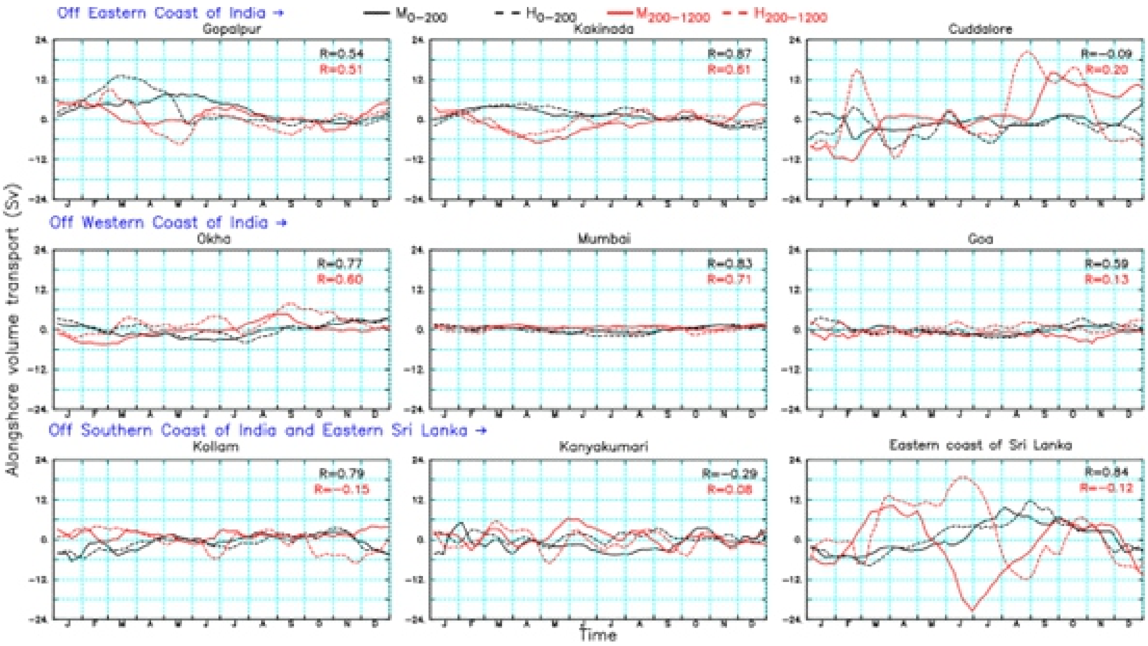


Figure-2: AVT (in Sv) of the MITgcm (solid lines) and INC-HYC (dashed lines). R represents the Pearson's correlation coefficient between the MITgcm and INC-HYC.

AFT exhibits contrasting seasonal patterns on both coasts, influenced by precipitation and river runoff. AFT and AVT align on the eastern coast, whereas they diverge on the western coast due to salinity dynamics. The strongest freshwater transport occurs during the monsoon, peaking at Gopalpur, Kakinada, and Kanyakumari. Spatially, net volume transport (NVT) and net freshwater transport (NFT) are stronger in the BoB than in the AS. The WBC drives poleward transport during MAM, while cyclonic eddies and the Sri Lankan Dome influence JJAS transport. By ON, the EICC shifts equatorward, transporting freshwater southward, and by DJF, freshwater moves westward into the southeastern AS. Eddy activity significantly impacts heat and freshwater transport along the eastern Indian coast. Two eddy regions in the northwestern BoB were identified for our study. Anticyclonic and cyclonic eddies modulate the mixed layer depth (MLD) and vertical velocity, shifting transport direction. Eddy heat transport (EHT) can peak up to 0.52 GW, while eddy-induced freshwater transport (EFT) peaks in October, transporting freshwater in the southwestward direction. Net heat transport (NHT) exhibits strong seasonality, with poleward transport during MAM in BoB and northward heat advection in JJAS by the Sri Lankan Dome. Dry winds and convective mixing drive DJF cooling. Meridional heat transport (MHT) is stronger in the AS, exceeding ±1.25 PW, whereas BoB MHT is weaker (±0.75 PW), controlled primarily by monsoonal forcing and basin-scale circulation.

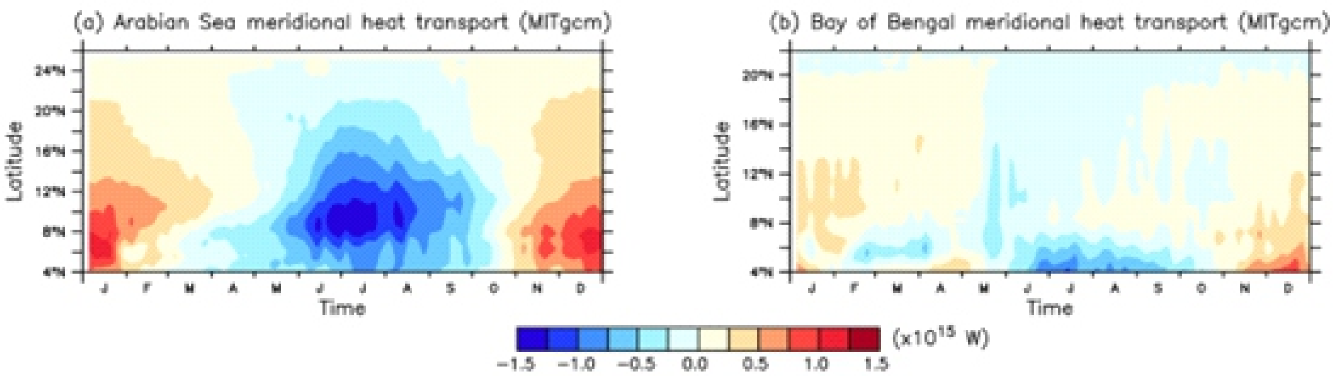


Figure-3: Meridional heat transport (MHT, in PW) computed over the upper 100 m using the MITgcm for the AS and BoB. The red colour indicates northward transport, and the blue colour indicates southward transport.

The main findings from this study are:

- Differences in coastal transports: Eastern coast transport is primarily seasonal due to the EICC, while intraseasonal oscillations driven by the WICC influence the western coast. AFT peaks during the monsoon due to river runoff, with counter-currents affecting surface and subsurface transport directions. Freshwater transport from the BoB to the AS peaks at Kanyakumari and along the eastern Sri Lankan coast in December.
- Seasonal influence on transport patterns: On the western coast, AVT and AFT exhibit opposing seasonal variations due to salinity dynamics, whereas on the eastern coast, both follow similar seasonal trends influenced by freshwater inputs from precipitation and river discharge.
- Eddy dynamics and their role in transport: The model captures climatological eddies and the Sri Lankan Dome. Eddies along the eastern coast remain active from June to July but weaken by August–September. Poleward transport by the WBC is weak before the monsoon but strengthens during the monsoon due to increased freshwater input, which later mixes with saltier AS waters in winter.
- Contribution of eddy to freshwater transport: Eddies in the northwestern BoB form due to instabilities from the WBC, which significantly impacts MLD and vertical velocity. These eddies transport freshwater zonally and meridionally from August to November, peaking in intensity by September. They are crucial in redistributing freshwater from the northern BoB along the coast.
- Heat transport and its seasonal influence: Before the monsoon, the WBC's poleward transport establishes a strong thermal gradient, while winter cooling is driven by dry winds and reduced solar radiation. Seasonal net heat flux variations depend on atmospheric conditions and vertical mixing. In MAM, weak winds and high solar radiation trap heat in the upper layers, whereas in JJAS, monsoon clouds cool surface waters. Post-monsoon, increased latent heat loss leads to further cooling, while the southeastern AS retains high heat flux due to freshwater inflows and downwelling Rossby waves preventing vertical mixing.
- MHT and wind influence: The AS experiences a seasonal MHT reversal due to wind-driven Ekman transport and vertical thermal wind shear, influenced by a bi-modal westward-propagating Rossby wave. MHT shifts in pre- and post-monsoon align with wind and circulation changes. Weakening monsoon winds reduce Ekman transport, leading to weaker southward MHT and increased AS warming. In contrast, BoB's MHT remains weaker due to strong stratification, slower circulation, and weaker winds. The NIO acts as a heat source in summer and a heat sink in winter, with southward heat transport between March and September and northward transport bringing warm equatorial waters between November and February.

In conclusion, our high-resolution MITgcm setup effectively captures volume, freshwater, and heat transport dynamics in the NIO. The eddy-resolving model improves coastal exchange estimates, showing stronger seasonal AVT on the eastern coast, while intraseasonal oscillations influence the western coast. AVT and AFT are in phase on the eastern coast but opposite on the western coast due to salinity dynamics. Eddies facilitate heat and freshwater exchange, while NHT and net heat flux highlight coastal and equatorial influences on heat dissipation. MHT is stronger in the AS than BoB, flushing the heat out in summer and bringing equatorial waters in during winter, underlining the model's effectiveness in simulating key climatological patterns.

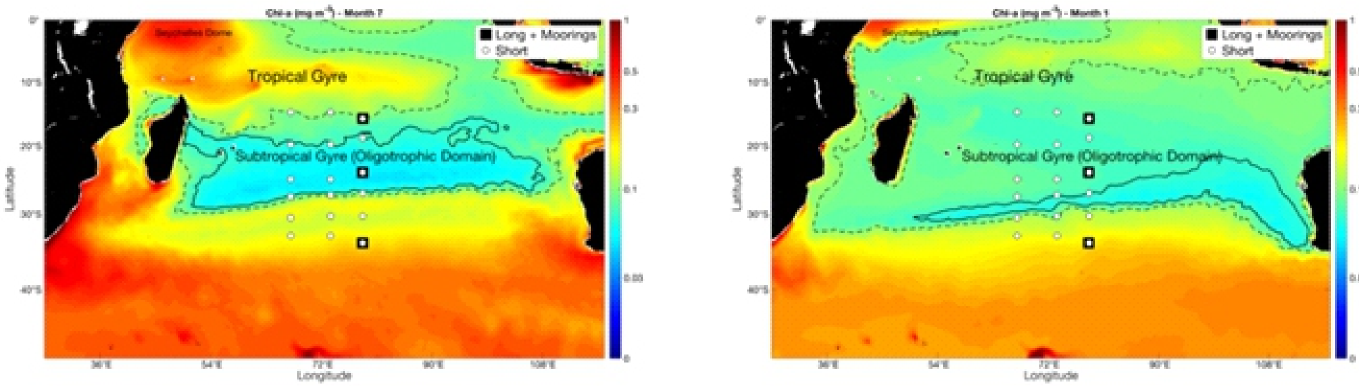
Source:* *Madkaiker, K., Rao, A. D., and Joseph, S.: High-resolution numerical modelling of seasonal volume, freshwater, and heat transport along the Indian coast, Ocean Sci., 20, 1167–1185, https://doi.org/10.5194/os-20-1167-2024, 2024.

New project EXPAND will investigate nitrogen fixation in the Indian Ocean

Mar Benavides (NOC, UK and IRD, France) will count on many international collaborations including researchers in India, France, Spain and the US.

Often called 'ocean deserts', subtropical gyres have low biological productivity but, due to their immense size, contribute significantly to carbon sequestration regulating global climate. In gyres, biological productivity strongly depends on nitrogen supplied by microbes called diazotrophs, capable of fixing molecular nitrogen into bioavailable nitrogen forms Earth system models predict increasing uncertainty in biological productivity towardsthe end of the 21st century. Such uncertainty responds to nitrogen fixation parametrisation in models[1] and is largely driven by the scarce observations available in the Indian Ocean[2], representing only 1% of the nitrogen fixation data available globally[3]. Moreover, our current understanding of nitrogen fixation is mainly based on nutrient availability (phosphorus and iron) impacts on diazotrophs. However, previous research in our team shows that other controls including ocean circulation and diazotroph/non-diazotroph interactions are key in shaping nitrogen fixation inputs locally. None of these controls have been comprehensively examined over the vast extension of the Indian Ocean, nor throughout seasons. We will conduct two oceanographic expeditions covering the full extension of the Indian Ocean gyre at its minimum and maximum expansion seasons (July and January, respectively) in 2026 and 2027 (Figure-1). Gyre expansion will be tracked with satellite and in situ hydrographic and current speed measurements. The impact of chemical (nutrients), physical (ocean circulation), and biological (species interactions) controls on nitrogen fixation will be comprehensively measured, using at-sea experiments and up-to-date isotopic and molecular analyses. Moreover, seasonal variability will be monitored over a full year with mooring lines anchored at the centre, northern and southern edges of the gyre, equipped with DNA samplers and a newly designed automatic device measuring nitrogen fixation rates. These datasets will link cellular to ecosystem processes, bridging the gap between ocean desert expansion and nitrogen fixation in the world's least explored gyre.

The EXPAND project, lead by Mar Benavides (NOC, UK and IRD, France) will count on many international collaborations including researchers in India, France, Spain and the US.



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Mapping Sustainable Skipjack Tuna Habitats in the Sri Lankan EEZ: An Integration of Machine Learning and Satellite-Derived Environmental Data

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Introduction

The skipjack tuna (Katsuwonus pelamis), that keeps alive the livelihoods of coastal communities while contributing a substantial contribution to the fisheries industry, is an essential component of the economy of Sri Lanka and marine ecosystem. However, the dynamic interaction of oceanographic parameters including sea surface temperature (SST), chlorophyll-a (Chl-a) concentration, and climate phenomena such as the El Niño-Southern Oscillation (ENSO) displays some complications for traditional fisheries management approaches (Hsu et al., 2021; Elepathage & Tang, 2019). Each of these variables interact with temporal and spatial distribution of skipjack tuna, which in consequently affects habitat suitability and catch efficiency.

The 517,000 km^2 Exclusive Economic Zone (EEZ) of Sri Lanka is the homeland to a variety of marine habitats with numerous levels of productivity. Research on integrated predictive habitat mapping has remained insufficient despite ecological and economic significance of skipjack tuna (Figure-1). Our study addresses this knowledge gap through a combination of satellite-derived data and machine learning models to forecast skipjack tuna habitats. The ultimate objective of the research is to deliver practical insights for sustainable fisheries management by utilizing high-resolution datasets and sophisticated modeling techniques.

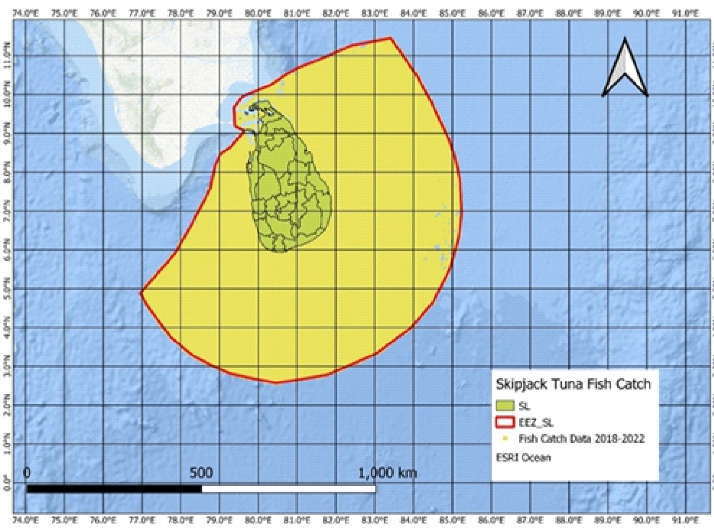

Figure-1: Skipjack Tuna Fish Catch habitat sustainability map within Sri Lankan EEZ zone.

Results and Discussion

This study implemented fisheries catch data (2018-2022) and environmental parameters derived through the Aqua MODIS satellite to investigate the temporal and spatial dynamics of skipjack tuna habitats in the EEZ of Sri Lanka. The Sea Surface Temperature (SST) and Chlorophyll-a (Chl-a) datasets had gaps that were reconstructed using sophisticated interpolation techniques such as Data Interpolating Convolutional Auto-Encoder (DINCAE) and Data Interpolating Empirical Orthogonal Functions (DINEOF) (Beckers & Rixen, 2003). Based on performance metrics, including a low Mean Absolute Error (MAE) of 0.6336 and a high R-squared value of 0.9840, predictive habitat suitability models that utilized Artificial Neural Networks (ANN) and ensemble machine learning techniques demonstrated strong reliability (Table-1).

Metric	Value
MAE	0.6336
MSE	0.9548
RMSE	0.9771
NRMSE	0.0293
MBD	-0.0015
R-squared	0.9840

Table-1: Performance Metrics for the Machine Learning Model

High suitability zones with suitable SST (28–30°C) and Chl-a concentrations (5–7 mg/m^3) were primarily identified in the southern and southeastern EEZ. Especially during the southwest monsoon (May–September), these locations were accompanied by nutrient-rich waters that were influenced by monsoonal upwelling. Throughout this period, normalized CPUE values varied from 0.6 to 1.0 (20.4–34 tons), which was consistent with elevated Chl-a levels (5.04–7 mg/m^3). On the opposite combination, the northeast monsoon (December–February) had lower productivity, with normalized CPUE values of 0.3–0.5 (10.2–17 tons), lower Chl-a concentrations (1.48–2.86 mg/m^3), and a cooler SST (28.8–29.6°C).

The endurance of the framework was confirmed by model validation using 2023 CPUE data, which generated an R-squared value of 0.9796 (Table-2).

Metric	Value
MAE	0.5909
MSE	0.7387
RMSE	0.8595
NRMSE	0.0342
MBD	0.0422
R-squared	0.9796

Reliable model performance was demonstrated by the close alignment of the observed versus predicted CPUE scatterplot (Figure-2).

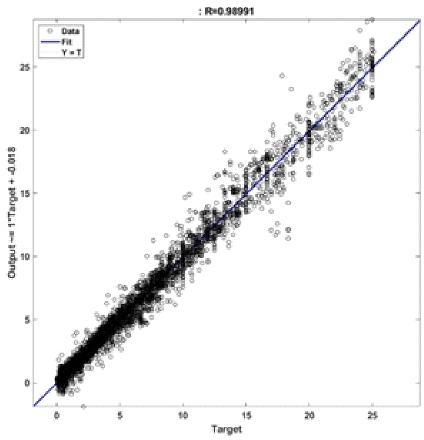

Figure-2: Validated Regression

The ability of model to accurately predict outcomes while capturing temporal variability was further demonstrated by the CPUE Model Validation Estimate (Figure-3). These results highlight the effectiveness of model in determining locations for sustainable fishing and comprehending the behavior of skipjack tuna.

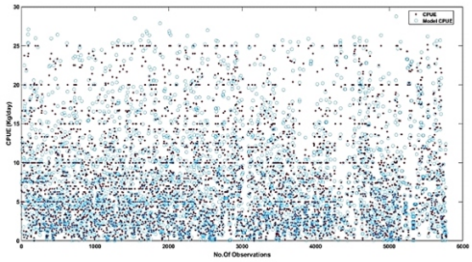

Figure-3: CPUE Model Validation Estimate

Seasonal analysis demonstrated that SST, Chl-a, and tuna distribution interacted, with transitional inter-monsoonal periods (March–April and October–November) illustrating mixed environmental conditions and moderate CPUE values (13.6–27.2 tons). Figure4 displayed monthly and seasonal variations in CPUE, SST, and Chl-a, highlighting the effects of monsoonal dynamics. Higher Chl-a and suitable SST during the southwest monsoon enabled for higher CPUE, while lower Chl-a and cooler SST during the northeast monsoon resulted in lower productivity.

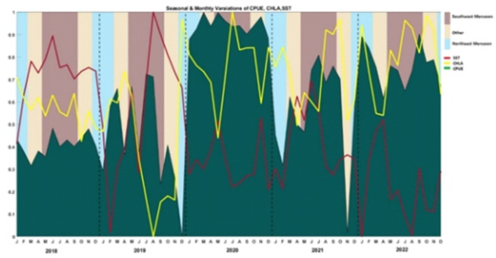

Figure-4: Monsoon-related seasonal changes in CPUE, Chl-a, SST

By integrating Geographic Information System (GIS) tools, it was achievable to classify habitat into low, moderate, and high suitability categories and visualize important fishing zones. These observations highlight how important it is to coordinate fishing activities with evolving environmental conditions in order to improve resource efficiency and sustainability.

Conclusion

By combining machine learning and environmental data from satellites, this study delivers a novel method for mapping sustainable skipjack tuna habitats in EEZ of Sri Lanka. The study presents a scalable framework for forecasting habitat suitability based on dynamic oceanographic parameters, filling in gaps in conventional fisheries management. The results highlight the importance it is to include environmental variability in fisheries management in order to guarantee equitable utilization of resources.

To operationalize the research findings and facilitate informed decision making and real time habitat monitoring, a prototype decision-support dashboard was suggested. To effectively address the complexity of marine ecosystems, future research should concentrate on improving temporal coverage, including more environmental factors, and enhancing predictive models. This study encourages sustainable skipjack tuna resource management, which is consistent with commitment of Sri Lanka to responsible marine resource management.

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Evaluating Sea Surface Temperature of Ocean Reanalysis Products in the Southeastern Arabian Sea

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Importance of SST in the Southeastern Arabian Sea

SST is a key driver of ocean-atmosphere interactions, influencing monsoon patterns, convection processes, and the development of extreme weather events such as tropical cyclones (Joseph, 1990; Shenoi et al., 2002). Accurate SST monitoring is critical for Monsoon forecasting, Cyclone prediction and Marine ecosystem management. SST anomalies can affect the intensity and timing of the Indian Summer Monsoon Rainfall (ISMR) (Shukla, 1975; Chakravorty et al., 2016) and contribute to the formation and intensification of tropical cyclones by providing necessary heat energy (DeMaria & Kaplan, 1994; Emanuel, 1999). Additionally, SST variations impact marine biodiversity, fishery productivity, and coastal economies (Kamykowski, 1987). Understanding the SST anomalies is essential for improving monsoon forecasting, cyclone prediction, and sustainable marine ecosystem management in the region.

The Southeastern Arabian Sea (SEAS) exhibits the warmest SSTs in the world during the pre-monsoon season during April and May, reaching temperatures above 30°C forming a mini-warm pool (Figure 1; Vinayachandran et al., 2007). These warm waters contribute to the formation of deep convection systems that impact the monsoon onset over India (Gadgil et al., 1984; Graham & Barnett, 1987). Because of its importance, accurate SST monitoring in the SEAS is crucial for monsoon onset, initialization of weather forecasting models, climate change studies, oceanographic research, and fisheries management.

A recent study by Rahman and Rahaman (2024) evaluates SST from ten ocean reanalysis products in the North Indian Ocean. Here we aim to assess the accuracy of these products by comparing them with in-situ buoy data from OMNI buoys (Acharya & Chattopadhyay, 2019) located over the southeastern Arabian Sea (AD09 and AD10; See Figure-1).

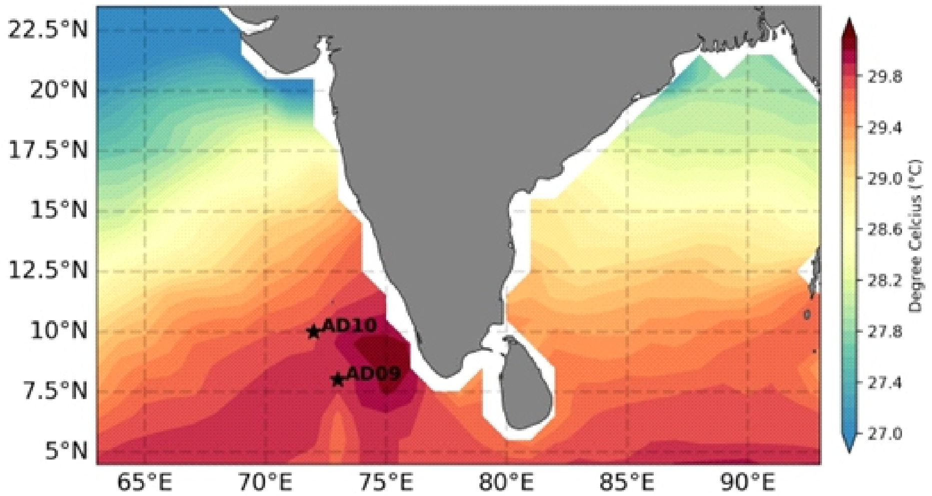

Figure-1: Sea Surface Temperature from OISST for march-april months averaged for five years (from 2013 to 2017) near the Indian coast.

Evaluation of Reanalysis Products in the SEAS

In this study we compared ten global ocean reanalysis products—ECCO, BRAN, SODA, NCEP-GODAS, GODAS-MOM4p1, ORAS5, GLORYS, GLOSEA, C-GLORS, and GREP with in-situ buoy observations. Additionally, five synthetic SST products (COBE, ERSST, OISST, OSTIA, and HadISST) were assessed against the same buoy data to determine their accuracy. The performance of reanalysis products in the SEAS varied when compared against SST from Ad09 and Ad10 buoys. ECCO exhibited a warm bias, overestimating SST while GLOSEA showed a cold bias, likely due to enhanced vertical mixing. Among the reanalysis products, SODA (Carton et al., 2018) and GODAS-MOM4p1 (Rahaman et al., 2016; 2018) performed best statistically, compared to buoy data at SEAS (Table-1). All models successfully captured the bimodal seasonal SST cycle in the SEAS, with peaks in April–May and cooling during the monsoon months (Figure-1A). However, the inter-model spread was highest in the SEAS with a consistent spread of 0.5^{0}C, indicating greater uncertainty compared to the central Arabian Sea. Satellite-derived products like AMSR2 exhibited a warm bias (Figure-1B), likely due to measurement techniques that capture sub-skin rather than bulk SST (Rahman and Rahaman, 2024). The accuracy of reanalysis products depended on factors such as input data quality, model resolution, and assimilation techniques. Nearshore SST accuracy remained a challenge, as coastal dynamics, river inflows, and upwelling events introduced variability that models struggled to resolve.

The study emphasizes the need for continuous improvements in SST monitoring in the SEAS to enhance climate forecasting, disaster preparedness, and marine resource management. SST anomalies in this region directly influence the monsoon rainfall, making accurate data essential for improving seasonal forecasting models used by agencies like the India Meteorological Department (IMD). Improved SST monitoring benefits operational oceanography, supporting maritime navigation, offshore industries, and coastal planning.

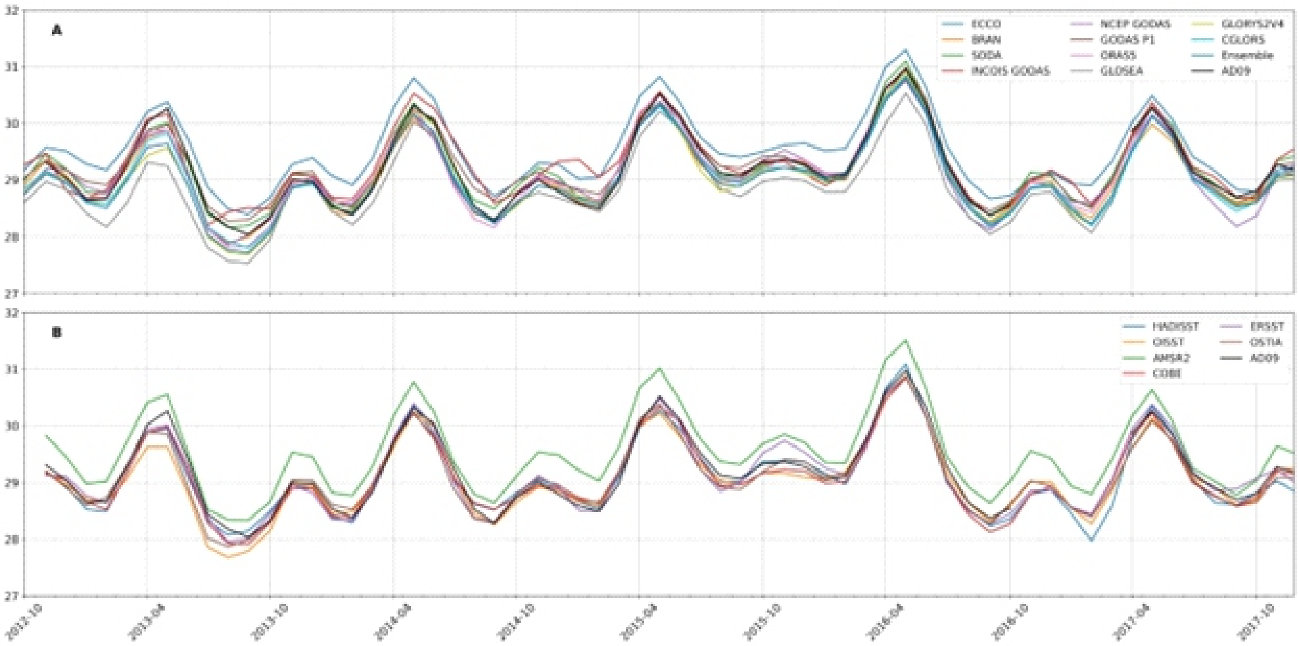

Figure-2: The SST time series of (A) all reanalysis products and (B) all observational products at South Eastern Arabian Sea (AD09) location.

Conclusion

The evaluation of SST from ocean reanalysis products in the Southeastern Arabian Sea implies the importance of reliable SST data for climate studies, weather forecasting, and marine applications. While SODA and GODAS-MOM4p1 emerged as the most accurate reanalysis product among the ten reanalysis products, ongoing improvements in SST retrieval methods and model parameterization are necessary to enhance prediction capabilities in this dynamic region.

The findings emphasize the need for higher-resolution reanalysis products and better data assimilation techniques to improve SST representation, particularly near the coast. As the Indian Ocean plays a pivotal role in global climate systems, continued research in SST variability and its impacts will be essential for advancing climate resilience and sustainable ocean management.

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Buoy ID		ECCO	BRAN	SODA	NCEP-GODAS	GODAS-MOM4P1	ORAS5	GLORYS	GLOSEA	C-GLORS	GREP	ERSST	COBE	OSTIA	OISST	HADISST	AMSR2	BUOY
AD09	MEAN	29.55	29.10	29.25	29.14	29.28	29.15	29.07	28.91	29.09	29.06	29.20	29.13	29.13	29.10	29.15	29.57	29.21
	BIAS	0.34	-0.11	0.04	-0.08	0.07	-0.06	-0.14	-0.30	-0.12	-0.16	-0.02	-0.08	-0.08	-0.11	-0.06	0.36	-
	CC	0.97	0.99	0.98	0.96	0.98	0.98	0.97	0.95	0.99	0.97	0.98	0.98	0.97	0.97	0.98	0.98	-
	RMSE	0.37	0.16	0.12	0.19	0.14	0.15	0.21	0.37	0.17	0.21	0.15	0.14	0.18	0.20	0.15	0.39	-
	STD	0.66	0.63	0.65	0.66	0.61	0.70	0.67	0.65	0.66	0.66	0.69	0.66	0.65	0.66	0.67	0.72	0.68
AD10	MEAN	29.52	29.12	29.27	29.24	29.36	29.21	29.18	28.97	29.16	29.13	29.25	29.14	29.18	29.18	29.18	29.62	29.29
	BIAS	0.23	-0.17	-0.02	-0.05	0.06	-0.08	-0.12	-0.33	-0.14	-0.17	-0.04	-0.15	-0.11	-0.12	-0.11	0.33	-
	CC	0.97	0.99	0.98	0.98	0.99	0.98	0.99	0.97	0.99	0.99	0.95	0.10	0.98	0.99	0.97	0.97	-
	RMSE	0.27	0.20	0.10	0.14	0.12	0.13	0.14	0.35	0.17	0.18	0.20	0.18	0.18	0.16	0.19	0.37	-
	STD	0.66	0.57	0.62	0.58	0.59	0.62	0.62	0.59	0.61	0.61	0.65	0.64	0.59	0.59	0.66	0.68	0.63

Table-1: The mean, bias, correlation coefficient (CC), root mean square error (RMSE) and standard deviation (STD) of SST for South Eastern Arabian Sea buoy locations (AD09 and AD10) calculated from October 2012 to December 2017.

Cruise SO308 South Indian Ocean GEOTRACES Gi07

31st October – 22nd December 2024
Durban (South Africa) – Fremantle (Australia)

Eric Achterberg and SO308 team, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

The GEOTRACES research cruise SO308 on the German vessel SONNE sailed from Durban (South Africa) to Fremantle (Australia) across the South Indian Ocean in the period October 31 to December 22, 2024. We have sampled shelf and slope stations along the Mozambique coast, crossed the Mozambique Channel and sampled along the EEZ of Madagascar. We crossed the oligotrophic gyre of the South Indian Ocean along about 23°S and visited stations on the Central Indian Ridge. We furthermore studied the shelf and slope system off Western Australia whilst sailing south with the Leeuwin current. Each station we sampled in detail the water column from the surface ocean to the seafloor, and collected water and particle samples. We used a titanium CTD rosette frame (Figure-1) for sampling of contamination-prone elements. The stainless steel CTD frame was used for non-contamination prone sampling of elements and isotopes like radium, thorium, uranium, rare earths and neodymium. This CTD was also used for sampling of microbial communities, metagenomics and proteomics. The CTD frames are full of biogeochemical sensors, and cameras to observe zooplankton and sinking particles. Every 2 or 3 days, at our superstations, we also added an additional stainless steel CTD cast, and deployed 7 in situ pumps to a maximum depth of 800 m for particle collection.

Figure-1: Titanium CTD frame comes on deck on RV SONNE. Photo A. Hollister.

In addition, we sampled aerosols, but also sediments with a mini multicorer (MUC). To operate in a time efficient manner, we hang the mini MUC underneath the CTD frame. The combined deployments have been very successful. One of the 4 cores is used for pore water extraction to allow determination of benthic fluxes to the bottom waters.

The research topic of the cruise is to determine in detail the distributions, sources and sinks of trace elements and their isotopes (TEIs) in the water column along a zonal section in one of the least studied ocean regions on earth. We aim to investigate the biogeochemical cycling of TEIs, and their interactions with surface ocean productivity and the carbon and nitrogen cycles (incl. N_2 fixation) given that some TEIs act as micronutrients. The supply pathways of TEIs to the South Indian Ocean from ocean boundaries is proposed to be investigated, including inputs from the atmosphere (east African and northwest Australian dust), continents (Zambezi river), sediments (on continental shelves/slopes and deep seafloor), and ocean crust (hydrothermalism). The TEI transport within water masses will be determined with a focus on the flow of hydrothermally derived TEIs towards the Southern Ocean but also the deep inflow of Southern Ocean waters into the SIO. The TEI transport assessment along the cruise track will also allow a more reliable use of some TEIs as paleo circulation proxies. The cruise forms an official contribution to the International GEOTRACES Programme and the Second International Indian Ocean Expedition.

At the end of the cruise, we have in total sampled 51 stations along our transect of about 11500 km between Durban and Fremantle (Figure-2). A total of 16 stations were superstations with an additional CTD deployment with seven in situ pumps. We had planned 51 stations, and we also completed them, with the locations of most stations as initially planned. This is rather unique in my experience as typically there are a range of changes to the station programme on our expeditions. We had to sail somewhat further south in the region south of Reunion and Mauritius, in order to avoid the strongest impacts of an westwards moving hurricane.

The Sonne cruise SO308 was very successful, and we achieved the majority of our objectives. We sampled for aerosols, dissolved and particulate trace elements and isotopes in the water column, sediments using a mini-multi-corer, and particle export including biomarkers for particle degradation. In addition, we conducted an extensive biology programme, aligned with the ambitions of BIOGEOSCAPES, which included collection of proteomic and metagenomic samples, assessment of microbial methane producers, (micro)nutrient limitation bioassays of phytoplankton growth, and assessment of diazotrophy. We deployed 19 Argo profiling floats, many of them with biogeochemical sensors, along the transect for the US and German Argo communities.

The cruise involved a range of national and international research groups and we had 15 different nationalities on board which created an excellent multi-cultural environment. The cruise was led by GEOMAR, and we had scientists involved from Constructor University, ZMT Bremen, the Universities of Tasmania, Xiamen, Zhejiang, Minnesota, South Florida, Chicago, Stanford, University College London, the Alfred Wegener Institute, Woods Hole, Max Planck Institute for Marine Microbiology (Bremen), IAEA Monaco, Helmholtz-Zentrum Hereon.

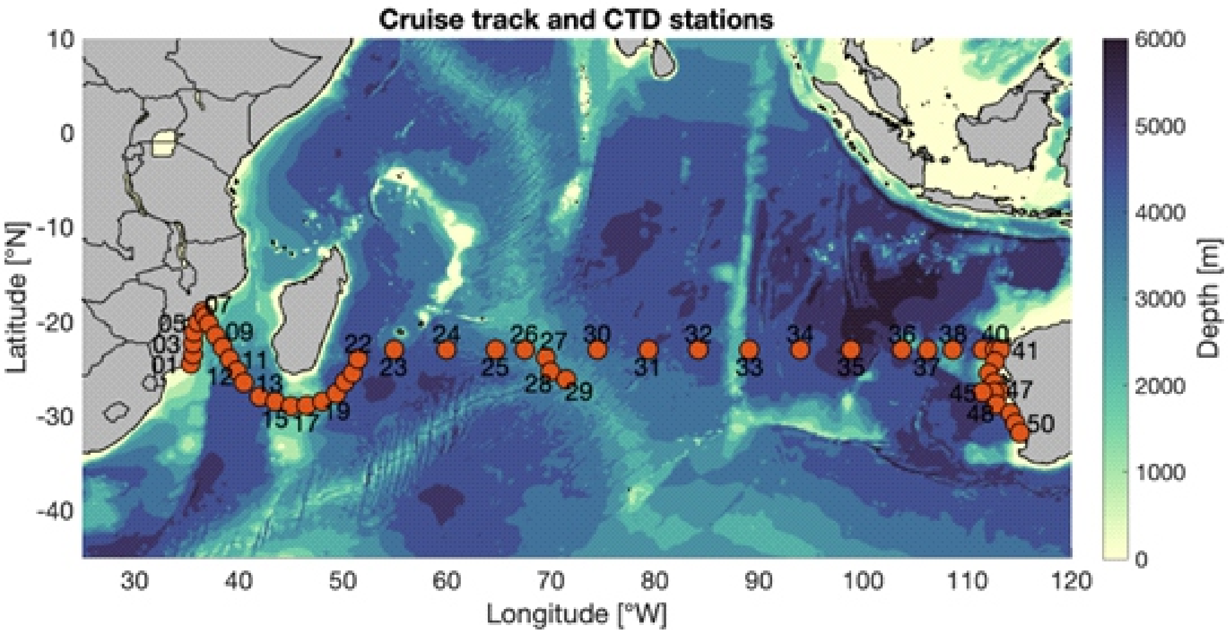

Figure-2: The cruise track with 51 stations (red dots) along the section.

In the coming months there will be plenty of samples to be analysed, and then manuscripts to be written. The success of the cruise was due to the great international team effort from all involved (Figure-3), both on land and on the vessel. In particular I would like to mention the captain and crew, who contributed greatly to the success of the cruise.

Figure-3: Scientists of SO308. Photo by Eric Achterberg.

Eric Achterberg and SO308 team
GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany

7th International Conference on Ocean Engineering (ICOE2025)

September 14-18, 2025, IIT Madras

The 7th International Conference on Ocean Engineering (ICOE2025) is set to be one of the most significant gatherings in the field of ocean science and engineering. Organized with a focus on the Blue Economy and sustainable ocean practices, ICOE2025 promises to be a transformative event, bringing together experts, innovators, and thought leaders from around the globe. Hosted by renowned institutions like the Indian Institute of Technology Madras (IIT Madras) and supported by various national and international partners, ICOE2025 is poised to drive new solutions for some of the most pressing challenges facing our oceans today.
Why Attend ICOE2025?

This year's conference will focus on a range of crucial topics, including:

- **Blue Economy:** Promoting sustainable use of ocean resources to drive economic growth while protecting marine ecosystems.
- **Sustainability:** Exploring the balance between development and conservation through cutting-edge technologies and innovative solutions.
- **Fisheries Management:** Discussing sustainable fishing practices and their role in ensuring food security and marine biodiversity.
- **Marine Energy:** Highlighting advances in renewable ocean energy systems and their potential to shape the future of clean energy.
- **Coastal Vulnerability & Erosion:** Addressing the impacts of climate change on coastal areas and finding solutions to mitigate risks.
- **Ocean Exploration:** Delving into the scientific advancements in oceanography and the importance of exploring and understanding our oceans.

Why is ICOE2025 Important?

The need to address the challenges facing our oceans has never been more urgent. Climate change, overfishing, and pollution threaten marine life and the livelihoods of communities that depend on the sea. ICOE2025 will serve as a hub for innovation, collaboration, and research to drive forward the sustainable use of ocean resources. The conference will feature distinguished speakers, world-class researchers, and hands-on workshops, allowing attendees to gain insights into the latest scientific developments, emerging technologies, and best practices for ocean sustainability.

Key Highlights of ICOE2025:

- Global Collaboration: A platform for interaction between scientists, policymakers, engineers, and industry professionals from across the world.
- Workshops and Special Sessions: Focused discussions and hands-on experiences aimed at tackling real-world ocean challenges.
- Research and Innovation: Opportunities to showcase the latest in ocean engineering and marine technologies.
- Networking: Build lasting partnerships that foster collaboration and knowledge exchange.
- Advocacy for the UN Ocean Decade: ICOE2025 will actively promote the mission and goals of the UN Ocean Decade, aligning with global efforts for sustainable ocean stewardship.

Get Involved

Whether you are a researcher, a policy maker, an engineer, or a student, ICOE2025 offers an invaluable opportunity to contribute to the global conversation on the future of our oceans. Together, we can shape the future of ocean engineering and ensure that the Blue Economy becomes a driving force for a sustainable and prosperous future.
Join us at ICOE2025 – an event not to be missed in the pursuit of ocean sustainability!
For more information, visit our website at https://ge.iitm.ac.in/icoe2025/.

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: **25th June, 2025**

Send your contributions as usual to **iioe-2@incois.gov.in**

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