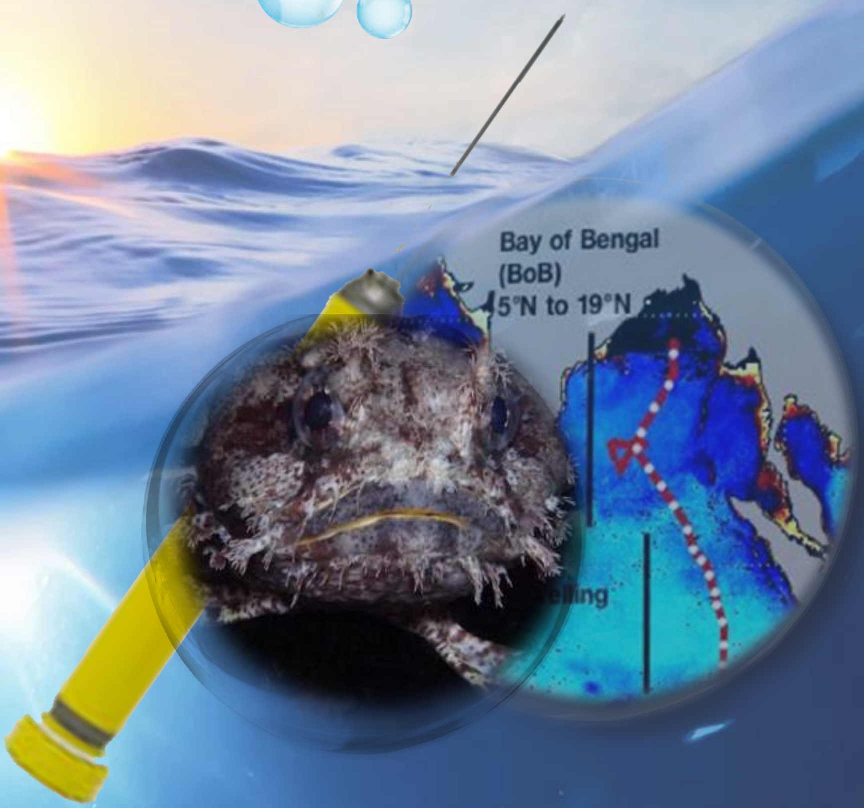
INTERNATIONAL INDIAN OCEAN EXPEDITION

Issue No. 10
February 2019

The Indian Ocean Bubble 2



IN THIS ISSUE

Current Affairs - Programmes/Committees

Proposed new structure for delivering IIOE-2

P Burkill[1], S Shenoi[2], V Ryabinin[3], H W Bange[4], R Hood[5], S Nayak[6], N D'Adamo[7], S Prakash[1] and E Urban[8]

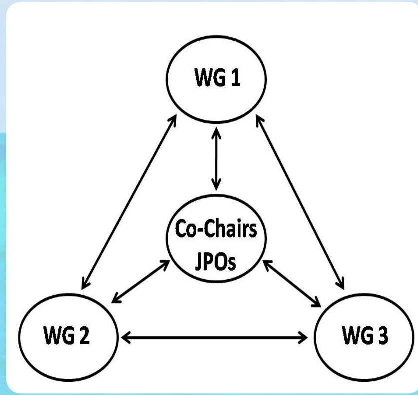
[1]University of Plymouth
[2]Indian National Centre for Ocean Information Services
[3]Intergovernmental Oceanographic Commission-UNESCO
[4]GEOMAR Helmholtz Centre for Ocean Research Kiel
[5]University of Maryland
[6]National Institute of Advanced Studies
[7]UNESCO IOC Perth Programme Office
[8]Scientific Committee on Oceanic Research (SCOR)

At the 2018 Steering Committee (SC) meeting in Jakarta, we discussed the IIOE-2's governance structure. Our main conclusion was that it was too complex, requiring too much of people's time. It was also too costly to run because sponsors were paying for a large number of participants to attend the meetings. Hence, there was a suggestion to develop a more cost-effective governance structure for IIOE-2, to enable the Core Group to best facilitate high level issues in support of the Steering Committee as a whole. We outline here a slimmed down governance structure to be discussed further at the next SC in March 2019. We present this to allow you to consider it in advance of the meeting.

What are the three sponsor's positions? SCOR is the sponsor that provides the most direct support to get people to meetings. While there is a general agreement that SCOR will pay $25k each year to facilitate IIOE-2 until 2020, we need to be mindful of SCOR's return on this investment. SCOR's main strength is funding SCOR Working Groups and it funds two new ones each year costing $30k each per year. The WGs are the heart of SCOR and they have been hugely successful at opening up new research topics through publishing findings in peer-reviewed papers. SCOR also oversees large-scale programmes, but the funding of these is generally pass-through funds from NSF, while SCOR's international programme offices are normally funded by host nations. For SCOR, IIOE-2 is unusual in being a large-scale programme that requires funds derived from SCOR dues, competing with funding for SCOR working groups. What will happen after 2020? That will be for the SCOR Executive Committee to decide, but there has already been discussions leading to the feeling that if IIOE-2 is continued to be supported, it has to deliver more scientific output for SCOR's investment. Although this will be challenging, it is a major motivator for reducing the complexity of our governance structure.

IOGOOS is an association of marine science institutes in the Indian Ocean region and aims at promoting, planning and executing collaborative projects in the region. Through the sponsorship of IIOE-2, IOGOOS is looking at the scientific outcomes of the project as well as the benefits to its members. IOGOOS has committed to support IIOE-2 to an extent of $10k each year utilising the budgetary support that it receives from IOC for functions in the Indian Ocean region. That funding is mainly used for the travel of its members to attend the meetings of IIOE-2 Steering Committee, IIOE-2 WGs and the annual meeting of IOGOOS.

Through the sponsorship of IIOE-2, the Intergovernmental Oceanographic Commission of UNESCO, or IOC, is looking at creating new knowledge that would be highly relevant for sustainable development of Indian Ocean riparian states. One pillar of this work is capacity development in marine research. IOC also would like to enhance communication between researchers and managers to enable informed policy decisions by member states as well as international bodies for effective ocean management and preservation. The cash contribution of IOC for SC member travel to meetings is currently limited, but it provides the much-needed platform for IIOE-2 functioning including the Joint Project Office (JPO) node in Perth, Australia, which works in concert with the other JPO node in Hyderabad, India, supported by the Indian Government.



As an outline for the new Core Group, we propose to simplify the current structure for the delivery of IIOE-2 as follows:

The Core Group will comprise:
IIOE-2 Co-Chairs (nominated by the three main sponsors).
WG 1 Chair(s): Science & Research (nominated by the Co-Chairs).
WG 2 Chair(s): Data & Information Management (nominated by the Co-Chairs)
WG 3 Chair(s): Operational Co-ordination (nominated by the Co-Chairs).
Heads of the IIOE-2 JPOs in Hyderabad, India, and Perth, Australia

The SCOR office in Delaware, USA (not shown above), will administer SCOR funds it contributes to IIOE-2. The Core Group will continue to meet by teleconference approximately every 6 weeks and will continue to deal with high level strategic issues.

Within WG1, the formal Science Theme Committee structure (currently comprising six Science Theme (ST) teams) is consolidated into one, reducing expenses and streamlining the overall functioning. This flattens the structure with the research into a single entity, while noting that the Chair(s) of WG1will need to decide how they will interact with the former chairs of ST 1-6.

WG2 Data & Information Management will continue its work without change.

WG3 would consolidate into one that would include former specific WG functions of Outreach & Communication, Sponsorship & Resources, Capacity Development and Translating Science for Society, respectively. A new sub-group will be tasked with Ocean Remote Sensing within WG3, perhaps as a 'task team' within WG3.

It will be for each of the chairs of WG 1, 2 and 3 to decide how they can best deliver their responsibilities. The next step will be to spell out the Terms of Reference for each component of the Core Group and that will be discussed and finalised at the March meeting in Port Elizabeth.

If you have any comments, please get in touch with one of the Co-Chairs (peter.burkill@plymouth.ac.uk; shenoi@incois.gov.in; v.ryabinin@unesco.org) and note that we aim to finalise the new Structure at the Port Elizabeth meeting in March 2019.

IIOE-2 Working Group 1 'Science & Research' Meeting, Kiel, 28-30 November 2018

Raleigh Hood[1], Hermann W. Bange[2], and Nick D'Adamo[3]

[1]University of Maryland Center for Environmental Science, Cambridge MD, USA
[2] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
[3] Perth Programme Office in support of the Intergovernmental Oceanographic Commission of UNESCO, Perth WA, Australia

IIOE-2 Working Group 1 convened a workshop at the GEOMAR Helmholtz Centre for Ocean Research in Kiel on November 28-30, 2018. With sponsorship from SCOR and the Kiel Future Ocean Excellence Cluster and hosted by Helmholtz Centre, the IIOE-2 science theme leaders met for 3 days to discuss the generation of scientific products to highlight IIOE-2 progress 3 years into the 5 year expedition and begin related forward thinking for a prospective continuance of IIOE-2 into the next decade, including in light of the IIOE-2's potential role in contributing both in its own right and also as a model case to the UN Decade of Ocean Science for Sustainable Development 2021-30. These products will include 1) a Joint Program Office (JPO) flyer designed for distribution to policy makers and the public, 2) a special issue of synthesis papers inspired by the IIOE-2 Science Plan research themes, and 3) a summary paper highlighting IIOE-2 progress for the special issue and for publication as an information article in a high profile scientific journal such as Science or Nature.

In addition to overview presentations by the science theme leaders and the German IIOE-2 National Committee, keynote presentations were given by GEOMAR Scientists Martin Visbeck, Jonathan Durgadoo, Colin Devey, and Cathleen Schlundt. There were special presentations given by Arvind Singh from PRL, India, on the activities and progress of the IIOE-2 Early Career Scientists Network (ECSN), and by Cyndy Chandler from WHOI, USA, on IIOE-2 data and information management. Combined, these presentations provided a broad overview of the activities and achievements of IIOE-2 thus far, and also highlighted some exciting new scientific challenges emerging in the Indian Ocean and globally.

The agenda was designed to provide ample time for discussion, which mostly revolved around finalizing the JPO flyer and the synthesis papers. Eight synthesis papers are anticipated related to 1) the unique biogeochemical features of the northern Indian Ocean (led by Tim Rixen), 2) plastic pollution (led by Chari Pattiaratchi), 3) saltwater intrusion (led by Willard Moore), 4) the physical and biogeochemical dynamics of upwelling and boundary currents (led by P. N. Vinayachandran), 5) circulation and air/sea exchange (led by Amit Tandon), 6) extreme events (led by Chari Pattiaratchi), 7) marine geology and geophysics (led by Jerome Dyment), and 8) atmospheric chemistry and physics (led by Susann Tegtmeier). There was a strong consensus that this special issue should be published in a joint special issue of the EGU journals Biogeosciences, Ocean Science and Atmospheric Chemistry and Physics. Synthesis papers are still being solicited for this special issue related to the IIOE-2 Science Plan science themes or other topics in the Indian Ocean. Please contact Hermann Bange (hbange@geomar.de) or Raleigh Hood (rhood@umces.edu) if you are interested in leading a synthesis paper for this special issue.

Kiel WG1 Workshop participants. Front row from left to right: Birgit Gaye, Doreen Rößler, Rena Czeschel, Jonathan Durgadoo, PN Vinayachandran, Raleigh Hood, Cyndy Chandler, and Tim Rixen. Back row from left to right: Chari Pattiaratchi, Arvind Singh, Ed Urban, Martin Visbeck, Peter Burkill, Nick D'Adamo, Yukio Masumoto, Jerome Dyment, Hermann Bange. Not Pictured: Colin Devey, Ben Milligan, Cathleen Schlundt, Amit Tandon

Out-of-the Box- Citizen Science and Resources

First comprehensive book on the nature of Timor-Leste, underwater and on land

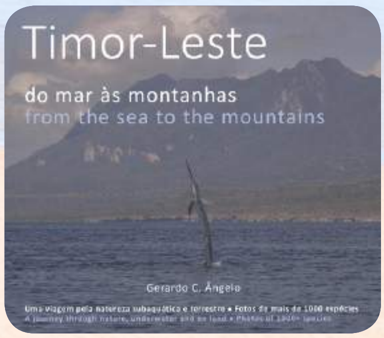
Gerardo Angelo*
** timorlestebook@futursilaba.com*

The author is an enthusiast that has travelled worldwide in search of elusive species. Living in Timor-Leste for an extended period allowed him to thoroughly observe its vast array of marine and terrestrial species. Born in Lisbon, Portugal, he pursued a career in engineering and management.

Located between Indonesia and Australia, well within the so-called Coral Triangle, Timor-Leste is one of the youngest and least-known countries in the world, after having regained its independence in 2002. The sea around Timor-Leste reaches depths of more than 3,000 metres, and all sorts of fascinating underwater habitats can be found along its coast, most still in pristine condition.

On land, mountains soar to almost 3,000 metres above sea level, and mysterious forests can still be found in many of the remote areas. These are, for the people who live in their vicinity, sacred places. "Timor-Leste: from the sea to the mountains" takes us on an unprecedented in-depth photographic journey through the nature of this country and its outstanding biodiversity.

Seven years in the making, this book includes photographs of more than 900 species of fish, molluscs, crustaceans and other marine animals, all of wild specimens in their natural habitats in the waters of Timor-Leste, as well as more than 100 species of birds, reptiles and mammals, many of them endemic. It is also an account of the experiences, often adventurous, of travelling to some of the most secluded places in this nation.



Aimed at raising awareness of this exceptional biological richness and at fostering engagement with conservation efforts, both locally and abroad, this book is also an invaluable resource for scuba divers, birdwatchers and the academic community and the first comprehensive book about the biodiversity of Timor-Leste, underwater and on land.

Species were identified by common and scientific names in their respective pages, and there's a comprehensive species index at the end, organized by taxonomy, which also includes the detailed location for each photo. The WoRMS database (as of June 2017) was used to check taxonomy.

A few fish highlights in the book include:

- Diamond filefish (Rudarius excelsus)
- Nuptial displays of flasher wrasses (Paracheilinus flavianalis and P. paineorum)
- Banded toadfish (Halophryne diemensis)
- Lanternfish (Myctophum sp.)
- Striped marlin (Kajikia audax)
- Guitarfish (Rhynchobatus australiae)

The book is an extensive resource and available for purchase at https://www.nhbs.com/timor-leste-from-the-sea-to-the-mountains-do-mar-as-montanhas-book and Amazon.

Timor-Leste: do mar às montanhas / from the sea to the mountains

ISBN: 978-989-54067-0-8

Count of species included in the book per Phylum, Class, Infraclass/Subclass:

Chordata	705	Aves	90		
		Reptilia	7		
		Mammalia	9		
		Actinopterygii	588		
		Elasmobranchii	9		
		Ascidiacea	2		
Arthropoda	88	Arachnida	2		
		Insecta	5		
		Malacostraca	81	Eumalacostraca	77
				Hoplocarida	4
Mollusca	178	Bivalvia	13	Heterodonta	6
				Pteriomorphia	7
		Cephalopoda	10	Coleoidea	10
		Gastropoda	154	Caenogastropoda	66
				Heterobranchia	2
				Opisthobranchia	84
				Vetigastropoda	2
Cnidaria	34	Anthozoa	33	Ceriantharia	3
				Hexacorallia	18
				Octocorallia	12
		Scyphozoa	1	Discomedusae	1
		Polyplacophora	1	Neoloricata	1
Echinodermata	36	Asteroidea	17		
		Echinoidea	7	Cidaroidea	1
				Euechinoidea	6
		Holothuroidea	11		
		Ophiuroidea	1		
Annelida	6	Polychaeta	6	Errantia	2
				Sedentaria	4
Ctenophora	1	Tentaculata	1		
Nemertea	2	Anopla	1	Heteronemertea	1
		Enopla	1	Hoplonemertea	1
Phoronida	1				
Platyhelminthes	5	Rabditophora	5	Trepaxonemata	5
Porifera	3	Demospongiae	3	Heteroscleromorpha	3
Tracheophyta	2				
Xenacoelomorpha	1				
Chlorophyta	1	Ulvophyceae	1		

Ocean Voice - Opinions/Discussion

A Shout-out for Better Estimates of Ocean Mixed Layer Depths from Observations

Prof. Raghu Murtugudde

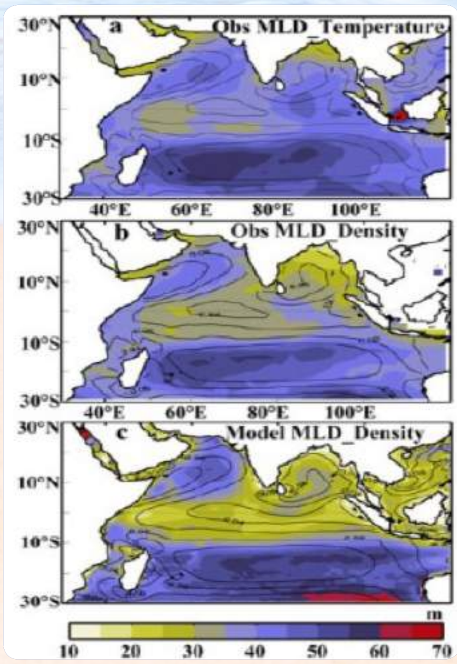
University of Maryland

mahatma@umd.edu

Prof. Murtugudde specialises in Earth System Modelling and Predictions and specifically focuses on Climate Impacts and the Ocean's Role in Climate Variability

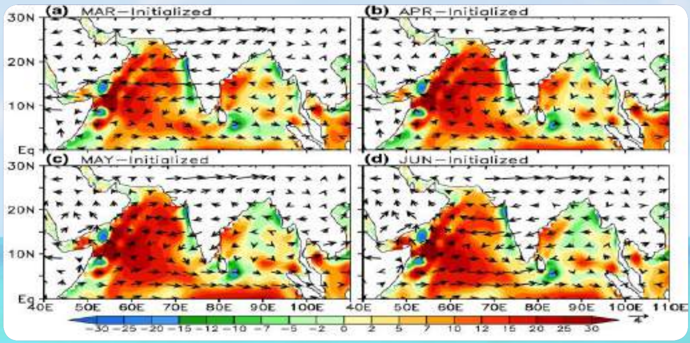
Oceanic mixed layer depth (MLD) is not a directly observable quantity and yet it is crucial for determining SSTs and thus for air-sea interactions, coupled climate variability as well as ecosystem and biogeochemical variability. Very high resolution near-surface temperature and salinity observations will be needed to estimate the MLDs with concurrent turbulent kinetic energy (TKE) so that forced ocean and coupled climate models can be validated against both MLDs given the TKE or MLDs with corresponding TKEs.

The Indian Ocean is characterized by the seasonally reversing monsoon winds but also dominated by intraseasonal variability with much of the MLD response and feedbacks yet to be fully understood at these timescales. The complex vertical structures, especially in the Bay of Bengal where freshwater forcing is a major contributor to the vertical structure, underscore the need for better observational estimates of MLDs. Not only is the monsoon variability and trend highly dependent on MLDs and BLTs in the Indian Ocean, they are also important for ENSO via their impact on the monsoon and MJOs.



From Keerthi et al. (2013) (Figure 2) showing climatological MLDs derived from hydrographic dataset using temperature criterion overlaid by climatological wind stress form QuikSCAT. b. Same from Argo using density criterion. c. Same for model MLD with density criterion and wind stress.

Observational estimates of MLDs do exist but they are limited by the availability of observations, most importantly their spatial coverage and vertical resolutions. Argo has now led to some estimates of intra-seasonal variability of MLDs as well as the BLTs. Such diagnostic estimates often struggle with the very definition of MLDs (see figure from Keerthi et al. (2013) above). We are forced to rely on acceptable MLDs from forced OGCMs to advance process understandings for MLD-dependent ocean variability. We have no such luck in coupled models since MLDs in most coupled models seriously deficient



From Narapusetty et al. (2018) (Figure 6) showing biases in MLDs and 850 hPa winds for July-August forecasts in CFSv2 initialized in March, April, May and June, respectively. Model MLDs are significantly deeper than ocean reanalysis estimates and the associated SSTs are much colder than observed.

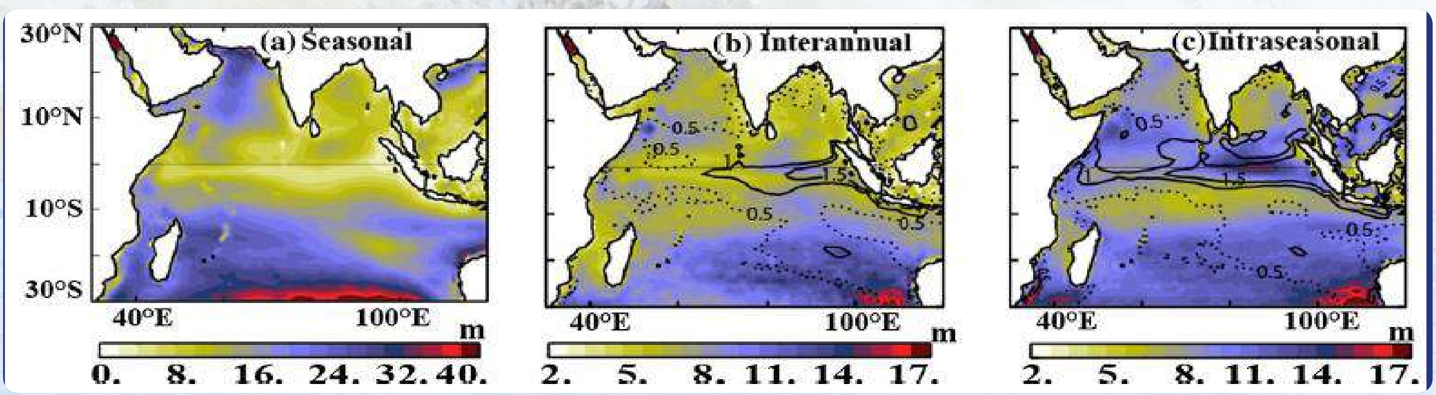
(see figure from Narapusetty et al. (2018) below).

Coupled model biases have persisted for well over a decade now and the most irksome ones in the tropics include the double ITCZ in the Pacific, the reversed SST gradient in the equatorial Atlantic and the reversed thermocline gradient in the equatorial Indian Ocean. As for the monsoon itself, the dry bias on the Indian subcontinent remains a major challenge for predictions and projections. Much attention is paid to the deficiencies in the atmospheric models when it comes to coupled climate model biases. But ocean's role cannot be ignored.

For example, ocean models tend to suffer from a diffuse thermocline which would indicate that diapycnal mixing may already be excessive and additional mixing may only worsen the model performance. And yet, a new parameterization of the Near-Inertial Wave mixing in the NCAR CESM was found to remove the double ITCZ (Jochum et al. 2013). Oceanic ML models have historically been bulk models which do not account for horizontal processes that affect MLDs. Diffusivity profile-based ML models address these concerns. Additional processes are now being introduced to represent the impacts of mixed layer eddies and Langmuir turbulence. Validation of these ML models at large-scales remains a challenge.

Despite the skin and bulk issues, we know much about SSTs in terms of their variability and trends. The same cannot be said about MLDs. Models are used to estimate subseasonal-to-interannual variability of MLDs (see figure from Keerthi et al. (2016) below). Organization of SSTs at all these timescales are critical for tropical climate variability which are intimately tied to MLD variability. Validation of model results for MLDs against observational estimates are thus critical.

Of course, the big gorilla in the room is the diurnal cycle of MLDs. While some diurnal cycle formulations exist, the impact of the diurnal cycle on mixing in the ocean remains a mystery. But that's for another day.



From Keerthi et al. (2016) (Figure 1) showing the standard deviation of MLD variations (in m) in the Indian Ocean at a seasonal, b interannual and c intraseasonal timescales from a ¼° simulation provided by the DRAKKAR project detailed in Keerthi et al. (2013). Contours on panel b (resp. c) show the ratio of interannual (resp. intraseasonal) against seasonal MLD standard deviation. This figure is adapted from Keerthi et al. (2013)

Ocean Vision

Elemental View - Chemistry

Biogeochemistry of the Indian Ocean

Catherine A. Garcia[1], Steven E. Baer[2,4], Nathan S. Garcia[1], Sara Rauschenberg[2], Benjamin S. Twining[2], Michael W. Lomas[2], Adam C. Martiny[1,3]

1. Department of Earth System Science, University of California at Irvine, Irvine, CA, 92617, USA

2. Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, 04544, USA

3. Department of Ecology and Evolution, University of California at Irvine, Irvine, CA, 92617, USA

4. Present address: Maine Maritime Academy, Castine, ME, 04420, USA

First Author Garcia is a PhD candidate focussed on Indian Ocean studies, specifically regarding phytoplankton diversity and their elemental composition

The Indian Ocean accounts for a fifth of global ocean net primary production (Behrenfeld and Falkowski 1997). As in other ocean basins, the surface phytoplankton community holds a central role in shaping the chemical distributions of key nutrients. While extensive research on the biogeochemical dynamics has been done in the Arabian Sea (Garrison et al. 2000; Morrison et al. 1998; Owens et al. 1993), Bay of Bengal (Kumar et al. 2004; Madhupratap et al. 2003; Thomalla et al. 2011), Indian sector of the Southern

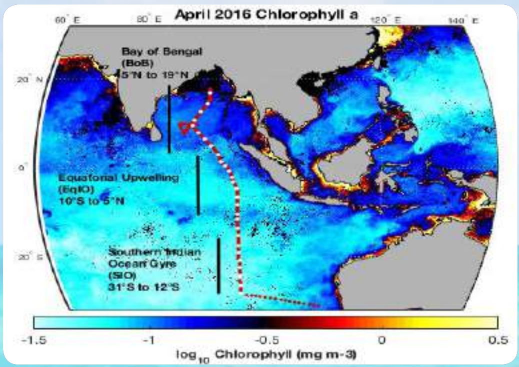


Figure 1: Study region. I09N GO-SHIP transect and proposed biogeochemical regions (SIO, EqIO, BoB). Stations sampled in Baer et al. are marked by white dots, and by Garcia et al. with both red and white. Chlorophyll a concentrations are form MODIS-Aqua April 2016.

ocean (Bianchi et al. 2018; Schlüter et al. 2011; Tyrrell 1999; Thomalla et al. 2011), and the Australian Coast (Waite et al. 2007), the central Indian Ocean is less well known. As part of a collaborative effort, researchers from the University of California, Irvine and Bigelow Laboratory for Ocean Sciences investigated the interactions between microbial community composition, nutrient uptake kinetics, primary productivity, and particulate matter elemental composition along a transect from the ultra-oligotrophic Indian Ocean into the Bay of Bengal. In March/April 2016, we participated in the GO-SHIP I09N (Global Ocean Ship-Based Hydrographic Investigations Program) transect from Fremantle, Australia to Phuket, Thailand aboard the R/V Roger Revelle (Fig.1). We collected surface and near surface (20m) biogeochemical measurements to complement the core hydrographic measurements typical of GO-SHIP cruises. Here, we describe the outcome of two studies recently published in Nature Communications (Garcia et al. 2018) and Deep-Sea Research Part II (Baer et al. 2018). Two further studies, which are currently in review will highlight the trace mental composition of particles and diversity of Cyanobacteria along this transect.

Prior efforts by the repeat WOCE lines and the first International Indian Ocean Expedition (IIOE) have captured the physical and chemical variability in the central Indian Ocean, but have focused less on the biology, aside from bulk chlorophyll. Based on existing nutrient profiles and physical observations, we expected the structure of the planktonic community, particulate elemental matter, and carbon and nitrogen productivity to vary between three hypothesized regions; the South Indian Ocean (SIO) gyre, a equatorial upwelling (EqIO) region, and the Bay of Bengal (BoB) intermonsoon gyre (Fig. 1). At a glance, the surface layer was warm (21°C in the SIO gyre to >30°C northwards), with inorganic nutrients below routine analytical detection (Fig. 2 a,b). Starting at the base of the euphotic zone, nutrients concentrations increased rapidly through the nutricline. In the study by Garcia et al., we used the initiation depth of the nutricline at each station as an indicator of the supply of nutrients to mixed layer (Fig 2b.). In the SIO gyre, we observed a deep nutricline near 130m, which rapidly shoaled (< 62m) around the Indonesian throughflow and remained shallow into the Bay of Bengal. Nutrient fluxes into the base of the euphotic zone, calculated in the study by Baer et al., confirm increasing fluxes of nitrate and phosphate as we moved northwards. High temperatures are often associated with nutrient-impoverished conditions, but along this transect the highest temperatures were found where nutrient supply was measured to be highest. This was in part driven by upwelling near the equatorial zone as well as higher nutrient water from the Lombok Strait, Ombai and the Timor Passage coming in this part of the tropical Indian Ocean. A positive relationship between temperature and nutrient availability is rare in the

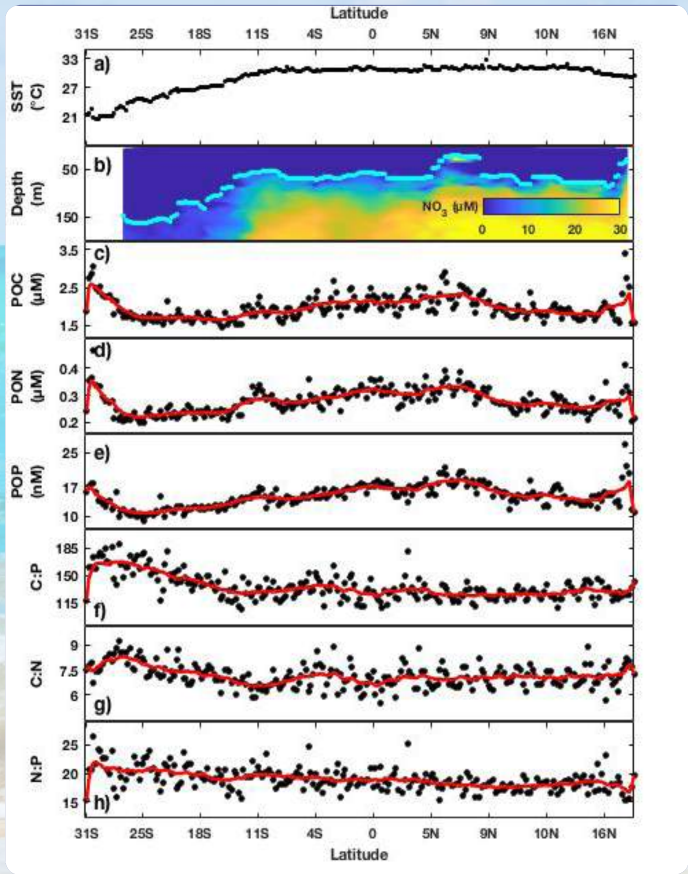


Figure 2: Observations of environmental conditions, relative phytoplankton biomass, POM concentrations, and ratios across the eastern tropical Indian Ocean. Sea surface temperature (a), nutricline depth (b), particulate organic carbon (c), nitrogen (d), and phosphorus (e), POC:POP ratio (f), POC:PON ratio (g), and PON:POP ratio(h). POM observations are filtered below 30 µm. Garcia et al. 2018.

open ocean. Thus, he patterns observed in the Indian Ocean in comparison to other ocean regions allowed us to separate the effects of temperature and nutrient supply on biogeochemical cycling.

The aim of the Garcia et al study was to understand how the concentration and elemental ratios (C:N:P) of particulate organic matter (POM) are controlled. Based on prior work, we proposed three biological hypotheses. The first hypothesis suggested that small, fast growing plankton like Prochlorococcus are frugal with nutrients and have high N:P and C:P ratio. The second hypothesis suggests that plankton need fewer phosphate rich ribosome when growing at high temperature leading to a positive relationship between temperature and C:P (Toseland et al. 2013). The third hypothesis suggests that plankton are more frugal with N or P when growing under oligotrophic conditions. Concentrations of particulate organic carbon, nitrogen and phosphorus all increased from the SIO gyre to the EqIO region (Garcia et al. 2018) (Fig. 2c-e). Despite high nutrient fluxes in the Bay of Bengal, the concentrations decreased in this region until the final station nearest the continental slope. This is likely due to increase stratification from freshwater inputs. POM C:N:P were the highest in the SIO gyre, but not significantly different in the other two regions (Fig 2f-h). Localized decreases in C:P and C:N occurred around the equator and the Indonesian throughflow when the nutricline shoaled. The unique environmental relationships in the central Indian Ocean helped us to understand that nutrient limitation is likely the most important regulator of plankton and POM C:N:P across low latitude regions.

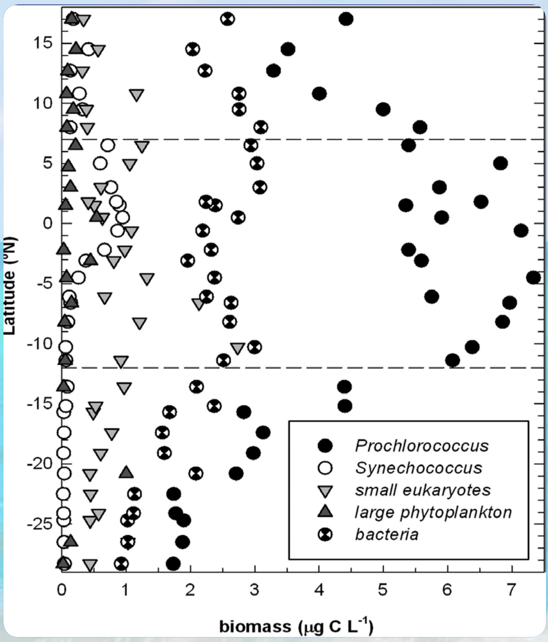


Figure 3: Microbial biomass estimates (μg C L-1) along the transect. Samples for phytoplankton and heterotrophic bacteria were collected at 20 m depth and normalized for carbon per cell (see Baer et al 2018). Horizontal dashed lines represent divisions between biogeochemical zones described in Baer et al. 2018

Baer et al. 2018 found that the autotrophic community was relatively constant. Single-cell cyanobacteria and heterotrophic bacteria dominated the planktonic community across the whole region (Fig 3). The absolute biomass (autotrophs and heterotrophs) was highest around 5°N and lowest in the SIO gyre. Approximately 40% of the absolute biomass was represented by heterotrophic bacteria. Of the autotrophic biomass, Baer et al. 2018 found that the majority of the phytoplankton carbon biomass (~78%) was dominated by Prochlorococcus. The contribution of of Synechococcus was small but increased around the equator. Small eukaryotes contributed on average ~20% to the autotrophic biomass along the entire transect, and large eukaryotic phytoplankton were insignificant. Although dominant, recent analysis of the micro-diversity within Prochlorococcus found niche-partitioning that corresponded to environmental gradients, and further confirms our division of the central Indian Ocean into three biochemical regimes (Larkin et al., in review). Thus, the central Indian Ocean communities are strongly dominated by picoplankton like Prochlorococcus but the overall biomass was low.

The study of Baer et al. provides a baseline of carbon and nitrogen productivity in the central Indian Ocean that can be used in biogeochemical models of the region. While the absolute value of nutrient uptake rates were generally low and typical of a low biomass system, the cell specific uptake rates were typical of an active growing community (Baer et al. 2018). Results reveal uptake rates of all nitrogen sources and carbon were significantly greater in the regions north of the SIO gyre, and peaked at ~5°N (Fig 4). Similar to particulate matter concentrations and biomass, absolute uptake rates decreased from EqIO into the Bay of Bengal. This is the third indicator that despite high nutrient fluxes and similar growth rates to the EqIO, the Bay of Bengal is accumulating less organic material than the Equatorial region to the south. The region around 5°N is where the nutricline is the shallowest and closest to the mixed layer depth. Northwards, the boundary between the mixed layer and nutricline expands. While upwelling is commonly observed near the equator, the intense stratification due to lower salinity, warmer temperatures, and low wind stress create a buoyancy barrier to vertical nutrient inputs in the Bay of Bengal (Kumar et al. 2002). Baer et al. found that phytoplankton biomass increased with shallower mixed layer and nutricline depths, and that the absolute carbon uptake correlated with phytoplankton biomass. Together these results suggest that sources of nutrient supply to the mixed layer under ultra-oligotrophic conditions shape the community structure and biomass, primary production, uptake rates, and elemental composition in the central Indian Ocean.

A surprising outcome was the importance of organic nutrients to nutrient cycling in the Indian Ocean (Baer et al. 2018). Of all the nitrogen uptake rates, the organic nitrogen source urea had the highest absolute uptake rates (Fig 4). A compilation of dissolved organic matter (DOM) concentrations reveal dissolved organic carbon (DOC) in the Indian Ocean is high compared to other regions, and cannot be explained by physical circulation (Hansell 2009). DOC concentrations and heterotrophic bacteria abundance in the Indian Ocean suggest active microbial recycling of organic matter, yet how DOC accumulates is a mystery given enriched DOP availability and high estimates of bacterial production (Fernandes et al. 2008). The ties between bacterial and primary production in the central Indian Ocean by all appearance are very dynamic and warrant further study.

We theorize that iron stress contributed to our observation that C:N:P ratios in the SIO gyre are depressed compared to ratios in all other subtropical gyres. In the North Atlantic basin, rates of nitrogen fixation are correlated to dissolved iron concentrations. Unlike the SIO gyre, the North Atlantic gyre receives a relatively large input of iron in the form

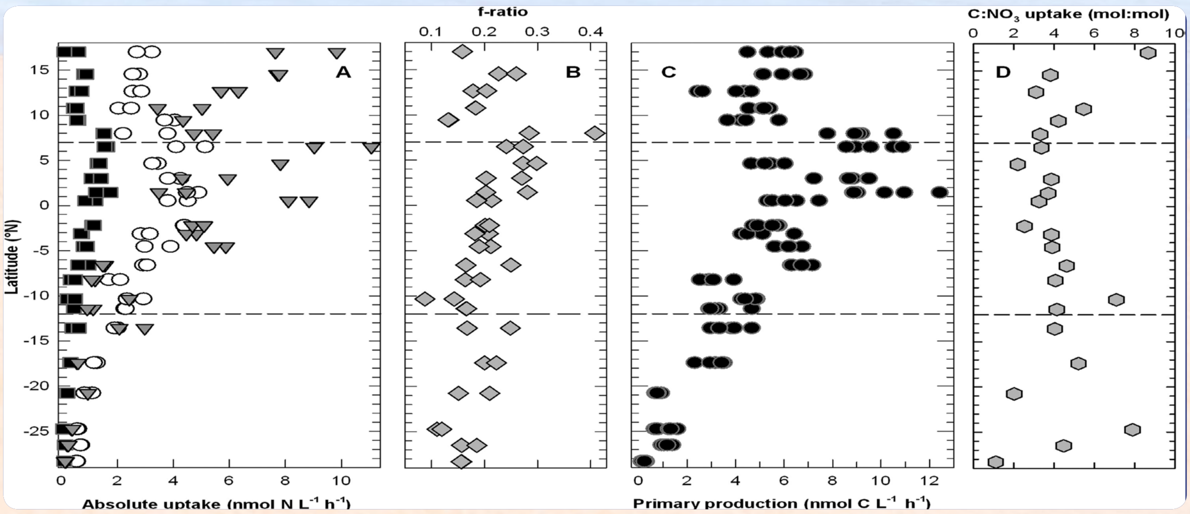


Figure 4: Near surface (20 m) carbon and nitrogen uptake rates measured along the transect. A) Absolute uptake rates of nitrate (NO_3^-; filled squares), ammonium (NH_4^+; open circles), and urea (gray triangles); B) f-ratio (filled diamonds); C) absolute uptake rates of carbon as bicarbonate (primary production); D) ratio of carbon:nitrate (C:NO_3) uptake rates.

of dust deposition from dry climates in Africa. While dust deposition occurs near the Arabian Sea, this transect was in the eastern central Indian Ocean, which has fewer external iron input as and phytoplankton are thought to be iron limited (Grand et al. 2015, Twining et al. in review). A detailed study of the trace metal composition of particles along this transect found that the ratio of particulate iron to particulate organic phosphorus was low in the SIO gyre and increased into the EqIO and BoB regions (Twining et al., in review). As such, phytoplankton may be more iron limited in the SIO gyre and perhaps N limited if N_2-fixation is limited by iron as well. According to the compilation of N_2-fixation rates by Dr. Deepika Sahoo and Dr. Arvind Singh in the previous Indian Ocean Bubble issue,N_2-fixation rates were much lower in the eastern Indian Ocean compared to rates in the Arabian Sea. We hypothesize that the supply of iron controls the drawdown of inorganic phosphorus via N_2-fixation limitation in the eastern Indian Ocean.

Baer, Steven E., Sara Rauschenberg, Catherine A. Garcia, Nathan S. Garcia, Adam C. Martiny, Benjamin S. Twining, and Michael W. Lomas. 2018. "Carbon and Nitrogen Productivity during Spring in the Oligotrophic Indian Ocean along the GO-SHIP IO9N Transect." Deep Sea Research Part II: Topical Studies in Oceanography, November. Pergamon. doi:10.1016/J.DSR2.2018.11.008.

Behrenfeld, Michael J., and Paul G. Falkowski. 1997. "Photosynthetic Rates Derived from Satellite-Based Chlorophyll Concentration." Limnology and Oceanography 42 (1): 1–20. doi:10.4319/lo.1997.42.1.0001.

Bianchi, Daniele, Thomas S. Weber, Rainer Kiko, and Curtis Deutsch. 2018. "Global Niche of Marine Anaerobic Metabolisms Expanded by Particle Microenvironments." Nature Geoscience 11 (4). Nature Publishing Group: 263. doi:10.1038/s41561-018-0081-0.

Fernandes, Veronica, Veera Rodrigues, N. Ramaiah, and Jane T. Paul. 2008. "Relevance of Bacterioplankton Abundance and Production in the Oligotrophic Equatorial Indian Ocean." Aquatic Ecology 42 (4). Springer Netherlands: 511–19. doi:10.1007/s10452-007-9142-y.

Garcia, Catherine A., Steven E. Baer, Nathan S. Garcia, Sara Rauschenberg, Benjamin S. Twining, Michael W. Lomas, and Adam C. Martiny. 2018. "Nutrient Supply Controls Particulate Elemental Concentrations and Ratios in the Low Latitude Eastern Indian Ocean." Nature Communications 9 (1). Nature Publishing Group: 4868. doi:10.1038/s41467-018-06892-w.

Garrison, David L, Marcia M Gowing, Margaret P Hughes, Lisa Campbell, David A Caron, Mark R Dennett, Alexi Shalapyonok, et al. 2000. "Microbial Food Web Structure in the Arabian Sea: A US JGOFS Study." Deep-Sea Research II 47: 1387–1422. http://ac.els-cdn.com/S0967064599001484/1-s2.0-S0967064599001484-main.pdf?_tid=c364bd78-5ad1-11e7-b00e-00000aab0f6b&acdnat=1498524443_491449d9a223bf4ef0a7b0ae4bb835ae.

Grand, Maxime M., Christopher I. Measures, Mariko Hatta, William T. Hiscock, William M. Landing, Peter L. Morton, Clifton S. Buck, Pamela M. Barrett, and Joseph A. Resing. 2015. "Dissolved Fe and Al in the Upper 1000 m of the Eastern Indian Ocean: A High-Resolution Transect along 95°E from the Antarctic Margin to the Bay of Bengal." Global Biogeochemical Cycles 29 (3): 375–96. doi:10.1002/2014GB004920.

Hansell, Dennis A. 2009. "Dissolved Organic Carbon in the Carbon Cycle of The Indian Ocean GO-SHIP Global Repeat Hydrography View Project The Joint Global Ocean Flux Study (JGOFS) 1988-2003 View Project Dissolved Organic Carbon in the Carbon Cycle of the Indian Ocean." Indian Ocean Biogeochemical Processes and Ecological Variability Geophysical Monograph Series 185. doi:10.1029/2007GM000684.

Klausmeier, Christopher A., Elena Litchman, and Simon A. Levin. 2004. "Phytoplankton Growth and Stoichiometry under Multiple Nutrient Limitation." Limnology and Oceanography 49 (4_part_2): 1463–70. doi:10.4319/lo.2004.49.4_part_2.1463.

Kumar, Sanjeev, R. Ramesh, S. Sardesai, and M. S. Sheshshayee. 2004. "High New Production in the Bay of Bengal: Possible Causes and Implications." Geophysical Research Letters 31 (18). John Wiley & Sons, Ltd: L18304. doi:10.1029/2004GL021005.

Madhupratap, M, Mangesh Gauns, N Ramaiah, S Prasanna Kumar, P.M Muraleedharan, S.N de Sousa, S Sardessai, and Usha Muraleedharan. 2003. "Biogeochemistry of the Bay of Bengal: Physical, Chemical and Primary Productivity Characteristics of the Central and Western Bay of Bengal during Summer Monsoon 2001." Deep Sea Research Part II: Topical Studies in Oceanography 50 (5). Pergamon: 881–96. doi:10.1016/S0967-0645(02)00611-2.

Makino, W., J. B. Cotner, R. W. Sterner, and J. J. Elser. 2003. "Are Bacteria More like Plants or Animals? Growth Rate and Resource Dependence of Bacterial C : N : P Stoichiometry." Functional Ecology 17 (1). Blackwell Science Ltd: 121–30. doi:10.1046/j.1365-2435.2003.00712.x.

Morrison, J.M, L.A Codispoti, S Gaurin, B Jones, V Manghnani, and Z Zheng. 1998. "Seasonal Variation of Hydrographic and Nutrient Fields during the US JGOFS Arabian Sea Process Study." Deep Sea Research Part II: Topical Studies in Oceanography 45 (10–11). Pergamon: 2053–2101. doi:10.1016/S0967-0645(98)00063-0.

Owens, N.J.P., P.H. Burkill, R.F.C. Mantoura, E.M.S. Woodward, I.E. Bellan, J. Aiken, R.J.M. Howland, and C.A. Llewellyn. 1993. "Size-Fractionated Primary Production and Nitrogen Assimilation in the Northwestern Indian Ocean." Deep Sea Research Part II: Topical Studies in Oceanography 40 (3). Pergamon: 697–709. doi:10.1016/0967-0645(93)90053-P.

Prasanna Kumar, S., P. M. Muraleedharan, T. G. Prasad, M. Gauns, N. Ramaiah, S. N. de Souza, S. Sardesai, and M. Madhupratap. 2002. "Why Is the Bay of Bengal Less Productive during Summer Monsoon Compared to the Arabian Sea?" Geophysical Research Letters 29 (24): 88-1-88–4. doi:10.1029/2002GL016013.

Schlüter, Louise, Peter Henriksen, Torkel Gissel Nielsen, and Hans H. Jakobsen. 2011. "Phytoplankton Composition and Biomass across the Southern Indian Ocean." Deep Sea Research Part I: Oceanographic Research Papers 58 (5): 546–56. doi:10.1016/j.dsr.2011.02.007.

Thomalla, S. J., H. N. Waldron, M. I. Lucas, J. F. Read, I. J. Ansorge, and E. Pakhomov. 2011. "Phytoplankton Distribution and Nitrogen Dynamics in the Southwest Indian Subtropical Gyre and Southern Ocean Waters." Ocean Science 7 (1): 113–27. doi:10.5194/os-7-113-2011.

Toseland, A., S. J. Daines, J. R. Clark, A. Kirkham, J. Strauss, C. Uhlig, T. M. Lenton, et al. 2013. "The Impact of Temperature on Marine Phytoplankton Resource Allocation and Metabolism." Nature Climate Change 3 (11). Nature Publishing Group: 979–84. doi:10.1038/nclimate1989.

Tyrrell, T. 1999. "The Relative Influences of Nitrogen and Phosphorus on Oceanic Primary Production," 525–31. doi:10.1038/22941.

Waite, A.M., P.A. Thompson, S. Pesant, M. Feng, L.E. Beckley, C.M. Domingues, D. Gaughan, et al. 2007. "The Leeuwin Current and Its Eddies: An Introductory Overview." Deep Sea Research Part II: Topical Studies in Oceanography 54 (8–10). Pergamon: 789–96. doi:10.1016/J.DSR2.2006.12.008.

Wilhelm, Steven W., and Curtis A. Suttle. 1999. "Viruses and Nutrient Cycles in the Sea." BioScience 49 (10). Oxford University Press: 781–88. doi:10.2307/1313569.

Cutting Edge- Instrumentation, Tools

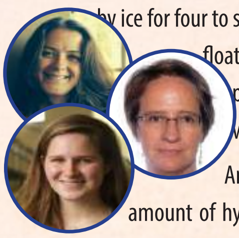
Argo reaches 2 million profiles globally! But what of the Indian Ocean?

Tamaryn Morris[1], Susan Wijffels[2], Cora Hersh[2]

[1]Marine Unit, South African Weather Service, Cape Town, South Africa

[2]Woods Hole Oceanographic Institute, Woods Hole, USA

Lead Author is a Senior Scientist representing South Africa on the Argo Steering Team and also coordinating implementation of the Agulhas System Climate Array



The Argo Programme was established in the late 1990's to provide systematic global observations of the upper 2000 m of the ocean to augment the sparse coverage of traditional ship-borne measurements. The primary objective was, and still is, to try monitor how the changes our climate is currently undergoing affects our ocean systems and the resultant impact this altered ocean has again on global climate. Traditional shipborne measurements have always been sparser in the Southern Hemisphere compared to the north, and practically non-existent in regions covered by ice for four to six months of the year. However, with the development of a free-floating, profiling, autonomous platform that can be deployed from practically any ocean-going vessel, the possibilities became endless with regards acquiring upper ocean observations.

An Argo float operates similarly to a buoyancy glider, pumping a small amount of hydraulic oil in to and out of an external bladder to allow the float to ascend or descend through the water column. The core Argo Programme requires floats to drift for nine days at a park depth of 1000 db, effectively avoiding collisions with vessels operating shallower, thereafter descending to a profiling depth of 2000 db. Measurements on the Sea-Bird SBE 41 / 41CP Argo CTD sensor are taken on the slow six hour up cast to the surface. These data are transmitted back to the data center tasked with monitoring that individual float. After an automated initial quality control process, the data is then made available to the Global Data Centers for open, free-access

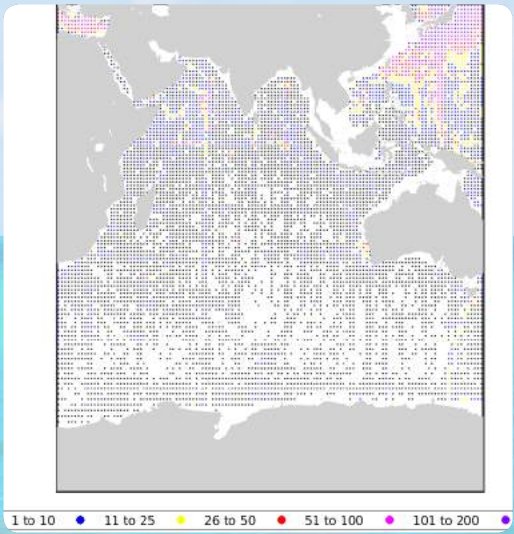


Figure 1: World Ocean Database profiles for the Indian Ocean as of January 2018. Map plotted courtesy of Cora Hersh, Woods Hole Oceanographic Institute, USA.

dissemination. Profiles are made available within 24 hours of the floats' transmission, ensuring for an efficient real-time global monitoring system for the ocean. Data is then validated by the data center's oceanographers and released as a delayed-time profile, usually about one year after first transmission. Typically, a float will make 150 of these profile cycles over their lifespan before their batteries begin to fail.

Since its inception in 1998, with the first Argo float deployments shortly thereafter in 1999, the Argo Programme has amassed two million profiles globally. Riser et al (2016), after analyzing data archived within the World Ocean Database (WOD) 2009, found for a 100 year period prior to 2009, only half a million largely ship-borne profiles to 1000 m or deeper. These ship-borne measurements were also heavily concentrated in regions of interest to specific research endeavours and did not cover the entirety of the World's oceans, leaving large gaps in the South Indian, Pacific and Atlantic Oceans. The Argo Programme has successfully quadrupled the WOD archive, and over 100 years of expensive and human-capacity intensive sampling, in just over 18 years.

Ocean observations have historically been concentrated in the Northern Hemisphere, as countries adjacent to the North Atlantic and North Pacific Oceans have established economies, and were able to drive the development and operation of research vessels and equipment. However, to appreciate the impact climate change will have on the Northern Hemisphere and its climate, or the teleconnections of climate modes across continents and vast ocean basins causing floods or droughts remotely, a global understanding of the upper ocean was required. Thus these autonomous profiling robots were, and still are, deployed for operational purposes feeding in to coupled-climate models throughout the global oceans. The added benefit of their free-floating capability is that over their lifespan of approximately 150 profiles, they are capable of ranging long distances sampling diverse oceanographic environments.

Yet given all this, the Indian Ocean remains the most understudied of the ice-free oceans. Only ~ 15.5% of all Argo floats deployed have recorded profiles in the Indian Ocean. Importantly, this does not equate to the number of Argo floats deployed within the Indian Ocean, merely those profiling within the Indian Ocean as they propagate with ocean currents. And of the two million profiles the Argo Programme has now amassed, only ~ 18.5% of these were recorded within the Indian Ocean. Regions in particular which lack Argo observations include the Mozambique Channel,

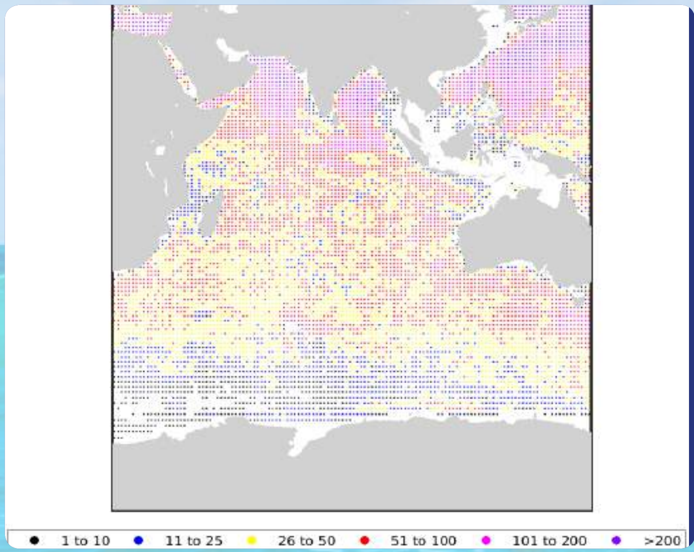


Figure 2: Argo float profiles for the Indian Ocean as of January 2018. Map plotted courtesy of Cora Hersh, Woods Hole Oceanographic Institute, USA.

the central expanse of the South Indian Ocean gyre and the Indonesian Throughflow region, which is of particular importance given the connectivity of the Pacific Ocean to the Indian Ocean. The Agulhas Current, the Southern Hemisphere's most powerful Western Boundary Current and a critical link in the Thermohaline Circulation transporting warm salty water to the South Atlantic, is also difficult to characterize using Argo floats given they are spat out of the system fairly quickly after entering it, perhaps not being the ideal tool for capturing Western Boundary Current dynamics. Similar to Riser et al (2016), figure 1 shows the profile density from the WOD of profiles to 1000 db as of January 2018 for the Indian Ocean specifically, while figure 2 shows the Argo float profile density, again as of January 2018, highlighting the value of the Argo Programme to the Indian Ocean. This represents a massive improvement in terms of effort capturing subsurface profiling, but when compared to other regions globally (e.g. North Atlantic and North Pacific Oceans), the Indian Ocean remains understudied.

Argo float technology has undergone several advancements in recent years, as well as the programme itself, to try capture some of the oceanographic processes not currently sampled. These include the development of a deep Argo floats and a sensor to sample the ocean beyond 2000 m, the inclusion of various biogeochemical sensors to study processes related to dissolved oxygen distribution, carbonate chemistry and the understanding of bio-optics related biology. Lastly, the Argo Programme has advised a greater number of float deployments in oceanographically dynamic regions such as Western Boundary Currents and the equatorial current regions to allow for high-resolution sampling.

The Argo Programme is heavily dependent on participation by many countries to achieve its goals. National contributions include the procurement and deployment of floats, particularly in regions not well studied or with marginal coverage, submission of deep cast CTD data globally to build a climatology to validate float data given instruments are never recovered for post-deployment calibration procedures and correction of data, support of the JCOMMOPS technical office for all Argo float coordination and the successful management of data centers, Argo data and validation. The marine science community is also involved in terms of standards and best practices development for float deployments, data handling and dissemination.

To this end, the programme encourages countries to become involved at any level possible, even if only able to deploy floats procured by other countries on vessels within their territorial waters. To find out more of where you, your country or institution can become involve, please contact Megan Scanderbeg, mscanderbeg@ucsd.edu, otherwise follow the Argo webpage, www.argo.net, the JCOMMOPS webpage for updated Argo position maps, www.jcommops.org, and the Coriolis website to access all available Argo data, www.coriolis.eu.org/Data-Products/Data-Delivery.

To achieve two million profiles globally in less than 20 years is a remarkable achievement, driven by a small group of dedicated and enthusiastic scientists from various institutions worldwide. The product is a vast database of observations, available free of charge to all who would like to use them, for climate science, for regional implications of global sea level rise, for sub-surface characteristics of key oceanographic features and many other diverse research outputs. Already a paper per day is published using Argo data. Given we are facing climate change square on now, and we no longer have many opportunities left to completely mitigate the impacts coming our way, we need to continue monitoring the ocean at a global scale to assist climate-coupled models such as those used by the Intergovernmental Panel on Climate Change (IPCC) to predict what the consequences of our actions will be, wherever they will take place.

Reference: Riser SC, Freeland HJ, Roemmich D, Wijffels S, Troisi A, Belbéoch M, et al. 2016. Fifteen years of ocean observations with the global Argo array. Nature Climate Change, 145-153. DOI: 10.1038/NCLIMATE2872.P

Ponman: A method for exploratory analysis of ocean depths using Bio-Argo

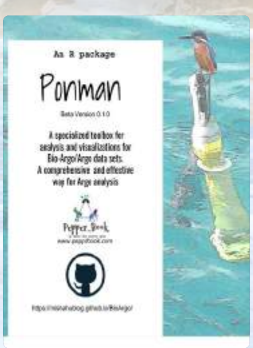
Midhun Shah Hussain[1], A.A. Mohammed Hatha[1], Smitha. B.R[2]

[1]Dept. of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology(CUSAT)-Kochi 16

[2]Centre for Marine Living Resource and Ecology(CMLRE)

Lead author is a PhD scholar

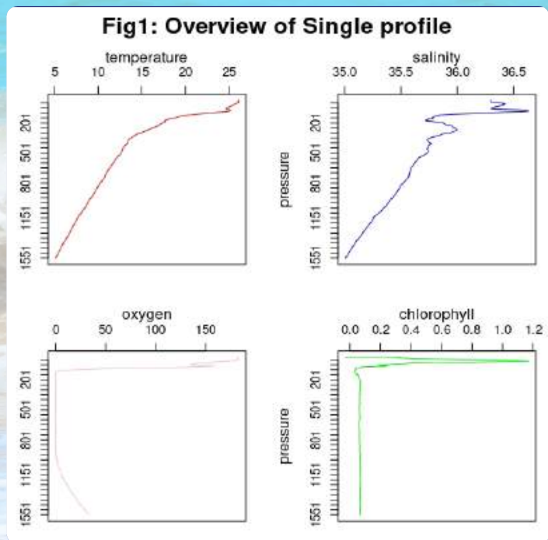
A brief introduction on Bio-Argo



Argos are one of the efficient ways of remote sensing in modern oceanography. Unlike satellites this technology explores the depths of the ocean, with the finest data acquisition methods. Presently Argo floats are managed by French Research Institute for the Exploitation of the Sea (popularly know as ifremer). Argo floats in India are managed by Earth System Science Organization-Indian National Centre for Ocean Information Services(ESSO-INCOIS). One of the notable properties of Argo floats are global and free access to data in near real-time. But unfortunately Argo floats are less utilized for studies especially in the Indian scenario, even though we have abundant numbers of them . This may be due to the lack of more accessible technology in processing and acquisition of data from the servers, or by the less popularity of this emerging technology. All Argo floats measure temperature and salinity. Number of floats have other sensors on-board, mostly information related to the biology or chemistry of the oceans. The programme for developing, testing and using these floats is known as Bio-Argo or Biogeochemical Argo. The present-day Bio-Argo floats are equipped with Chlorophyll, Oxygen, Nitrate, CDOM and Turbidity sensors, which vary according to the missions of deployment. In Indian waters, the deployed Bio-Argo floats are equipped with sensors on oxygen, chlorophyll-a and backscattering, equipped with WETLabs ECO FLNTU package for measuring chlorophyll-a fluorescence (470 nm) in addition to this is the SeaBird SBE 41CP CTD unit to measure temperature and conductivity (salinity) and Aanderaa Optode 3830 dissolved oxygen sensor. These floats are programmed to collect profiles at local noon. The accuracy of temperature, salinity, pressure, chlorophyll-a, and dissolved oxygen concentration measured by these floats are 0.002°C, 0.005psu, 2.4decibars, 0.02 mgm-3, and 8 mM, respectively1.

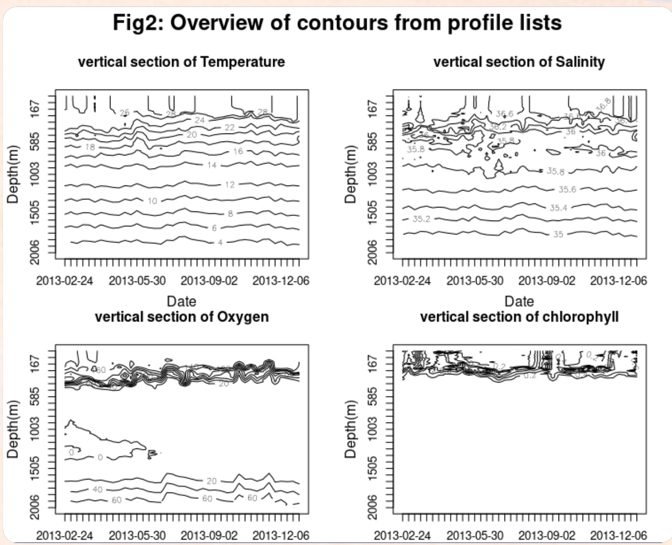
Ponman and its features :

Fig1: Overview of Single profile



Ponman is an eponymous name given to the package, after the white-throated kingfisher (Halcyon smyrnensis) widely distributed in Kerala, famous for its deep dive fishing from rivers. By the way Ponman is a package developed in R Language to reduce the data-researcher barrier and to promote the effective use of Bio-Argo data from ocean depths. More than an R package it has a comprehensive tool sets for Bio-Argo, from data acquisition to plotting. Ponman is a user-friendly package for a regular R user with supporting documentation. Oceanographers handle enormous amounts of data, the downloading and analysis of which, is a tedious job. Ponman

Fig2: Overview of contours from profile lists



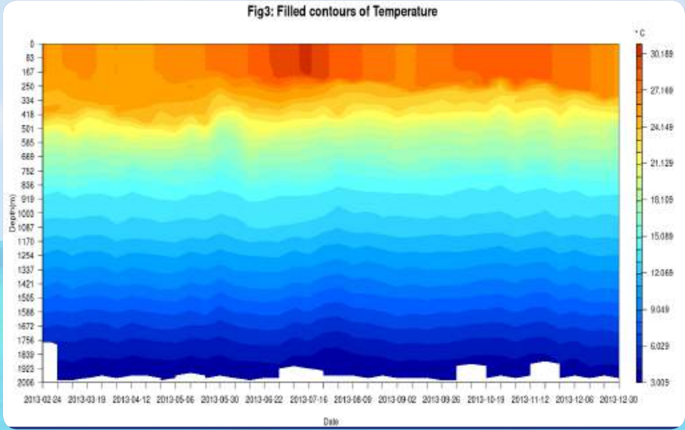


Fig3: Filled contours of Temperature

for Bio-Argo can download the data directly to the workspace according to priorities. Ponman prefers netcdf (.nc) files, a set of self-describing software libraries, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. Reading and extraction of the data from .nc files to readable data frame is the first thing one can complete with Ponman

Data acquisition made easy

Ponman accesses the data through FTP(File transfer protocol) from ifremer database, according to the space -time relevance or by specific platform numbers. As we don't have any accessible API, FTP is our only option to get the data. In future we will overcome this limitation. Note that Ponman can manually process already-downloaded data (.nc formats) using other protocols.

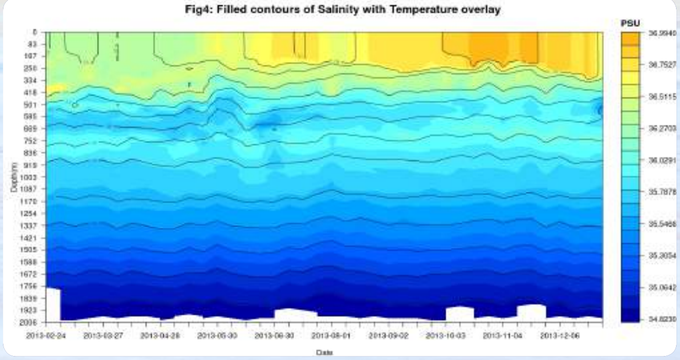


Fig4: Filled contours of Salinity with Temperature overlay

Eg:

```
# getting data to the system
R> argo2010<- get_data2ponman(mode = "geotime",location = "indian_ocean",year = "2010",month = "02")
```

Single and batch files processing

The package gives options for both single and batch Processing. Based on the analysis requirements, either single or section wise profiling, time-series options etc. are provided in Ponman. Also, the sub-setting or pooling of data/profiles can be performed in respect of space and time.

Eg:

```
# Make batch filelists from working directory or the folder where data downloaded.
R> profile_list2013<- list.files()
R> profile2013<- batch(profile_list2013)
```

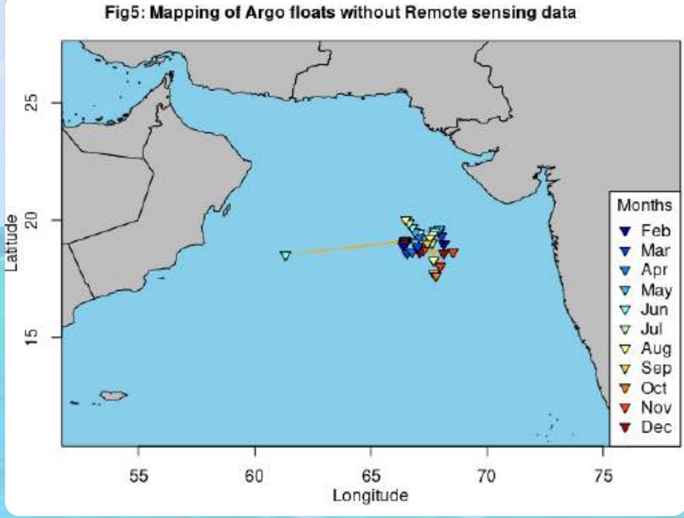


Fig5: Mapping of Argo floats without Remote sensing data

```
#Filter by depth
R> Depth300<- Filter_bioArgo(batchlist = profile2013,parameter = "pressure",start = 0,end = 300)
#Filter by Month
R>February Filter_bioArgo(batchlist = profile2013,parameter = "date",month = "02")
```

Plotting of data

Among the multitude of graphical systems in R, Ponman is developed on a basic plotting system. But R experts are free to experiment with preferable plotting systems. The options are listed below;

- Profile parameters in line graphs or in overview mode giving basic plots on all the available parameters.
- Vertical contour graphs: a) Contour lines b) Filled contours (with or without overlays)
- Mapping of Argo floats (trajectory) overplayed with climatology derived from satellite data.

Option on line graphs by default uses single profile(Fig1) which can also be plotted with 'overview' for all the available parameters. Contour plotting uses batch processing which interpolates data with minimal error over a temporal section. The temporal section is preferred over spatial section as the irregular drifting of

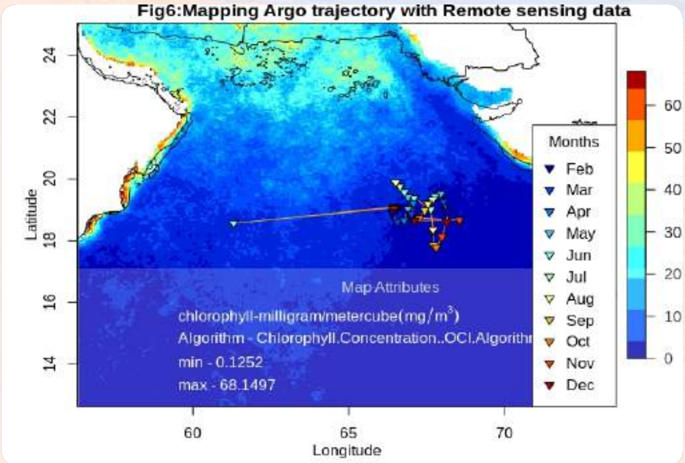


Fig6:Mapping Argo trajectory with Remote sensing data

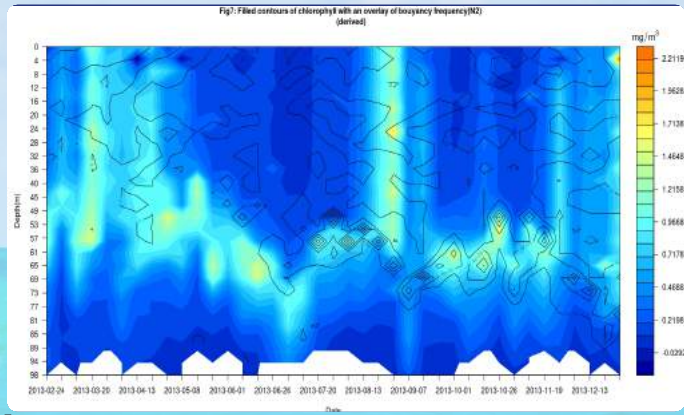
Argo floats makes it non-linear. The line contours show an overview of the batch file on available parameters(Fig2). The filled contour(Fig3) can be used to represent multiple parameters with overlay option(Fig4), which is either derived or innately extracted from Bio-Argo. Mapping options in Ponman also include plotting Argo trajectories(Fig5), as well as surface maps embedded with remote sensing data(Fig6) in the relevant time domain. Embedding remote sensing data using Ponman needs some improvement from the current version. Note, the native arguments of R plots such as changing colors or line widths are still possible.

Eg:

```
#plotting filled contours with overlays
R>Filledsectionplots(Argolist = profile2013,parameter = "temperature",overlay = "salinity",col.val = matlab.like(30))
#Mapping of Argo floats without remote sensing data
R>Mapargo2013<-Sat_bioArgo(profile2013,lat = c(15,22),lon = c(65,70),legend.year = TRUE,col="grey",bg="blue")
#Mapping of Argo floats with remote sensing data
R>Mapargo2013<-Sat_bioArgo(profile2013,satdata="~/MEGAsyncA20030602018090.L3m_MC_CHL_chlor_a_4km.nc",
legend.month = TRUE)
```

Derived parameters

Ponman also generates derived parameters such as density($\sigma\ \theta$), mixed layer depth (MLD-m) and buoyancy frequency(N2) using the R package "gsw". These parameters can be contoured as an overlay on filled contour of any basic parameter(Fig7). More additions of derived parameters in Ponman are in progress.



Eg:

```
# Adding the overlay of buoyancy frequency(N2)
Filledsectionplots(Argolist = profile2013,parameter = "chlorophyll",col.val = matlab.like(30),overlay = "N2")
```

For Bug reports, tutorials and further improvements of Ponman

Ponman is unquestionably unique in R, but not bug free. It needs continuous up-gradation to strengthen quality. Users can send bug reports, new feature requests and feedback to the website www.pepprbook.com or get in touch with us on https://github.com/mishahublog/BioArgo/tree/ponman. Ponman is not published officially in Comprehensive R Archive Network(CRAN), but the installation is fairly simple as any official package. The above mentioned sites can also accessible for tutorials and installation help.

Reference

1.Ravichandran, M., Girishkumar, M. S. & Riser, S. Observed variability of chlorophyll-a using Argo profiling floats in the southeastern Arabian Sea. Deep Sea Research Part I: Oceanographic Research Papers 65, 15–25 (2012).

Transporters- Physics

The improved COARE 3.5 Algorithm for ocean heat flux estimations

Samar Kumar Ghose and Debadatta Swain

School of Earth, Ocean and Climate Sciences, Indian Institute of Technology Bhubaneswar, Jatni – 752050, Odisha, INDIA

Lead author is a PhD scholar

Heat flux is defined as the amount of heat transferred per unit area per unit time from or to a surface. In the earth system, incoming short wave solar radiation is the only source for the input of heat. This radiation is absorbed by atmosphere, clouds and earth surfaces, and then radiated back in the form of outgoing long wave radiation. Besides this, another two forms of heat transfer, namely latent heat flux (LHF) and sensible heat flux (SHF) are associated with the earth system. LHF is the energy associated with phase change in the process of evaporation. SHF is the transfer of heat between two surfaces caused by difference of temperature. Generally LHF is the principal component of heat transfer processes between ocean and atmosphere. LHF acquires prominence in global climate due to its large amplitude of interannual and spatial variability (Kubota et al. 2003).

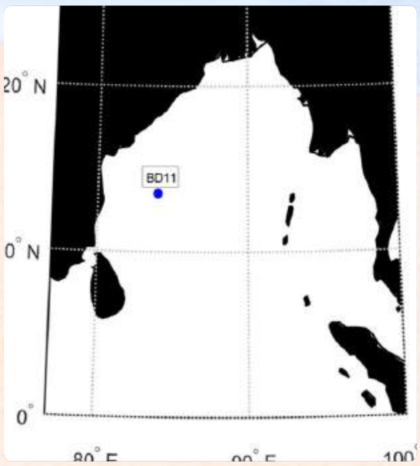


Figure 1: Schematic of buoy location

LHF cannot be measured directly as it depends on several met-ocean parameters like wind speed (WS), relative humidity (RH), sea surface temperature (SST), air temperature (AT), sea surface pressure (P), etc. Hence, it is conventionally estimated using bulk-flux algorithm, which includes the above mentioned met-ocean parameters. The evolution of this flux algorithm is based primarily on the calculation of wind stress related drag coefficient. Different researchers have followed different methods to estimate drag coefficients. Coupled wave-wind model and surge simulation model was followed by Moon et al. in 2006 and 2009, respectively. Parameterization including wave breaking, sea spray and

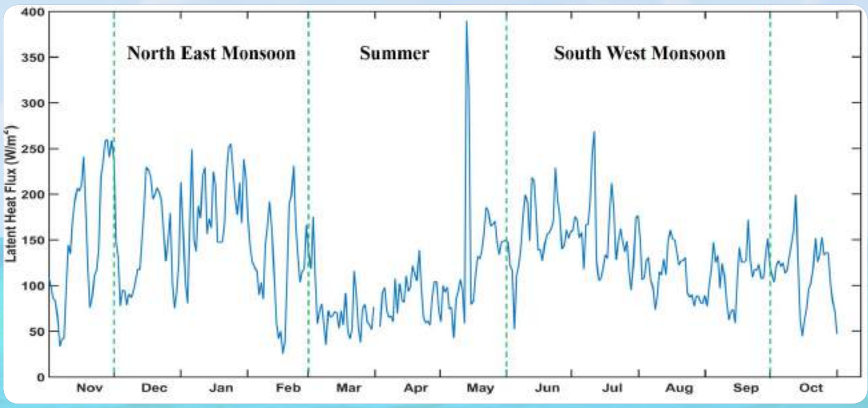


Figure 2: Variability of LHF from November 2012 to October 2013; the green dashed lines demarcates the three different seasons.

bottom friction for spectral wave model was followed by Zijlema et al. (2012). The formulation for estimation of the heat fluxes were modified and fine-tuned regularly by Fairall et al., (1990, 1996, 2003) in the form of Coupled Ocean Atmosphere Response Experiment (COARE) using cruise observations data for validation at different periods. The latest modified version of this algorithm as proposed by Edson et al. (2013) is popularly known as the COARE 3.5 algorithm.

In this study, COARE 3.5 algorithm is used to estimate the LHF at a buoy location (13.5 ºN and 84 ºE)in the Bay of Bengal (BoB) using met-ocean parameters obtained from the buoy BD11 (Fig. 1) during the period 1st November 2012 to 31st October 2013, ensuring the availability of the longest period of continuous data.Hourly met-ocean parameters obtained from BD11, namely WS, AT, RH, P and SST are used as input for the COARE 3.5 algorithm. Besides these, the latitude, longitude and the sensor height to obtain these parameters are also necessary in the estimation processes. Analysis of the fluxes consists of north east monsoon (December, January and February), south west monsoon (June, July, August and September) and summer (March, April and May) season.

At the study location,LHF is considered positive upward and the hourly estimated LHF is averaged to discern its seasonal variability (Fig. 2). It is observed that the LHF is prominently higher during both the monsoon seasons as compared with summer season. This can be understood better by focusing on the variation of corresponding met-ocean parameters, which is discussed in next section. But there is an unusual peak observed in the 1st week of May; further analysis revealed that this sharp rise in LHF was due to the cyclone Mahasen.

Further to understand the process of heat transfer, WS variability, humidity difference (Qs-Q10), AT and SST are plotted along with LHF (Fig. 3). WS during both monsoon seasons is quite high compared to the summer seasons. WS during south west monsoon is higher than north east monsoon and it is well established that higher the WS, more is the heat transfer through LHF (Fig. 3(a)).This can be attributed to the fact that increase in WS changes the stability dependent drag coefficient (Moon et al., 2006; Zijlema et al., 2012; Bryant and Akbar, 2016). WS is directly proportional to LHF. Similarly, the humidity difference (Qs-Q10) is also directly proportion to LHF (Swain et al, 2009) (Fig. 3(b)), where Qs and Q10is the humidity near the sea surface and at 10m above the sea surface, respectively. Higher WS takes away the moisture quickly and the dry air fills the space, which enhances the air-sea interaction process. Similarly, when the moisture is already in air; that is Qs-Q10 is low, LHF decreases.

Again the variation of LHF with AT and SST is studied to observe its impact on heat-exchanges. It is clearly observed from Fig. 3(c), that AT is comparatively high during summer season compared to monsoon seasons. Though no direct relation is evident with LHF, indirectly higher AT allows more moisture to ingest into it, hence lower the humidity difference. Similarly, SST is also high during summer as compared to the monsoon seasons (Fig. 3(d)). During north east monsoon, when SST is lower the LHF is high and vice versa during the south west monsoon. So it has also no direct effect on LHF. Higher SST increases the humidity content near the sea surface (Qs), and hence can regulate LHF through humidity difference.

Altogether, it can be summarized that the COARE 3.5 is a well-defined approach to estimate LHF in the BoB. Further, the LHF is higher during monsoon seasons with the support of large WS and humidity difference. Secondly, SST and AT show no direct effect on LHF. However, they do affect the two basic parameters WS and RH, which directly regulates the LHF.

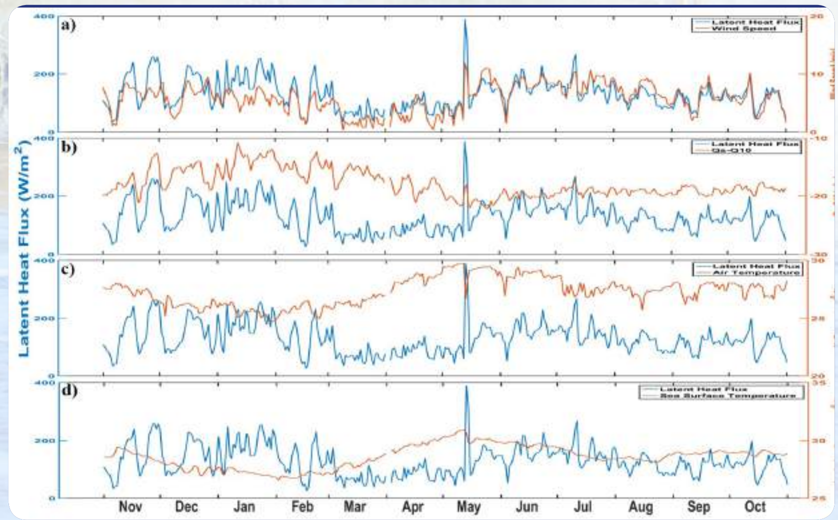


Figure 3: Variability of LHF with (a) WS, (b) Qs-Q10, (c) AT and (d) SST; Time period is from November 2012 to October 2013

References

Bryant, K. M. and M. Akbar, 2016, An Exploration of Wind Stress Calculation Techniques in Hurricane Storm Surge Modeling. Journal of Marine Science and Engineering, Vol.4, 31-58 DOI:10.3390/jmse4030058.

Edson, J. B.,V. Jampana, R. A. Weller, S. P. Bigorre, A. J. Plueddemann, C. W. Fairall, S. D. Miller, L. Mahrt, D. Vickers, and H. Hersbach, 2013, On the Exchange of Momentum over the open Ocean. Journal of Physical Oceanography, Vol. 43, 1589-1610.

Fairall, C. W., J. B. Edson, S. E. Larsen and P. G. Mesteyer, 1990, Inertial-Dissipation of Air–Sea Flux Measurements: A Prototype System Using Real-Time Spectral Computations. Journal Atmospheric Ocean Technology Vol. 7, 425–453, doi10.1175/15200426 (1990)007\0425.

Fairall, C. W., E. F. Bradley, J. S. Godfrey, G. A. Wick, J. B. Edson and G. S. Young, 1996, Cool Skin and Warm Layer Effects on Sea Surface Temperature. Journal of Geophysical Research, Vol. 101, 1295-1308.

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev and J. B. Edson, 2003, Bulk Parameterization of Air Sea Fluxes: Updates And Verification For Coare Algorithm. Journal of Climate, Vol. 16, 571-591.

Kubota, M., A. Kano, H. Matsu and H. Tomita, 2003, Inter comparison of Various Surface Latent Heat Flux Fields. Journal of Climate, Volume-16, 670-678.

Moon, I. J., I. Ginis and T. Hara, Effect of Surface Waves on Air–Sea Momentum Exchange. Part II: Behavior ofDrag Coefficient under Tropical Cyclones. Journal of Atmospheric Science 2006, 61, 2334–2348.

Moon, I. J.,J. I.Kwon,J. C. Lee, J. S. Shim,S. K. Kang, I. S. Oh andS.J.Kwon, Effect of the Surface Wind Stress Parameterization on the Storm Surge Modeling. Ocean Model. 2009, 29, 115–127.

Swain, D., S. H. Rahman and M. Ravichandran, 2009, Comparison of NCEP Turbulent Heat Fluxes with in situ Observations over the south-eastern Arabian Sea. Meteorology and Atmospheric Physics, Vol. 104, 163-175, doi 10.1007/s00703-009-0023-x.

Zijlema, M.,G. P. van Vledder andL.H.Holthuijsen, Bottom Friction and Wind Drag for Wave Models.Coastal Engineering 2012, 65, 19–26.

Investigating the shelf dynamics and sedimentary records of South Eastern Arabian Sea: A multidisciplinary approach

Glejin Johnson, Anoop TR, Shynu R, Anilkumar N, Tiju I Varghese, Prasad R, Prakash TN

Coastal Processes Group, National Centre for Earth Science Studies, Thiruvananthapuram Kerala-695011

Corresponding author: anil@ncess.gov.in

The oceanic region, shelf sea covers only the 8% of global ocean but it has leading role in world fish economy and in open ocean carbon dioxide storage (20 to 50%) through 'Shelf Sea pumping[1]'. This also acts as an important gate way for the exchange of mass, heat and momentum between well mixed surf zone and stratified deeper ocean. The exchange between these two regions occurs as irreversible small-scale mixing of water and its constituents in the shelf region[2].

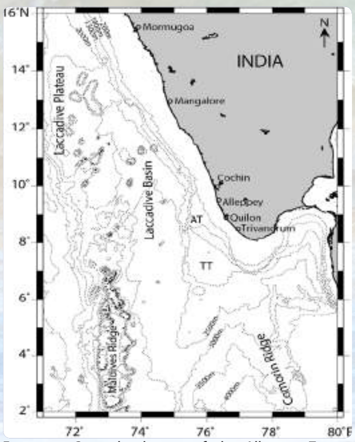


Figure 1: Generalized map of the Alleppey Terrace (AT) Complex in the southwestern continental margin of India and adjoining deep sea regions along with selected bathymetric contours obtained from GEBCO digital data set (Yatheesh et al 2013).

Assimilation of coastal current can also improve the forecasting of tropical cyclone intensity [3]. Compared to deep ocean region, the shelf sea region got less attention not only because of its complexity but also scarce data to reveal the various processes.

National Centre for Earth Science Studies (NCESS) has initiated a multi-institutional and multi-disciplinary expedition to understand the processes and ecosystem response of shelf seas of the southwest coast (SW) of India. As a preliminary approach, we have planned 21 ship days onboard ORV Sagar Kanya along the SW shelf sea of India during May 2019. The region considered for this study is part of the South Eastern Arabian sea (SEAS)/Lakshadweep Sea. The main focus is to understand the role of Alleppey Terrace (AT, Figure 1)/ Quilon mount (an anomalous lateral bathymetric protrusion in the form of contiguous terrace-like features exists in the continental margin off SW coast of India[4,5]) on the dynamics and sedimentary deposits of the adjoining Shelf Sea. AT covers an area between 8.6°N & 9.2°N and 75.5°E &76°E. It has steep gradient in west of 75.5°E as the depth rapidly increases towards the west and it weakly decreases in east of 76°E. The previous studies with the help of numerical models indicated the role of AT in cyclonic eddy formation and sea surface temperature variability[5]. This region is also characterized by complex internal tides[6]. The role of these type of topographic structures in the ocean processes are carried out mostly in the open ocean but there are only limited studies in the shelf sea[7].

Ambiguously explained phenomena are reported in this region such as mudbank formation, flash coastal flooding, anomalous flash receding of sea (opposite phenomenon to coastal flooding), early occurrence (January-March) of upwelling and abnormal reversal of coastal current[8]. All these incidents may be due to the influence of topographic structures[7]. In 2012, the flash receding of sea is characterized by much cooler, hypoxic, and nutrient rich, but with low biomass at 40-meter depth for a short period of time (~35 km away from coast) off Cochin[8]. It means that the sea receding phenomena has a significant impact on the dynamics of shelf sea region but to be verified.

SEAS has some unique features compared to rest of the shelf seas around India. The quadruplet interaction between the waters from Arabian Sea, Bay of Bengal, Gulf of Mannar and Equatorial Indian Ocean make distinctiveness to the region with seasonal variation. This region is dominated by Southern Ocean swells even during monsoon seasons. The hardly observed seasonal reversal of surface wind direction in this region compared to other parts of Arabian Sea is attributed to the presence of Western Ghats[9]. Moreover, the seasonal reversal of circulation pattern in the SEAS shall influence the changes in the water masses and regional biogeochemistry which leads potential linkage for global climate change phenomena[10]. The proposed cruise period is associated with strong changes in the atmospheric and oceanic circulation patterns associated with the onset of south-west monsoon (SWM). Prior to the onset of the summer monsoon over India in late May or early June, a huge warm pool, with sea surface temperature (SST) greater than 28°C, covers the north Indian Ocean results one of the warmest regions in the world oceans, while the core of this warm pool lies in the SEAS which makes this region the warmest. The role of the warm-pool waters in triggering the monsoon is not yet fully understood (Vinayachandran et al, 2007[11] and references there in).

The complex circulation patterns around these type of topographic structures leaves signatures in the sedimentary deposits[7]. In geological point of view the temporal variations in the provenance of sediments are also reported in the SEAS sedimentary records. Besides this, onshore and offshore occurrence of thick Quaternary sedimentary deposits provide significant mineral deposits and records of sea level changes and associated coastal evolution. The occurrence of peat and carbonized wood in the continental shelf sediments in SEAS suggests the shallow-marine, intertidal conditions and drowning of mangrove forests along the paleo-coastlines during Holocene transgression event. This region is also found to be a hotspot for mudbank, and high amounts of placer minerals originated from the hinterland Precambrian rocks. Moreover, the systematic study is essential to generate a reliable regional sea level curve for the late Quaternary. Hence a comprehensive knowledge about the geological and oceanographical study will help to formulate a sustainable management plan pertaining to the coastal ecosystem.

In the forthcoming cruise work we are planning to address the various scientific problems in the regions of SEAS. Internal waves (IW) of low-frequency and high-frequency bands is in the eastern Arabian Sea[12]. These onshore propagating IWs can cause turbulent mixing, sediment resuspension of shelf sediments and also impact on the near-shore ecosystem. Hence it is essential to improve the climate models. But this aspect of ocean processes in the Indian shelf sea is hardly studied by researchers. In the present study also we are planning to address the air sea interactions in shelf sea region with special emphasis to mixed layer heat budget. Previous studies in the global ocean have reported the significant increase in ocean heat content in the last few decades. Further these physical changes may influence the bio-geochemical processes in the shelf region. Hence during this expedition, a multidisciplinary approach will be made to address the impact of shelf sea dynamics on the south west coast of India.

Reference

1. Thomas, H., Bozec, Y., Elkalay, K., & De Baar, H. J. (2004). Enhanced open ocean storage of CO2 from shelf sea pumping. Science, 304(5673), 1005-1008.

2. Huthnance JM, 1995. Circulation, exchange and water masses at the ocean margin: the role of physical processes at the shelf edge. Progress in Oceanography 35(4), 353-431

3. Li, Y., &Toumi, R. (2018). Improved tropical cyclone intensity forecasts by assimilating coastal surface currents in an idealized study. Geophysical Research Letters, 45(18), 10-019.

4. Yatheesh, V., Kurian, P. J., Bhattacharya, G. C., &Rajan, S. (2013). Morphotectonic architecture of an India–Madagascar breakup related anomalous submarine terrace complex on the southwest continental margin of India. Marine and Petroleum Geology, 46, 304-318.

5. Anand, P., & Kumar, P. V. (2018). Influence of Bathymetry on the Performance of Regional Scale Model. Defence Science Journal, 68(1).

6. Subeesh, M. P., Unnikrishnan, A. S., Fernando, V., Agarwadekar, Y., Khalap, S. T., Satelkar, N. P., &Shenoi, S. S. C. (2013). Observed tidal currents on the continental shelf off the west coast of India. Continental Shelf Research, 69, 123-140.

7. Turnewitsch, R., Falahat, S., Nycander, J., Dale, A., Scott, R. B., &Furnival, D. (2013). Deep-sea fluid and sediment dynamics—Influence of hill-to seamount-scale seafloor topography. Earth-Science Reviews, 127, 203-241.

8. Gupta, G. V. M., Sudheesh, V., Sudharma, K. V., Saravanane, N., Dhanya, V., Dhanya, K. R., ... & Naqvi, S. W. A. (2016). Evolution to decay of upwelling and associated biogeochemistry over the southeastern Arabian Sea shelf. Journal of Geophysical Research: Biogeosciences, 121(1), 159-175.

9. Luis, A. J., & Kawamura, H. (2000). Wintertime wind forcing and sea surface cooling near the south India tip observed using NSCAT and AVHRR. Remote sensing of environment, 73(1), 55-64.

10. Naqvi, S. W. A., Jayakumar, D. A., Narvekar, P. V., Naik, H., Sarma, V. V. S. S., D'souza, W., ... & George, M. D. (2000). Increased marine production of N 2 O due to intensifying anoxia on the Indian continental shelf. Nature, 408(6810), 346.

11. inayachandran, P. N., Shankar, D., Kurian, J., Durand, F., &Shenoi, S. S. C. (2007). Arabian Sea mini warm pool and the monsoon onset vortex. current Science, 203-214.

12. Murthy, P. G. K., Sharma, G. S., James, V. V., &Suseela, K. V. (1992). Internal wave characteristics in the eastern Arabian Sea during summer monsoon. Proceedings of the Indian Academy of Sciences-Earth and Planetary Sciences, 101(4), 317-327.I

Networking

New insights into the Indian Ocean

Lynnath Beckley,

Murdoch University, Australia

The upcoming Australian Marine Sciences Association conference AMSA 2019 (7 – 11 July 2019) will feature the symposium "New insights into the Indian Ocean". The symposium invites oral and poster presentations that focus on all aspects of research in the Indian Ocean particularly those pertaining to the six science themes of the Second International Indian Ocean Expedition (IIOE-2):

Human impacts and benefits
Boundary current dynamics, upwelling variability and ecosystem impacts
Monsoon variability and ecosystem response
Circulation, climate variability and change
Extreme events and their impacts on ecosystems and human populations
Unique geological, physical, biogeochemical and ecological features of the Indian Ocean

This symposium also welcomes presentations that are not derived from IIOE-2 endorsed projects. The symposium will be convened by Jessica Benthuysen (Australian Institute of Marine Science), Lynnath Beckley (Murdoch University), and Danielle Su (University of Western Australia). The theme of AMSA 2019 is "Marine Science for a Blue Economy" and the conference will take place at the Esplanade Hotel in Fremantle, Western Australia.

Abstracts can be submitted at: http://amsa19.amsa.asn.au/ until 15 February 2019.

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 .jpg files).

Deadline: 30th June 2019

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

For monthly updates on the IIOE-2 programme activities, join our mailing list by signing up at *http://www.iioe-2.incois.gov.in/IIOE-2/Signup.jsp*

@IIOE2

@iioe_2

ESSO

INCOIS