INTERNATIONAL INDIAN OCEAN EXPEDITION

Issue No.4
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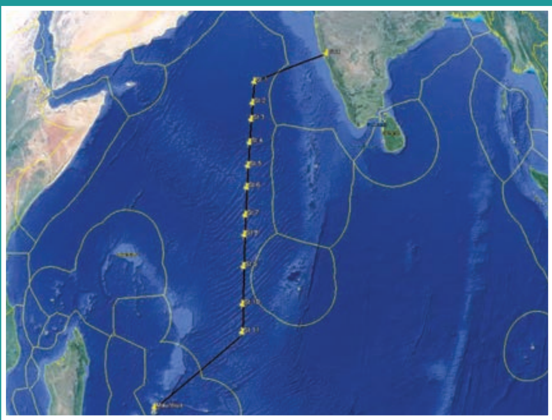
The Indian Ocean Bubble 2

First Cruise-IIOE-2

The first cruise of IIOE-2 will be flagged off on 4 December'15 on the last day of the IO50 Symposium at Goa, India. The route will be from Vasco-da-Gama, Goa to Port Louis, Mauritius.

Participating countries will include India, Australia, UK, USA, Mauritius, Israel, Singapore and Japan.

The primary objective of the 18-day expedition is to determine the structure of water masses along 67°E longitude and understand the physical-biological coupling across the equatorial region. The aim is also to assess possible changes with respect to the measurements made during IIOE and understand the impact of global warming/ocean acidification on chemistry and biology of this ocean.



IN THIS ISSUE

Blast from the Past - Memories

Monsoon Low Level Jet stream discovered during IIOE (1962-1965)

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From the aircraft wind measurements made during the International Indian Ocean Expedition (IIOE) of 1962 to 1965, Bunker (1965) found that high winds of about 50 knots (1 knot=0.51 m/s) occurred during the summer monsoon season over southwest Arabian Sea at low levels. These winds showed strong shear vertically, both below and above the wind speed maximum which was at about one km above sea level (Fig.1).

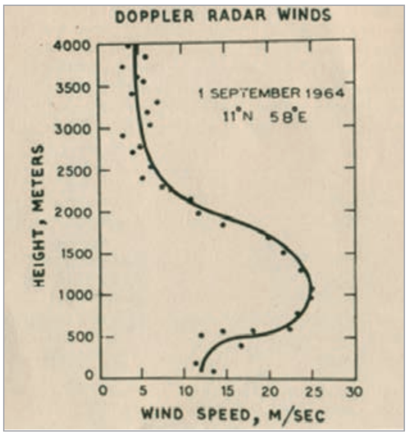

Fig.1. The vertical profile of wind speed in the monsoon flow over west Arabian sea (from Bunker, 1965)

According to Reiter (1961) a Jet stream should have large gradients of wind speed both in the horizontal and vertical. The author who had participated in Bunker's aircraft wind measurement programme in IIOE searched for the existence of such strong monsoon winds at low levels of the atmosphere over peninsular India which resulted in the discovery of the Low Level Jet stream (LLJ) - Joseph and Raman (1966). They analysed July RAWIN and PILOT wind data of peninsular India of five years -1961 to 1965 and found that the level of wind speed maximum of this LLJ was near 1.5 km (850 hPa) and it had core wind speeds of 40 to 60 kts. Fig.2 taken from Joseph and Raman (1966) indicates the wind and the LLJ axis at 850 hPa on an active monsoon day and the vertical profile of wind speed at a point on the axis of the LLJ.

Findlater (1969) established the existence of a cross equatorial LLJ in the Asian Summer Monsoon's low level circulation which included the wind maxima over southwest Arabian Sea found by Bunker (1965) and the LLJ over peninsular India of Joseph and Raman (1966). Findlater showed that the cross-equatorial LLJ

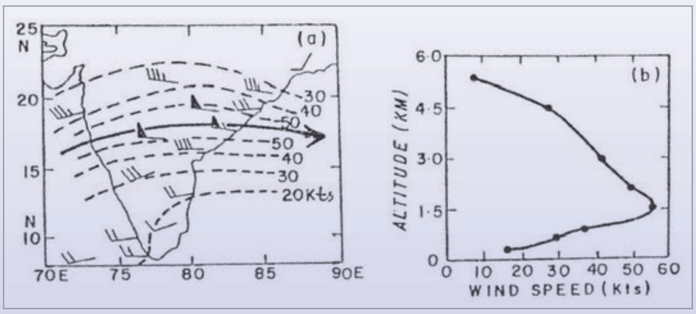

Fig.2. (a) Winds and Low Level Jetstream axis over peninsular India at 850 hPa level on an active monsoon day (b) vertical profile of wind speed on the same day at a point where the jet axis crosses the east coast of India (data of Vishakapatnam) - from Joseph and Raman (1966).

had its origin in the easterly trade winds of the south Indian Ocean. It crossed the equator in a narrow longitudinal belt close to the east African coast as a southerly current with wind speeds at times as high as 100 kts. LLJ turned into a westerly current over the Arabian sea, and passed through peninsular India and the Bay of Bengal. Fig.3 gives the wind at 850 hPa over south Asia of June to September averaged over the years 1950 to 2010 using NCEP/NCAR reanalysis data (Kalnay et al, 1996) which shows the inter-hemispheric LLJ of the Asian summer monsoon. LLJ is an important semi-permanent component of the Asian summer monsoon: (a) It acts as a conduit carrying the moisture generated by the trade winds over south Indian Ocean and the evaporative flux from the Arabian sea to the areas of monsoon rainfall generation over south Asia (b) The area of cyclonic vorticity in the atmospheric boundary layer close to the LLJ axis is a dynamic forcing for the generation of upward motion of the moist monsoon air for the production of rainfall and (c) synoptic scale

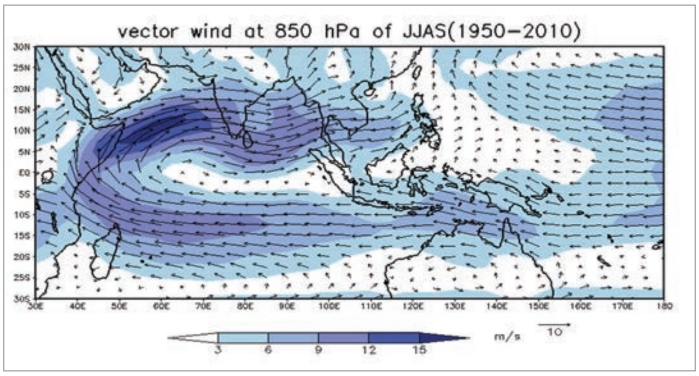

Fig.3. NCEP/NCAR reanalysis wind (Kalnay et al, 1996) at 850 hPa over south Asia of June to September averaged over the years 1950 to 2010 which shows the inter-hemispheric LLJ of the Asian summer monsoon

low pressure systems called Monsoon Depressions from over the north Bay of Bengal which has high Sea Surface Temperature (SST) in the cyclonic vorticity area north of the LLJ axis. The strong coastal upwelling along and off the coasts of Somalia and Arabia and the open ocean upwelling associated with the LLJ along with the evaporative cooling of the ocean surface by its strong winds produce major changes in the temperature structure of the top layer of north Indian ocean during the monsoon season June to September.

Intra-seasonal variability of LLJ was studied by Joseph and Sijikumar (2004). They found that LLJ passing through India has different locations for its axis in the active and break phases of the monsoon. In the active phase, LLJ axis passes through peninsular India along a latitude close to 15°N; in break monsoon the LLJ axis shifts to a position south of peninsular India and close to north of the equator. They also found that the linear correlation coefficient between the convective heating of the atmosphere over the Bay of Bengal and the strength of the zonal winds of LLJ through peninsular India is large and positive (and also statistically significant) at a lag of 2-3 days, with convective heating leading. In the active monsoon phase a large portion of the Bay of Bengal north of the LLJ axis has heavy rainfall and monsoon depressions form there and move in a north-westerly direction across north India. In the break monsoon phase deep convection and rainfall shifts to an area close to and south of the equator in the Indian Ocean and Bay of Bengal has subdued convection and rainfall.

Joseph and Sabin (2008) has given an ocean – atmosphere interaction mechanism for the active – break cycle of the monsoon in which the LLJ, the net heat flux over the ocean surface, deep convection north of the LLJ axis and the shallow ocean mixed layer over north Bay of Bengal have important roles. The birth of the LLJ coincides with the onset of monsoon over Kerala in India according to Joseph et al (2006) and Boos and Emanuel (2009). After its formation at the time of monsoon onset over Kerala, LLJ has a life duration of about 100 days, with major fluctuations in the active-break cycle as described earlier.

During a season of monsoon drought over India, the zonal winds of the LLJ over the Arabian sea become weaker whereas they become stronger and extend eastwards over the west Pacific ocean (Fig.4b). This eastward extension of LLJ associated with increased convection there (Fig.4a) is hypothesized to cause long "breaks" in the monsoon through ocean–atmosphere interaction – Joseph (2014). Monsoon rainfall of India has an inter-annual variability, called the Tropospheric Biennial Oscillation in which the LLJ has an important role – the weak (strong) LLJ during the monsoon season that gives deficient (excess) monsoon rains over India creates a positive (negative) SST anomaly over tropical Indian ocean that persists till the following monsoon changing the rainfall potential of the monsoon of the following year. The observational study by Meehl (1997) and the modeling study by Chang and Li (2000) and the references therein may be seen in this connection. The strength of the zonal winds of the LLJ through peninsular India had a statistically significant climate change (a decreasing trend) during the recent six decades according to a study by Joseph and Simon (2005 a,b). I am sure that scientists participating in IIOE-2 that would begin soon will plan and study the atmosphere and ocean in relation to the LLJ and the association of LLJ with the Asian summer monsoon and the ongoing global warming.

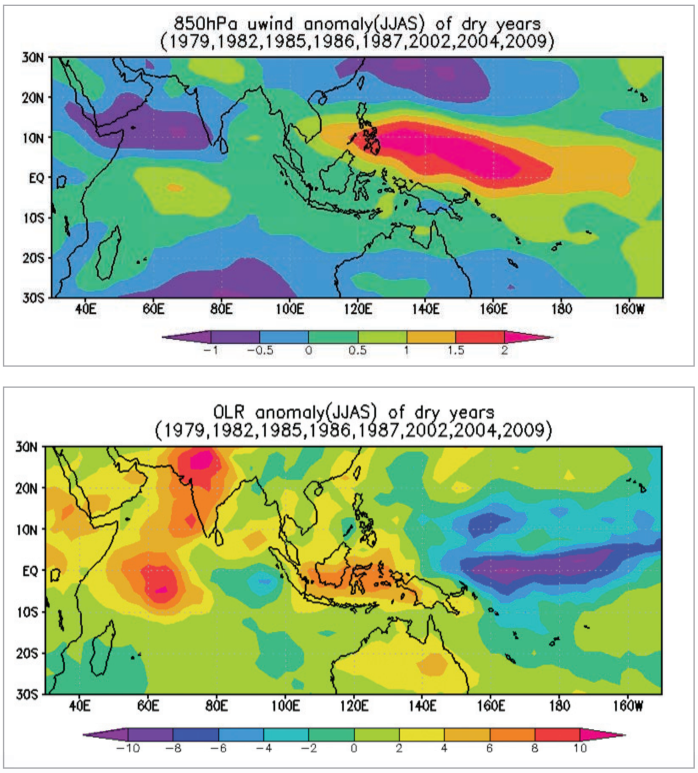

Fig.4. Composite of Outgoing Longwave Radiation (OLR) anomaly in Watts / sq. m of june to September of the 8 drought monsoons (dry years) of 1979-2010 (at top) and 850 hPa zonal wind (uwind) anomaly in m/s of the same 8 monsoon seasons (at bottom)

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Current Affairs - Meetings/Plans/Programmes

IIOE-2 Planning

Planning for IIOE-2 started in 2011 and the IOC(International Oceanographic Commission) Assembly at its 28th Session in June 2015 formalised its participation in IIOE-2 in partnership with SCOR (Scientific Committee for Oceanic Research) and IOGOOS (Indian Ocean -Global Ocean Observing System)

The SCOR Science Plan Development Committee's IIOE-2 Science Plan was also accepted as the science framework for IIOE-2.

Between 19-21 October 2015 the ESSO- Indian National Centre for Ocean Information Services (ESSO-INCOIS) in Hyderabad hosted the Implementation Plan drafting workshop for members of the Interim Planning Committee (IPC) and the assisting editorial group. The meeting reviewed eight key focus areas of the implementation plan including Governance, Science and Research, Data and Information Management, Capacity Development, Operational Coordination, Outreach and Communication, Translating Science for Society, and Sponsorship and Resources. The Plan includes specific objectives for each focus area and associated concrete actions that will underpin and facilitate implementation. The finalised plan will be presented during the official launch of IIOE-2 on 4 December2015 in Goa, India.

IIOE-2 will be supported by an International Project Office Framework with two key nodes in Hyderabad and Perth respectively.

Participants at the Implementation Plan Drafting Workshop at ESSO-INCOIS, Hyderabad.

Participants at the Implementation Plan Drafting Workshop at ESSO-INCOIS, Hyderabad

For more information contact shenoi@incois.gov.in or N.D'Adamo@bom.gov.au

Focii of Indian IIOE-2 Science Plan

IIOE hailed a watershed in the pursuit of understanding the Indian Ocean and its culmination led to the birth of National Institute of Oceanography in Goa, the first multi-disciplinary oceanographic research institute in the Indian Ocean region.

While various international/national expeditions in the post-IIOE era further contributed significantly towards our understanding of the Indian Ocean, certain areas still demand deeper study. India now has suites of both in-situ and satellite observation systems and several oceanographic research vessels which will be available to the scientific community during IIOE-2. Enhanced modeling capabilities assisted by these tools of observation will certainly provide a much better understanding of the Indian Ocean.

Indian scientists propose to focus on:

- Modulation of the physical and biogeochemical variability of the Indian Ocean by large scale oscillations and perturbations, such as the Wyrtki Jets, Madden-Julian Oscillation and Indian Ocean Dipole and related observed climate change signals
- Comprehensive understanding of the upper layer ocean dynamics and ocean-atmosphere interactions for accurate monsoon prediction
- Resolution of the mechanism maintaining the observed contrast between Bay of Bengal and Arabian Sea in terms of denitrification and nitrogen cycling
- Shoreline changes, coastal eutrophication/hypoxia and associated ecosystem response considering the high density population residing along the Indian Coast

Persian Gulf and Gulf of Oman Oceanographic Studies (PG-GOOS)

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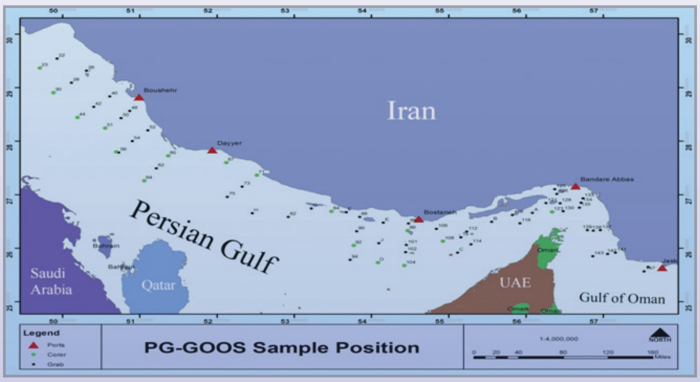
A comprehensive research cruise entitled "Persian Gulf and Gulf of Oman Oceanographic Studies" (PG-GOOS) has been conducted in 2012 and 2013 by the Iranian National Institute for Oceanography and Atmospheric Science. The expedition kicked off in November 15, 2012 from Qeshm harbour (Qeshm Island, Strait of Hormuz). The kick-off ceremony commenced with speeches of national authorities as well as a message from IOC/UNESCO executive secretary, Dr. Wendy Watson-Wright. More than 70 scientists from different disciplines including physical oceanography, marine geology, marine biology and chemical oceanography were involved in sampling, measurement and laboratory analysis during eight cruise phases. The operation was mainly performed in the Exclusive Economic Zone of I.R. Iran in the Persian Gulf and Gulf of Oman. The oceanographic operation was organized in a framework of 30 profilesand120 stations. Water samples have been collected using Multi-Water Sampler (Rosette) from the near-surface layer down to a maximum depth of 750m in the Gulf of Oman. Surface sediment samples were obtained by a grab sampler and short sediment cores with maximum core length of 2m were recovered using a gravity corer. Different types of nets were used to sample plankton. CTD profiler was utilized to measure in situ physical and chemical properties of the water column. Some sediment samples as well as water samples were fixed and preserved for further laboratory analysis on land and some others were analyzed on board. Chemical analysis on sediment samples for measuring pollutants and analysis on core samples for palaeo-oceanographic reconstruction are currently underway and may take more time. Here we present the preliminary results of CTD and nutrient data analysis as well as surficial sediments and benthic fauna distribution patterns. The results of fixed and moored stations are not reflected in this report.

Analysis of CTD data show that inflow of low salinity surface water of the Gulf of Oman into the more saline water of the Persian Gulf occurs year round but it is more developed in summer. However, in winter, the difference between densities of water masses is more distinct while it invigorates with temperature and salinity in summer.



Sampling locations and PG-GOOS participants at work

Total alkalinity (A_T) of surface water increases westward from the Gulf of Oman to the north-western parts of the Persian Gulf (ΔA_T=140 $\mu molkg^{-1}$). A_T increases in accordance with the Persian Gulf depth due to significantly higher salinity of the deep water. Surface pH values in the Gulf of Oman and Strait of Hormuz are significantly lower than those in the Persian Gulf and have a reverse relationship with depth in the whole area of study. Concentration of dissolved oxygen in surface waters did not change considerably at all measured stations. Silt is the major component of the detritus in northern Persian Gulf and Gulf of Oman. However, sediment composition shows more carbonate content in shallow subtropical shelf of the Persian Gulf relative to the detrital basin of the Gulf of Oman. Quantitative analysis demonstrated that dominant groups among phytoplankton, zooplankton, zooneuston, macrobenthos and meiobenthos were dinoflagellates, copepods, gastropods and foraminifers, respectively. Higher abundance of zooplankton and macrobenthos were recorded during the autumn cruise, whereas higher abundance of phytoplankton and zooneuston are reported from the summer cruise. Several taxa have been reported for the first time from these areas; including : *Desmocolex sp.* (meiobenthos), *Endeis sp.* (macrobenthos), *Cardiopoda sp.* (zooplankton), and *Halobates sp.* (zooneuston).

The preliminary results of PG-GOOS supports general trends observed in previous expeditions, while new details have been unraveled in the transitional area between Persian Gulf and Gulf of Oman, as well as in deep waters.

From left to right: Dr. V. Chegini Director of INIOAS at the time of Expedition, Dr. H. Zomorodian Founder and first Director of INIOAS, Dr. I. Oliounine, IOC/UNESCO counselor and Dr N. H. Zaker current Director of INIOAS

Ocean Voice - Opinions

A CPR Survey for the Indian Ocean – a personal view

Peter Burkill (University of Plymouth, UK& Visiting Scientist NIO Goa, India) and Raleigh Hood (University of Maryland, USA)

We live in a changing environment and the ocean's plankton respond to such changes. One of the challenges we face for understanding our changing environment is being able to effectively measure and monitor such changes. This is particularly true in the study of plankton. While we can use satellite-derived ocean colour to build up time series of phytoplankton in surface waters, this still tells us rather little about the biodiversity of the whole plankton community. One procedure for monitoring changes in plankton biodiversity is through the Continuous Plankton Recorder (CPR) Survey run by the Sir Alister Hardy Foundation for Ocean Sciences (SAHFOS www.sahfos.ac.uk) based in Plymouth UK.

The CPR Survey began in 1931 and has focused primarily on the North Atlantic where it has demonstrated significant changes in the biodiversity and phenology of plankton over the last seven decades. In 1997,SAHFOS extended the CPR survey to the North Pacific and, in 2011 an international consortium called the Global Alliance of CPR Surveys (GACS) was set up. GACS members include Angola, Australia, Brazil, China, India, Namibia, New Zealand, South Africa, USA and the UK. One of main aims of GACS is to foster a global network to monitor plankton biodiversity through the use of the CPR.

So how does the Indian Ocean fit in? It is clear that, while monitoring biodiversity of some of the waters of the Arctic, Antarctic, Atlantic and Pacific is now underway, there is currently no survey of the Indian Ocean. Moreover, the Indian Ocean is, by far, the least well-sampled ocean basin providing an opportunity not only for monitoring, but also discovery. How, for example, does the plankton community respond to monsoonal forcing? We know that there are dramatic changes in species composition and also behavioural responses, but our current understanding is based largely on limited shipboard observations from the JGOFS era of the 1990's. Another question is- what is the composition of the plankton community in the southern part of the basin? These waters are virtually unknown in terms of plankton species composition. These questions are not just academic, they are essential to managing squid and tuna fisheries in the regional. With the advent of IIOE-2, the Indian Ocean scientific community should consider carefully what could be achieved, particularly through international collaboration.

How does the CPR work? The CPR is about one metre in length and is made of stainless steel. It is towed on a wire behind a merchant navy vessel at typically monthly intervals along regular routes. The CPR can be towed at speeds of up to 25 knots in sea states of up to Beaufort force 11. The CPR works best on long tows and is equipped with an internal cassette that lasts 500 nautical miles. Cassettes can be changed during a tow (Fig.1). As a result, tows of huge length across ocean basins are possible.

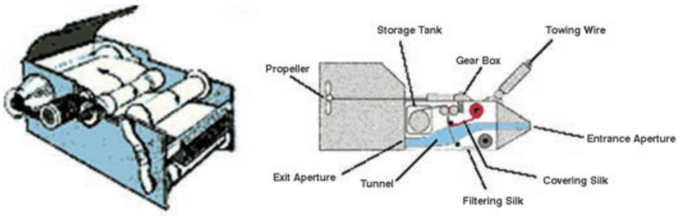


Fig.1. a) the internal cassette that collects plankton onto silks; b) a section of the CPR showing the flow of water through the instrument (from www.sahfos.ac.uk).

The CPR is also equipped with sensors that measure salinity, temperature and chlorophyll fluorescence. After it is towed, the CPR and its cassettes are returned to its home laboratory where plankton are analysed taxonomically and data from sensors are downloaded. Month by month, a database is built up of plankton biodiversity and environmental conditions along regular tow routes.

Where could a CPR survey in the Indian Ocean begin? Given the dynamic nature of the Arabian Sea, we believe it would be good to set up a CPR route between India and the Gulf of Oman and perhaps beyond this into the Persian Gulf (Fig. 2). The merchant ships that ply such routes operate throughout the year and are relatively immune from the sea states generated by the summer monsoon. Monsoon conditions are challenging for research ships and so merchant ships provide a unique opportunity to sample during a period for which we have very little data. Such a route would also provide a relatively high temporal resolution characterization of monsoon-driven seasonal changes in plankton community composition.

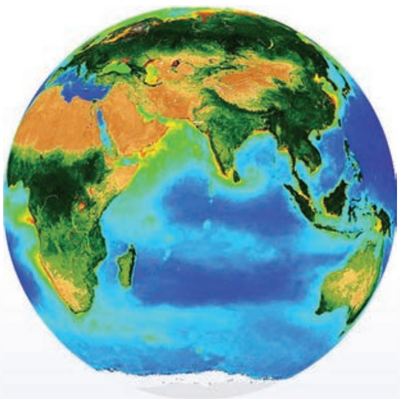


Fig.2. Satellite image of the Indian Ocean with three potential CPR routes overlaid

It is easy to envisage other CPR routes such as one from Western Australia to the Red Sea and another between South Africa and Pakistan (Fig. 2). The former traverses a wide range of water types, from oligotrophic to equatorial and Somali upwelling waters, across the whole ocean basin. The latter route is orthogonal to the other two routes and traverses a range of different waters that are seasonally forced to differing extents. Such long routes would be unique, with sampling of plankton biodiversity in waters that we know little about. The first route is shorter and might take the highest priority since India already has a CPR and is contemplating its use. All three routes could be managed by countries that are already in GACS. The African coastal route might become an integral part of the West Indian Ocean Upwelling Research Initiative (WIOURI), currently being developed by Mike Roberts of DEA, South Africa.

While we have focused our rationale on biodiversity, we also need to urge some *caution*. Training for the analysis of biodiversity in these waters is a major challenge and we suggest suggest that beginning a CPR Survey in the Indian Ocean might best be started by using biogeochemical sensors alone. During such a trial period, experience would be gained by both scientists and the merchant navy vessel staff that would deploy CPRs. It also means that the initial running costs of such a survey would be relatively modest and could be ramped up later to include the extra manpower needed for full biodiversity analysis. Each route would need a commitment for a minimum period of 5 years to make it worthwhile. IIOE-2 may be able to help with resourcing for manpower and also training which would fit well with planned capacity development efforts.

The establishment of CPR surveys in the Indian Ocean could provide important scientific information in this under-sampled basin and it would be an important legacy of IIOE-2. Could a sorting centre, like the one established in Kochi during the original IIOE to process zooplankton net-tow samples, be established? This is an ambitious goal, but it is not inconceivable given the resources that are potentially available from the more affluent Indian Ocean Rim nations. We call on the international community to join together and make CPR surveys in the Indian Ocean a reality.

<u>*Footnote:*</u> Although Peter Burkill is a former Director of SAHFOS, neither author has a vested interested in CPR Surveys. Both authors are members of the IIOE-2 Interim Planning Committee and the paper arose from informal discussions at a recent IPC meeting.

Changing productivity trends in the Arabian Sea

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In the global climate system, phytoplankton- free-floating microscopic florae are arguably the biggest regulators of global temperatures through carbon sequestration. This ocean's "green machines" are responsible for half of the photosynthesis that takes place on our planet. Studying phytoplankton blooms is one way of monitoring the effects of climate change. Any change in its concentration would have significant impact on the marine ecosystem.

Satellite based monitoring of phytoplankton has provided continuous data with high temporal resolution for more than a decade now. Analysis of such data has given significant insights on whether global ocean biomass is increasing or decreasing. Gregg et al., (2003) showed a significant 6% decrease in the global net oceanic primary production since 1980 by analysing satellite and in situ blended ocean chlorophyll records. On the other hand, Antoine and Morel (2005) showed an overall increase of the world ocean average chlorophyll concentration by about 22% from the CZCS to the SeaWiFS era. Using 6 years of SeaWiFS data, Gregg et al., (2005) showed an increase of 4.1% in the global ocean chlorophyll. The northern (14%) and equatorial (9%) Indian Oceans contributed significantly to the observed global increase. The increasing trend was determined to be particularly significant in the western Arabian Sea with a more than 300% surface chlorophyll increase (Goes et al. 2005) attributed to the strengthening of the monsoonal winds in this region due to global warming. This particular result deviates from other studies where the observed increase is attributed to the influence of one of the strongest El-Niño events during 1997–1998 and an Indian Ocean Dipole event(e.g., Kahru and Mitchell 2007; Prakash and Ramesh 2007; Prasanna Kumar et al., 2010; Prakash et al., 2012). Nevertheless, this new finding generated a considerable interest in the scientific community on ecosystem responses/upcoming challenges of impending global warming, and encouraged scientists to look for signals from other parts of basin/world ocean.

A comprehensive analysis of longer time scale (1997-2010) by Prakash et al., (2012) does not indicate any appreciable overall trend over the Arabian Sea as a whole. However, the south-western Arabian Sea, appears to have distinct trend regimes (Fig. 1) in summer productivity , before and after 2003: the summer peak chlorophyll concentration increased consistently from 1998 to 2003 (slope: 0.24 ± 0.06) but then decreased during 2003-2010 (slope: -0.06 ± 0.03). Interestingly, analysis of wind data does not show any appreciable change in wind strength/stress curl during this period. Thermocline, however, shows increasing and decreasing trend similar to chlorophyll. Since thermocline and SLA are correlated, the changing trend of surface chlorophyll may be governed by the changing SLA through its manifestation of thermocline. Independent study of decadal variability of SLA in the Indian Ocean also corroborates this result. We need to sustain satellite-based observations and encourage more in situ time series measurements to identify the effect of recent climate perturbations, if any, on marine ecosystem: Time series data of more than 40 yrs are required to distinguish anthropogenic trends from natural variability [Henson et al., 2010].

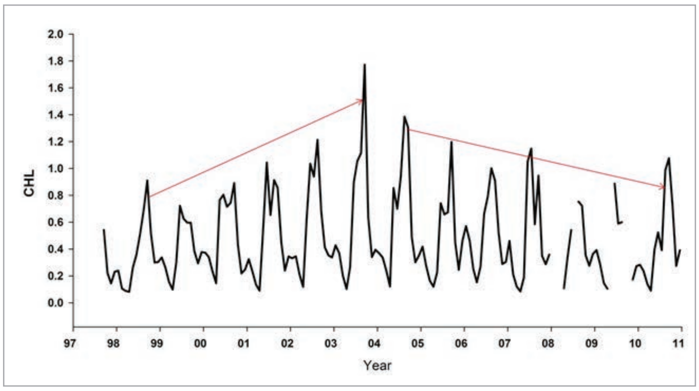

Fig.1. Area averaged monthly time series of Chlorophyll -a for south-western Arabian Sea (47-55°E&5-10°N). The trend lines shown depict the increasing and decreasing trends during 1998–2003 and 2004–2010, respectively

New Horizons - Initiatives

Citizen Oceanography Meets the Marine Microbiome: Crowdsourcing Oceanographic Data

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**Indigo V Expeditions*

Indigo V Expeditions pioneered citizen oceanography as a novel approach to better understand ocean health. For the first time, coupled with molecular diagnostics tools, we have established an ocean health baseline across the Indian Ocean.

Because of their abundance and functional role, microbes are the key providers of ecosystem services, acting as both drivers and early indicators of perturbations in the marine environment. Therefore, monitoring the marine microbiome is a useful parameter to detect potential deleterious effects in any given ecosystem and assists efforts to better manage and protect fisheries, ecosystems and the greater ocean basin.

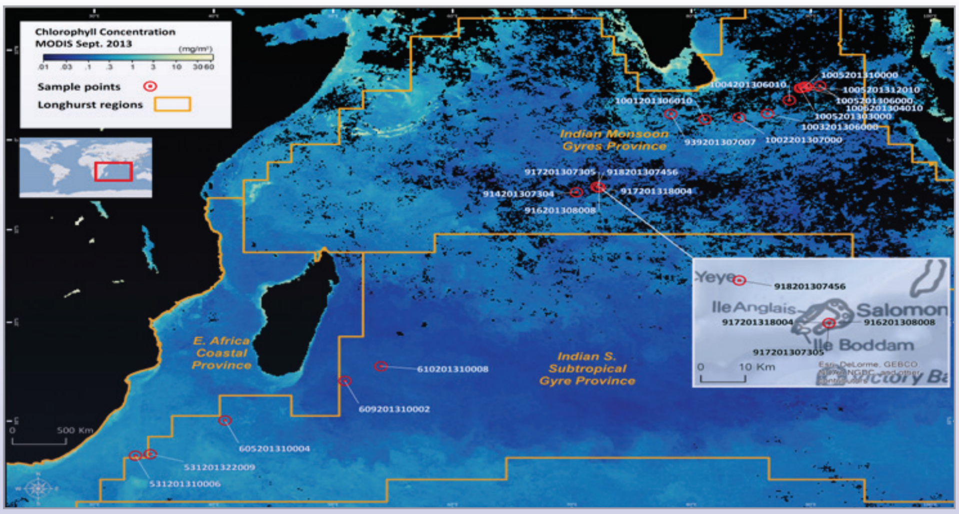

Fig. 1. Map of sampling stations during our Indian Ocean C oncept Cruise, which resulted in establishing the world's first 'ocean health' IO baseline. Data also revealed distinct groups of planktonic communities, disrupting the conventionally held view that the marine microbiome is largely uniform across large swaths of ocean.

In an effort to establish ocean health baselines to predict the response of marine habitats to environmental change, in 2013 during our Indian Ocean Concept Cruise, we undertook a broad survey of microbial diversity across the Indian Ocean, including the first microbial samples collected in the pristine lagoon of Salomon Islands, Chagos Archipelago. This was the first large-scale ecogenomic survey aboard a private yacht employing a 'citizen oceanography' approach and tools and protocols easily adapted to ocean going sailboats and resulted in the first 'ocean health' baseline across the Indian Ocean.

Our data also provided a window into the abundance, diversity and activity of keystone microbial players in marine biogeochemical cycles, spanning from bacteriophage, viruses, and bacteria through to microbial eukaryotes that collectively form the foundation of the food web. Our project highlighted biogeographic patterns in the taxonomic composition of microbial communities across the Indian Ocean.

Samples from within the Salomon Islands Atoll contained an entirely unique microbiome community, which was different even from samples just outside the atoll despite constant water exchange. The interior microbiome samples were dominated by the photosynthetic Synechococcus cyanobateria, while the 'exterior' oceanic samples were dominated by photosynthetic Prochlorococcus as well as typical heterotrophic bacteria, Pelagibacter SAR11 (see Fig.1).

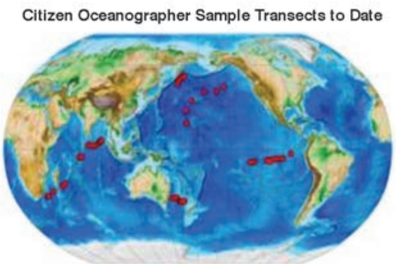

Fig.2. Map of citizen oceanographer sampling transects across world oceans. Data sets are currently being analysed and prepared for publication.

Sequencing the genes expressed by the microbial community within the Salomon Islands Atoll, revealed that Synechococcus was also responsible for driving shifts in the expression of different functional genes. Enrichment of expressed genes (mRNA transcripts) related to photosynthesis and nutrient cycling indicated bottom-up controls of community structure suggesting that increased cycling of organic nitrogen compounds stimulated the Synechococcus community.

For the first time, we also discovered that the Indian Ocean can be partitioned into distinct planktonic community groups: the Bay of Bengal Region, Salomon Atoll Inside, Salomon Atoll Outside, Mid Southern Ocean and the Southern Ocean.

Fig. 3. Sailing route aboard S/Y Indigo V during March to July 2016 research cruise, which is now open to proposals

Our findings have disrupted the conventionally held view that the marine microbiome is largely uniform across large swaths of ocean ecosystems. Our full paper was recently published in Nature Scientific Reports and may be viewed here; <http://www.nature.com/articles/srep15383>. To date, our network of citizen oceanographers have collected the largest sampling of the Pacific Ocean to date in a single season (see Fig. 2). Data is currently being analysed and prepared for publication.

Indigo V Expeditions will be setting sail again in early 2016 for our involvement with the Second International Indian Ocean Expedition (IIOE-2). We will be sailing from Phuket (Thailand) to Galle (Sri Lanka), to Chagos Archipelago (BIOT) and Mauritius with a number of additional return voyages back to Chagos and St Brandon.

The data collected will help develop an in-depth integrative marine microbiome model that will lead to better management and monitoring practices for our national resources while authentically, and directly, engaging the community in ocean health monitoring.

We are now accepting proposals for ship time. Please visit www.indigovexpedtions.org for more information.

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Ocean Vision
Census - Biology

Rainfall Aided Recovery of Shallow Water Bleached Corals in South Andaman

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Shallow water coral bleaching was observed in the months of April and May, 2015 in South Andaman (Malakar et al. 2015). By the first half of May 2015, fully bleached colonies were observed in four study stations namely North Bay, Marina Park, Burmanullah and Chidiyatapu located in the eastern coast of South Andaman. As monitoring continued, by the month of July 2015 recovery of all bleached corals was observed. This can be attributed to the normalization of SST due to adequate rainfall since the second half of May 2015. The onset of monsoon in the second half of May has led to recovery of bleached corals in very shallow waters of South Andaman.

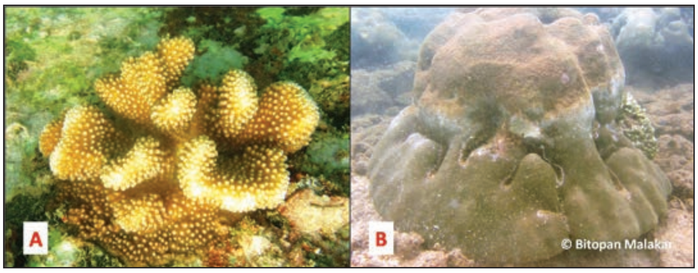

Fig.1. (A) Fully recovered Pocillopora sp. in Marina Park.
(B) Partially recovered Porites sp. in Burmanullah

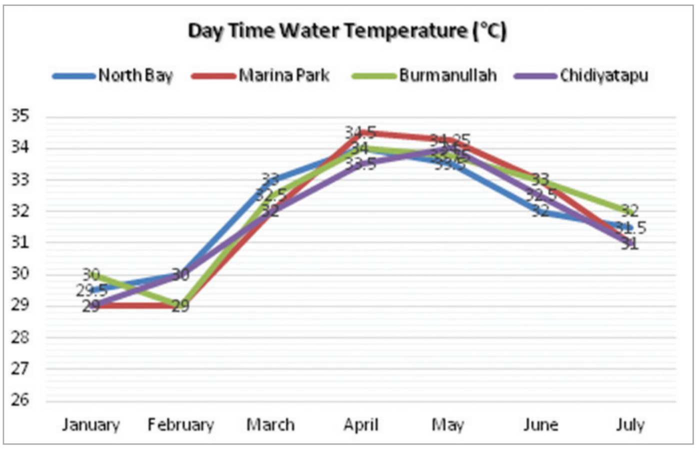

Fig.2. The variations in water temperature from January 2015 to July 2015 as recorded in the field

Four stations were monitored as reported earlier (Malakar et al. 2015). Similar trend of bleaching and recovery was recorded from all the stations. Water temperature as high as 36.5°C was recorded in the first half of May and fully bleached coral colonies were observed consequently. The arrival of monsoon in the second half of May has helped in decreasing water temperature thereby preventing the spread of bleaching to deeper waters viz. reef crest and reef slope. The phenomenon of bleaching and recovery was clear in shallow waters where the reef is exposed during low tides or under less than 30 cm of water. At present all bleached corals have mostly fully recovered and some partially recovered (Fig.1)

It is evident that until monsoon arrived in the second half of May (Fig. 2) day time water temperature of shallow coral reefs was on the rise but with the onset of monsoon water temperature dropped by an average of than 2.5° C in all the stations. This let to normalization of SST and the temperature stress on shallow water corals decreased. The result was visible by July when most of the partly and fully bleached corals (*Acropora* spp., *Pocillopora* sp. and *Porites* spp.) fully recovered.

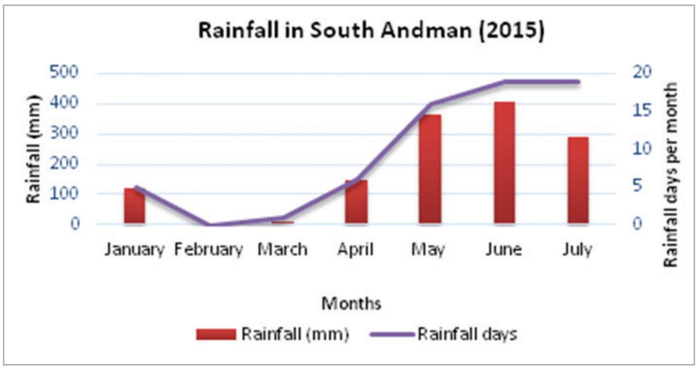

Fig. 3. The variations in rainfall and rainfall days in South Andaman from January 2015 to July 2015 (Source: Meteorological Department, Port Blair)

Key to this recovery process of shallow water corals was the onset of monsoon exactly in the second half of May. Rainfall was meagre in the first four months (Fig. 3) of 2015 which is also known as the pre-monsoon season here in Andaman and Nicobar. This led to the rise in SST in shallow reef areas in South Andaman. It is to be noted that the first half of May was without any rainfall. The increase in rainfall and rainfall days thereafter till July was vital for the drop in day time water temperature in shallow reefs which resulted in the recovery of the bleached corals.

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Oxygen Minimum Zones (OMZ), Diversity and Metagenomics: An Exploration

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Ocean offers an unlimited source of wonders. Amongst them the diversity of life forms is very fascinating. Marine micro-eukaryotes and plankton are known to influence the structure and function of the aquatic food web thereby playing a critical role in nutrient cycling and in patterns of surface and deep-ocean ecology. In the last few decades, the role of microorganisms in the biogeochemistry of the ocean is becoming increasingly apparent. It is estimated that clear sea water carries about 106 organisms and more than 97% of them represent non cultured biota. In a large part of the world this diversity remains unexplored. Oxygen is one of the principle components in any marine ecosystem which can certainly affect the distribution and diversity of marine organisms including microorganisms. As oxygen levels decline, energy is increasingly diverted away from higher trophic levels into microbial community metabolism causing changes in carbon and nutrient cycling. Oxygen Minimum Zones (OMZs): areas with less oxygen concentration (<0.5 ml/l) are observed in marine environments with low oxygen supply and with oxygen depletion at different depths. OMZs are thought to support complex microbial communities which are tolerant to low oxygen supply and thus can use other resources for energy production. As oxygen levels decline, microbial community metabolism diverts to other pathways causing changes in carbon and nutrient cycling and in abundance of biota. OMZ micro-organisms can use various metabolic pathway components like nitrification, anaerobic ammonium oxidation (anammox), denitrification, and inorganic carbon fixation as survival strategies.

Currently OMZs are expanding due to global climate change causing disturbances in marine ecosystem functions. OMZ regions are distributed all over the world and are known to be influenced by climatic change. OMZs occur in the Indian Ocean, the Arabian Sea and the Bay of Bengal (Julian P. McCreary Jr, 2013). The lower part of the Arabian-Sea OMZ (ASOMZ; below 400 m) intensifies northward across the basin and upper part (above 400 m) is located in the central/eastern basin. The Arabian-Sea OMZ (ASOMZ) is the second-most intense OMZ in the world tropical ocean (Kamykowski and Zentara, 1990). Although the cause and consequences of OMZ areas are being explored (Julian P. McCreary Jr, 2013, P Hingamp, N Grimsle, 2013), very few (Baby Divya and K. V. Soumya, 2010) systematic studies have been carried out with respect to microbial diversity and their functional significance.

Metagenomics enables the culture-independent analysis of a microbial community in any environmental sample and provides a means to assess, characterize, and quantify this untapped diversity of microbes and discover novel genes, metabolic pathways, and important products with biotechnological, pharmaceutical, and medical relevance. Metagenomic analysis can take a sequence-based or a functional approach (or a combination of both) to study a complex microbial community, but always begins with the isolation of DNA from the environment of interest. With the experience in microbial genomic diversity analysis and utilising the strength in genomic and bioinformatics analysis, we are exploring the Indian OMZ areas and related unexplored word of microorganisms.

Metagenomic analysis of sample collected from various depths (Minimum oxygen zones): preliminary analysis

We participated in the Sagar Sampada cruise in May and June 2015 and collected water samples from minimum oxygen zone. We have carried out the analysis of the cultivable microflora under different nutrient, salt and incubation conditions and are in the process of establishing the proof of concept and feasibility analysis for metagenomics. The water samples were collected from the west coast at 100m, 200m, 500m and 1000m depth. CTD equipment was employed to study the oxygen minimum zone. Sea water was collected from several stations for isolation of cultivable bacteria. Zobel's medium with 5% sea salt was used as a basal media for isolation of cultivable bacteria. Isolated single colonies from sea water were inoculated in basal media and kept at 10°C to 12°C in dark for 7 to 30 days. The sampling map and location information is depicted in Fig.1.

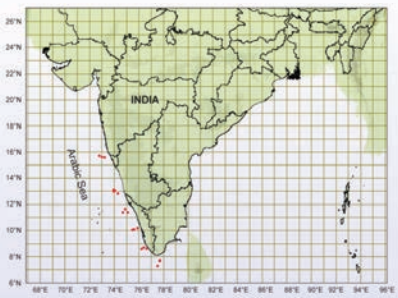

Fig.1. Sagar Sampada collection sites

The microbes were characterised by classical microbiological techniques. In addition, DNA was isolated from all of these colonies by phenol-chloroform method and 16S PCR was performed using 27F and 1492R or 1390R primer pairs according to standard protocol. PCR products were sequenced and used for bacterial identification using NCBI- BLAST tool. In total 4 different types of bacteria could be identified from 11 colonies which include *Halomonas, Marinobacter, Pseudoalteromonas,* and *Idiomarina* species. This data shows the diversity of bacteria which includes halophytic bacteria (*Halomonas sp.*), hydrocarbon degrading bacteria (*Marinobacter*) and bacteria involved in biofilm formation (*Pseudoalteromonas*).

One litre water sample from each station was filtered with a 0.22µm filter for DNA isolation which we are currently utilising to evaluate total microbial diversity through metagenomics. We have also explored the available metagenomic datasets extensively and utilised the functional metagenomic approach to identify metabolic pathways and to establish tools and technology for exploration of this hitherto unexplored world. We have accessed data from high throughput analysis utilising several metagenomic approaches, tools and websites, namely MEAGEN, MG RAST, etc. A bioinformatics approach and pipeline to study the functional metagenomic diversity in among the various OMZ areas has now been established. It has been recognised that in OMZs, nitrogen metabolism is one of the main pathways by which microorganisms survive and gain the energy for degradation of organic materials (Yu Z, Yang J and Liu L, 2014). The data obtained from the sample from MG-RAST database was used for the case study (Maribeb Castro-González et.al., 2015)

Enzymes namely, Nitrous oxide reductase, Nitrite Reductase , Nitrate reductase and Nitric oxide reductase, etc are involved in the nitrogen metabolising pathway and hence become important to understand functional diversity among OMZ samples. The sequences for the genes involved in Nitrogen metabolism were downloaded from NCBI nucleotide databases and comparative genomic analysis was carried out using available metagenomic datasets. The following bacteria, namely, *Gammaproteobacteria, Alphaproteobacteria* and *Delta proteobacteria* were observed to be most abundant in the datasets analysed.

It is now be feasible to further explore marine diversity and metabolic capabilities of ocean microbes especially in OMZs , by combining a culture based approach along with metagenomic analysis of biodiversity to gain insight into their metabolic capabilities.

Acknowledgements

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Diving exploration and faunal survey of anchialine caves in Christmas Island, Indian Ocean

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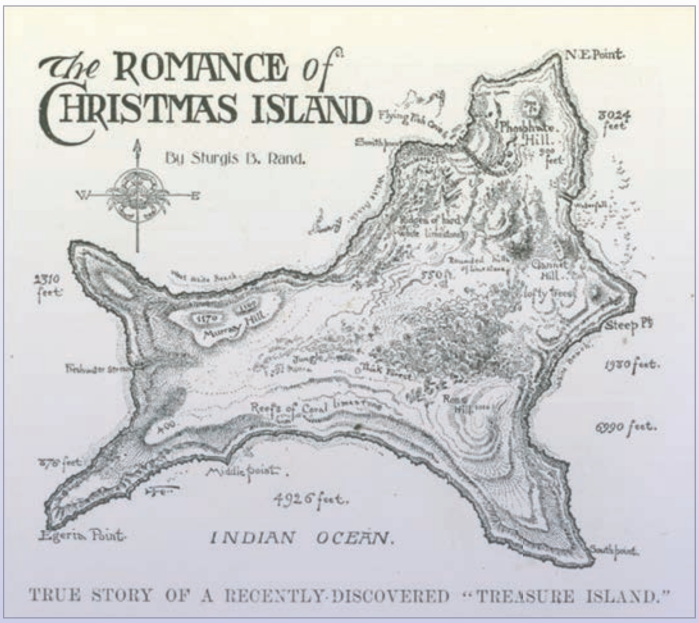
Background: Anchialine caves contain tidal, sea level pools of fresh to fully marine waters that are inhabited by a diverse community of obligate, cave-adapted (stygobitic) fauna dominated by crustaceans (Iliffe, 2000; Iliffe & Kornicker, 2009). A variety of anchialine taxa stygobites are found in caves on opposite sides of the Atlantic as well as from the Indian Ocean and have been referred to as Tethyan relicts. Anchialine Tethyan relict fauna from the Indian Ocean tend to have a similar distribution (Caribbean, Canary Island and Western Australia) and include members of the crustacean class Remipedia, thermosbaenacean genus ***Halosbaena***, and thaumatocyprid genus ***Humphreysella***. Further investigations of anchialine caves from the Indian Ocean promise to yield discoveries of new fauna and localities that can shed light on the origin, timing and modes of dispersal of these unique organisms.

Christmas Island, a territory of Australia, lies in the eastern Indian Ocean at 10º 30′ S, or about 350 km southwest of Java and separated from it by the Java Trench. The island, which is the tip of a submerged seamount, rises 4.5 km from the ocean floor. It consists of late Cretaceous to early Tertiary age volcanic rocks that are capped by Tertiary limestones, which in turn are partially buried by phosphate- rich soil with pinnacled karst. The limestones tend to be relatively thin (20–30 m) in the center of the island, but then thicken towards the coast above the steep-dipping volcanic surface where they reach up to 250 m in thickness. The steeply cliffed coastline rises via a series of terraces to the phosphate-blanketed interior plateau. Despite the high rainfall, little surface water is present since karstic subterranean drainage occurs through numerous caves. Groundwater flow follows the limestone/volcanic contact to emerge at major conduit springs, located at or below sea level. Uplifted caves occur along the present coast. Cave development takes place at the mixing zones between fresh and sea water in the coastal zone, and between vadose and phreatic waters beneath the plateau. Cave locations and forms are controlled by the rock structure (especially jointing), the location of the volcanic contact, and the combination of uplift with present and past sea levels - which controls the location of the mixing zone (Grimes, 2001).



Expedition objectives and accomplishments

- Explore anchialine and submarine caves, focusing on known caves with highest biodiversity as well as previously unstudied caves
- Collect and photo-document cave-adapted aquatic fauna for use in taxonomic and molecular genetic studies
- Photo and video surveys of the caves to highlight unique features and habitats
- Assemble data to justify protection and preservation of the island's unique caves

Expedition plan: A two-week expedition to Christmas Island sponsored by the National Geographic Society took place from March 18 – April 1, 2013.

Team members: An eight person team consisting of world renowned marine biologists, technical cave and rebreather divers, and underwater photographers from the US and Australia participated this expedition included:

Prof. Thomas Iliffe (Texas A&M University) expert cave and rebreather diver who has led numerous expeditions, studying anchialine caves world-wide and discovering more than 300 new species.

Dr. Bill Humphreys (Western Australia Museum) expert on Australian anchialine ecology and leader of the 1998 biospeleological expedition to Christmas Island.

Dr. Harry Harris (project medical diving officer, Australia) Expedition leader for Pearse Resurgence expeditions in New Zealand; expert cave and deep diver and UW photographer.

Jill Heinerth (Into the Planet, US) pioneering underwater cave explorer and award-winning filmmaker, specializing in HD still and video photography and media management.

Brian Kakuk (Bahamas Caves Research Foundation) former US Navy diver and foremost expert on diving in the Blue Holes of the Bahamas.

Ken Smith (Australia) veteran cave diver having explored most of Australia's caves as well as numerous ones overseas; developed low frequency pinger used in precision cave mapping.

Craig Challen (Australia) one of Australia's leading technical divers with record setting dives of distance in Cocklebiddy Cave, Australia, and depth in Pearse Resurgence, New Zealand.

John Dalla-Zaunna (Australia) mapping coordinator of the CDAA (Cave Divers Association of Australia) specializing in 3D & virtual cave mapping & design.

Diving exploration: Considering that two distinctly different types of caves were explored and investigated during the expedition, specialized techniques are required for each. Inland anchialine caves required side-mounted tanks that facilitate transport of tanks through dry caves and allowed divers to penetrate low profile restrictions. Search for ocean caves required boats for access and closed circuit, mixed gas rebreathers due to depths of 80 m or more. All divers participating in the project were highly experienced at these types of dives meeting recognized cave diving safety standards.

Biological methodology: Inland caves contained haloclines at 2-3 m depths, with saltwater below. The focus of the expedition was to examine these deeper waters for

stygobitic fauna. Since undisturbed waters were exceptionally clear, initial collections focused on visual observation and collection. As visibility deteriorated due to being disturbed, a plankton net was used to capture smaller organisms. Finally, baited plastic bottle traps were left at depths below the halocline for approximately 24 hours to attract shrimp and other scavengers. In the lab, still and video photography were used to document coloration and swimming behavior. After photographic documentation, specimens were preserved in ethanol, RNA later, or suitable preservatives depending on their use for taxonomic, molecular or electron microscopic purposes. All material was curated for deposition in the collections of the Western Australia Museum.

Biological discoveries: Exciting and unanticipated animals, likely representing new species, were collected, primarily from inland caves close to the coast. The thermosbaenacean *Halosbaena* is one of the iconic marker taxa of anchialine systems from tropical and subtropical waters. Caves with this species characteristically contain an assemblage of other anchialine restricted crustaceans. The occurrence of Halosbaena on Christmas Island was unexpected, although the thaumatocyprid ostracod *Humphreysella baltanasi* (previously *Danielopolina baltanasi*; see Humphreys et al., 2009 and photo at right). Specimens of ***H.*** *baltanasi* collected during the expedition will be used for molecular genetic comparison with other closely related

species. Until recently this type of anchialine fauna was restricted to areas bounded by shallow continental waters such as the Caribbean, Canary Island and NW Australia. The occurrence of such fauna on isolated seamounts such as Christmas Island and also Minami Daito-jima (island) in the Okinawans (Pacific) suggests that the ancestors of these animals have been able to disperse across the ocean within the time of emergence of such islands; in the case of Christmas Island, since the mid-Miocene or possibly Eocene. A swimming polychaete worm from the family Spionidae looks very much like a member of the genus *Prionospio* (see photo at left). Another undescribed swimming species from this genus occurs in a submarine lava tube in Lanzarote, Canary Islands – nearly on the opposite side of the world! DNA sequencing can determine how closely related they actually are. A cave adapted amphipod appears to be new species within the family Anamixidae and the genus *Anamixis* (see photo at right). Finally, a number of copepods were collected from several caves and are currently being identified.

Photo/video documentation: Still and HD video photography allowed for thorough documentation of the caves and for the procedures and personnel used to explore them. The three UW photographers in our team were assigned appropriate tasks to ensure complete coverage.

Results: We anticipate that several new species will be described as a result of this expedition. The geology (volcanic seamount capped with limestone), types of caves (dry limestone caves with anchialine pools in their interior), and geologic history (mid-ocean basaltic seamount of Cretaceous to Tertiary age) of Christmas Island in the Indian Ocean compares closely with that of Bermuda in the Atlantic. The rich anchialine fauna of Bermuda (>80 cave-adapted species) suggests that numerous additional discoveries await on Christmas Island. Considering that very little information exists on anchialine fauna from the Indian Ocean, our data should be of considerable biogeographic and evolutionary importance. Furthermore, our diving exploration of the underwater caves of Christmas Island provides significant data relevant to the mode and timing of cave formation in relation to sea level history and island uplift.

Although Christmas Island is world famous for its abundant populations of land crabs, it is also home to an Australian national park containing verdant tropical forests, coastal limestone cliffs and terraces, deserted beaches and pristine coral reefs. This unique tropical island ecosystem includes the prodigious land crabs and rare sea bird colonies, but also now as a result of this expedition, new cave-adapted organisms with close relatives from anchialine caves around the world have been added. The island's natural history offers a fascinating glimpse into a biologically diverse and unspoiled tropical paradise.

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Studies On Cestode Parasitizing Some Marine Fishes from Raigad Region India

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Introduction

Marine Parasitology is an important field in aquatic science having a close linkage to other marine science fields such as fisheries, mariculture, fish ecology and environmental monitoring and should be viewed in the context of this close linkage. Fish parasites play a major role in marine biodiversity, infecting hosts at all different trophic levels. The growth of marine aquaculture, concerns about the effects of pollution on fish health and the possible use of parasites as biological indicator organisms has led to a steady increase in interest in this topic.

Marine fish and fisheries products are important sources of protein and contribute a great deal to available food resources worldwide. Over-fishing and environmental degradation are already threatening most of the larger fish stocks and a further increase in fishery production seems to be dependent on the cultivation of aquatic organisms with semi-extensive and intensive mariculture. An intensive culture leads to an increasing risk of infection by disease causing parasite, such as fungi, viruses, bacteria, protozoa and Helminth.

Parasites in marine fish are of public concern if they are found dead or alive within food products that are intended for human consumption. Besides infection from living parasites, pathogens that are already dead or their remains within the fish tissue might harm the consumer by causing allergic reactions. The disgusting appearance of heavily parasitized fish can prevent them from being sold on local and international markets as their presence in the musculature can offend potential consumers. Thus, parasites can significantly contribute to financial losses for the fisheries industry.

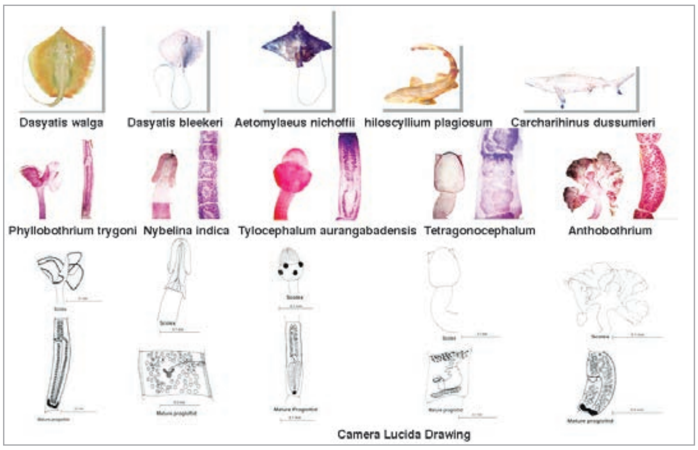
Fish landing Centre

Fish Market

In any aquatic ecosystem, parasites play an important role in the ecology in coastal and marine ecosystem parasites species found to cause none or limited pathological damage. Wild fishes under the condition of mariculture may become pathogenic (Damant and Paperna, 1986., Paperna, Damante and Overstreet, 1984). Therefore, studies of parasitic infection of economically important marine fish species have recently become an area of interest. However very little is known about the parasitic fauna of marine fishes of Raigad dist. West coast of Maharashtra in comparison with the information available from other coastal region of the continent. In which Cestode parasites which belong to helminth group have diverse population in Marine fish species at Raigad coast.

Material and Methods:

For the study of cestode parasites of marine fishes, 8 species i.e. *Rastrelliger kanagurata, Dasyatis bleekeri, Dasyatis walga, Aetomylaeus nichoffii, Chiloscyllium plagiosum, Mobula mobular, Carcharchinus dussumier and Rhynchobatus djeddensis* were selected considering their food value, economic importance and availability throughout the year irrespective of season. Fishes were collected from off shore fishing stations at Alibag, Borli, Murud, Dighi and Shrivardhan. The cestode parasites were collected, flattened, preserved in 4 % formalin, stained with Harris haematoxylin stain, passed through various alcoholic grades, cleared in xylol, mounted in D.P.X. and whole mount slides were prepared, for further morphological studies. Drawing were made with



the help of Camera Lucida and all measurements were taken in millimetres. Parasites were identified by using the key given by Yamaguti (1960), Wardle, McLeod (1952), Shipley and Hornell, (1905), B.V. Jadhav (1985, 1987).

Result

Out of eight species of marine fish hosts examined, only five species were found infected with cestode parasites i.e *Dasyatis walga* infected with *Nybelina indica, Dasyatis bleekeri* infected with *Tetragonocephalum, Aetomylaeus nichoffii* infected with *Tylocephalum aurangabadensis, Chiloscyllium plagiosum* infected with *Phyllobothrium trygoni* and *Carcharihinus dussumieri* infected with *Anthobothrium*.

Dasyatis bleekari was observed to be the most heavily infected host. Most of the cestode parasites were found on the anterior of the intestine. An increase in the infected with size of the host species especially in *Aetomylaeus nichoffii*. There are many reasons but one obvious reason is that as a fish grows, the amount of food consumed increases, which includes the larval stage of the parasites. The parasites did not seem to affect the health status of their host.

Most recently, Palm (2000, 2004) studied the *Indonesian trypanorhynch cestodes*, a worldwide distributed taxon of shark parasites that infest marine teleosts as intermediate hosts. Klimpel et al. (2001) recorded *Tentacularia coryphaenae, Nybelinia africana, Heter onybelinia yamagutii, Hepatoxylon trichiuri, Sphyriocephalus tergestinus* and *Callitetrarhynchus gracilis* from deep water fish species.

Conclusion

A special interest for the fish consumer is zoonotic parasites, which can cause diseases and devaluate the fish. Parasite data can be an economically important indicator for seafood dealers or brokers as well as fishery managers to get a better understanding of the occurrence of potential harmful parasites and the natural infestation in order to estimate the real threat to human consumers as well as to the fish handling industry. The present study demonstrates the high biodiversity of cestode parasites in marine fish species from the Raigad region. The component community as well as the infracommunity was species rich.

Acknowledgements

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Elemental View - Chemistry

The N cycle in the south-eastern Indian Ocean: From the Tropics to the subtropics

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Introduction

The marine nitrogen (N) cycle plays a pivotal role in controlling marine productivity, since planktonic growth in most of the open ocean is limited by the bio-availability of N. Assimilation rates of NO_3^- and NH_4^+, which are delivered via different processes (mixing and grazing respectively), give crucial information to quantify production at the base of the foodweb. Specialized plankton (diazotrophs) are able to take up atmospheric N_2 usually when the pool of NO_3^- and NH_4^+ is at low concentrations. This process is known as N_2 fixation. The distribution and growth rates of diazotrophs and the magnitude of N_2 fixation along with the input of new N through this process remains poorly constrained globally, but particularly in the Indian Ocean (Fig.1).

Currently our understanding of oceanic and atmospheric processes in the Indian Ocean is still very limited relative to the Atlantic and Pacific Oceans (IIOE-2 Science Plan). This knowledge gap seems counter intuitive compared to ecological and anthropogenic importance of the Indian Ocean basin. The Indian Ocean has the third-largest water mass globally and covers vital sea lanes that sustain Asia's largest economies. The Indian Ocean rim is also home to 2.6 billion people, almost 40 percent of the world's population (Alexander et al., 2012). Nearly a decade ago the International Geosphere-Biosphere Program and the UN Scientific Committee on Ocean Research have highlighted the importance to understand the biogeochemical role of the Indian Ocean in a more global oceanic context (CLIVAR Pub. Series No.100,

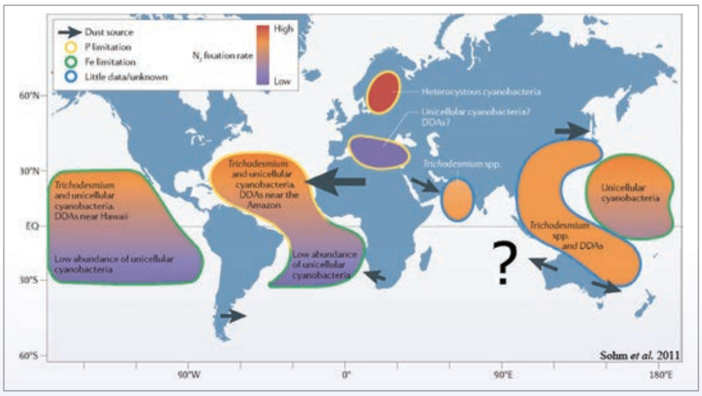

Fig.1. Global N_2 fixation rates from Sohm et al. (2011). Note blank data and question mark in the eastern Indian Ocean

2006). The Sustained Indian Ocean Biogeochemistry and Ecosystem Research program also developed a Science Plan for Indian Ocean research, where the input of new N from N_2-fixation by the diazotrophic community was highlighted as a key unknown for the Indian Ocean (Fig.1 SIBER Science Plan, 2011 Theme 4).

While research on N_2-fixation rates has been conducted in the western Indian Ocean (Capone et al., 1998, Subramaniam et al., 1999) so far only a single study, visited the tropical south eastern Indian Ocean off Australia (Montoya et al., 2004) and only one regional voyage visited the subtropical south eastern Indian Ocean (Holl et al., 2007). Model estimates however, conclude that N_2-fixation in the Indian Ocean should be so large as to be globally significant (Sigman et al., 2009, Monteiro et al., 2010). Currently the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) are coordinating a new phase of international research focused on the Indian Ocean beginning in late 2015 and continuing through 2020 to address key unknowns in biogeochemical cycling, including N_2 fixation, in this large ocean basin (See, The 2nd International Indian Ocean Expedition Science Plan; (Hood et al., 2011)).

Results

A latitudinal gradient of N_2 fixation and low $\delta^{15}N$ up the food chain

To explore the contribution of planktonic diazotrophs to the overall N budget Raes et al. (2014) investigated the relationships between dissolved inorganic nutrients, phytoplankton pigment composition, microbial community structure, nitrogen fixation rates and the $\delta^{15}N$ of fractionated zooplankton samples along the shelf break of Western Australia from (32°S to 12°S; Fig.2). They showed that bulk dinitrogen fixation rates declined from 4.8 nmol.L^{-1}.h^{-1} in the colder and more saline sub-tropical waters at higher latitudes (32°S) to 1.5 nmol.L^{-1}.h^{-1} in the warmer and fresher Timor Sea at lower latitudes (12°S; r^2=0.6, p<0.01). During their voyage they encountered a regional bloom of *Trichodesmium* between 13˚- 9˚S in the Timor Sea. *Trichodesmium* specific N_2 fixation rates were 0.05±0.01 nmol.col^{-1}.h^{-1}. Along their transect highest dissolved inorganic nitrogen (DIN) concentrations occurred at highest NH_4^+:NO_3^- ratios. These findings deviate from the paradigm that suggests that greater DIN concentrations come primarily from increased NO_3^- through advection, mixing or upwelling. Isotopic analysis suggested that injections of low $\delta^{15}N$ from N_2 fixation lowered the zooplankton $\delta^{15}N$ signature of animals up to ~500 µm in size and that nearly 47% of the fixed nitrogen was utilised by zooplankton (≤ 500µm fraction) in the Timor Sea.

Sources of new N

To understand the controls of primary productivity and the associated capture of CO_2 through photosynthesis in the southeastern Indian Ocean Raes et al. (2015b) compiled the physical and biogeochemical data from 4 voyages conducted in 2010, 2011, 2012 and 2013. Their findings show overall higher NH_4^+ assimilation rates (~530 µmol m^{-2} h^{-1}) relative to NO_3^- assimilation rates (~375 µmol m^{-2} h^{-1}) which suggest that the assimilation dynamics of C are primarily regulated by microbial regeneration. Interestingly N_2 fixation rates did not decline when other source of DIN were available, although the assimilation of N_2 is a highly energetic process (enthalpy = +945.5 kJ). Their measurements showed that the diazotrophic community assimilated ~2 nmol N L^{-1} h^{-1} at relative elevated NH4+ assimilation rates ~12 nmol L^{-1} h^{-1} and NO_3^- assimilation rates ~6 nmol L^{-1} h^{-1}. A main finding of their data analysis was that the small diffusive deep-water NO_3^- fluxes could not support the measured NO_3^- assimilation rates and consequently point to another source of dissolved inorganic NO_3^-. Their results suggest that nitrification above the pycnoclines (referred to as "shallow nitrification") could be a crucial component of the N cycle in the eastern Indian Ocean. In their analysis Raes et al. (2015b) provide a conceptual understanding how NO_3^- in the photic zone could be derived from new N through N_2-fixation. They propose that N injected through N_2 fixation can be recycled within the photic zone as NH_4^+, and sequentially oxidized to NO_2^- and NO_3^- within the photic zone (See Fig.3) and in shallow (100-200 m) lower dissolved oxygen layers (100-180µmol L^{-1}).

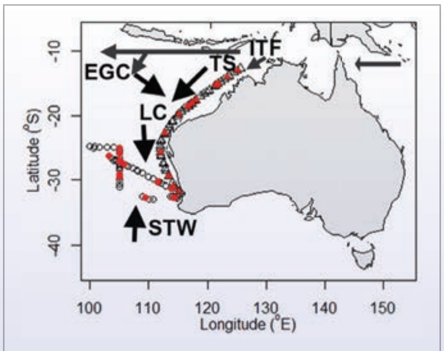

Fig.2. Area map with voyage tracks and CTD stations. Triangles present sampling stations from the latitudinal SS2012T06 voyage and circles from the SS2012v04 voyage. Red triangles and circles highlight stations were samples for functional N genes were taken (eg. nosZ; see section below the powerful greenhouse gas N_2O). Arrows highlight the major current systems in the southeast Indian Ocean; Subtropical waters (STW), Leeuwin Current (LC), Eastern Gyral Current (EGC), Timor Sea (TS) and Indonesian Throughflow (ITF).

The powerful greenhouse gas N_2O

Emissions of nitrous oxide (N_2O) are of an eminent concern as the greenhouse warming power is 300 times stronger than CO_2 (Codispoti, 2010). N_2O is the precursor of nitric oxide (NO) radicals and the single most destructive source of ozone-depletion (Montzka et al., 2011). Marine N_2O production is predicted to increase under global warming scenarios including ocean acidification, sea surface warming and coastal eutrophication(Codispoti, 2010). Yet, little data exist about the sink and source terms of the production and reduction of N_2O outside the well-known oxygen minimum zones (OMZ; Stramma et al. (2010)). Raes et al. (2015a) have shown the presence of functional marker genes for the reduction of N_2O in the last

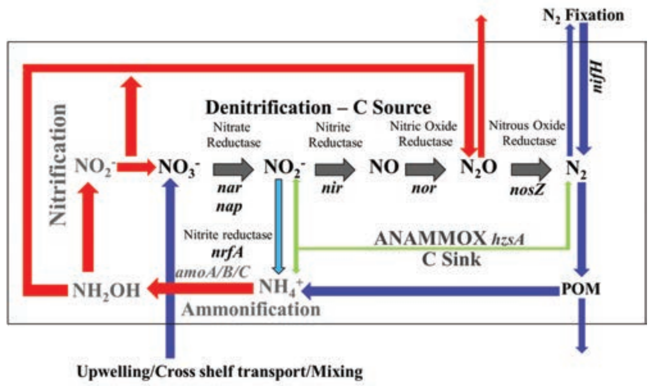

Fig.3. N –cycle emphasizing the production of N_2O through denitrification (grey arrows) and nitrification (red arrows). The production of N_2 through anammox is presented with green arrows. Arrow width indicates suggested pathway importance in the eastern Indian Ocean. Marker genes for the different steps of the nitrogen cycle are in italics. The nitrous oxide reductase gene (nosZ) is highlighted with a dashed blue circle. Heterotrophic denitrification (nir/nor genes) is highlighted as a C source while the autotrophic anammox process (hzsA genes) is highlighted as a C sink. Note: dissimilatory reduction of NO_3^- to NH_4^+ and N_2O is not presented on this figure. Figure adapted from Throbäck et al. (2004)

step of the denitrification process (See Fig.3; nitrous oxide reductase genes; *nosZ)* in oxygenated surface waters (180-250 O_2 µmol.kg^{-1}) in the eastern Indian Ocean. Their measurements showed that the overall copy numbers of *nosZ* genes represented a significant proportion of the microbial community, which is unexpected in these oxygenated waters. Their data also showed strong temperature sensitivity for *nosZ* genes and reaction rates along a vast latitudinal gradient (32˚S-12˚S). Their findings suggest a large N_2O sink in the warmer Tropical waters of the eastern Indian Ocean. Clone sequencing from PCR products revealed that most of the denitrification genes belonged to the Rhodobacteraceae. Their work highlights the need to investigate the feedback and tight linkages between nitrification and denitrification (both sources of N_2O, but the latter also a source of bioavailable N losses) in the understudied yet strategic Indian Ocean and other oligotrophic systems.

Functional diversity

The resilience of an ecosystem is thought to be based on its diversity. A current question that remains is how microbial diversity relates to ecosystem functionality under current and future climate driven changes. Illumina analysis of the V1-V3 region of the 16S rRNA gene in the rRNA operon allowed us to map and compare the microbial diversity of different water masses in the eastern Indian Ocean (data gathered from 2 voyages aboard the R.V. Southern Surveyor (SS) in the southeastern Indian Ocean in 2012 in the region bounded by 34˚S and 100˚E and from 34˚S to 12˚S; See Fig.2). Our data analysis suggest that differences in the microbial community along the latitudinal and biogeochemical gradient in the eastern Indian Ocean are correlated with primary productivity, just as they are in different ecotypes such as polar fronts (Wilkins et al., 2013) and oligotrophic gyres in the North Pacific Ocean (Jones et al., 1996). Our data do not yet answer the question how microbial diversity is related to ecosystem function and resilience but highlight the need to set up experiments that will allow us to answer this question. Questions that remain are: How do we link microbial diversity to ecosystem functions so we can sketch a mechanistic productivity model? How do we link microbial taxonomy to productivity? How do we relate the vast amount of sequencing data to assimilation and dissimilation processes?

Conclusion:

The Scientific Committee on Oceanic Research and the Intergovernmental Oceanographic Commission (IOC) of UNESCO have addressed, in their latest Indian Ocean Science plan (2015), the need to "advance our understanding of the interactions between oceanic and atmospheric processes that give rise to the complex physical dynamics of the Indian Ocean. Of high priority is to determine how those dynamics affect climate, extreme events, marine biogeochemical cycles, ecosystems and human populations." Although modeling outputs (Hood et al., 2006, Monteiro et al., 2010) confirm that the Indian Ocean has an important role in the global N cycle, we still lack vital information to quantify the net atmosphere-ocean N flux in this Ocean basin. The cited works above address the roles of N_2 fixation in the eastern Indian Ocean and provide insights into various components of the regional biogeochemistry that influence N and C fixation and sequestration in this Ocean basin.

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Stable isotopic composition of boundary layer water vapour over Bay of Bengal

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The relative mass differences of $H_2^{18}O$, HDO and $H_2^{16}O$ alter their relative abundances (i.e., isotopic fractionation) during phase change of water in Earth's hydrological cycle[1]. Monitoring of stable isotopic ratios (ie, $^{18}O/^{16}O$ and D/H usually reported as $\delta^{18}O$ and δD) of waters therefore has wide applications in hydro-climate studies[1].

Since oceanic evaporation is the primary source of water in hydrological cycle, measurement of $\delta^{18}O$ and δD of marine vapour is essential for such studies. However, due to the difficult sampling procedure for water vapour, such studies are very limited[2,3]. As Bay of Bengal (BoB) is one of the moisture sources of rainfall over India and adjoining countries water vapour sampling was done for the first time over BoB during two cruises (SK-296 during July-August 2012 and SN-82 during November 2013), thanks to help from Chief scientists G. S. Bhat and M. Ravichandran. Water vapour samples were collected using cryogenic trapping method and their isotopic ratios were measured using an Isotope Ratio Mass Spectrometer at PRL[4].

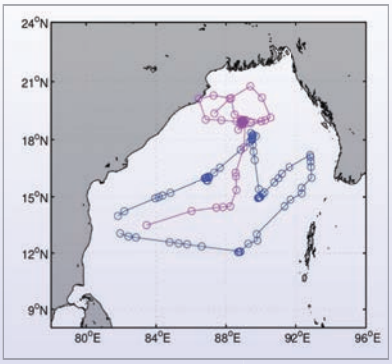

Fig.1. Cruise tracks (lines) and locations of water vapour collection (open circles). Purple and blue colors represent cruises SK-296 (July-August 2012) and SN-82 (November 2013), respectively.

Values of $\delta^{18}O$ and δD of vapour over BoB are higher during the Indian Summer Monsoon (ISM) compared to the North East Monsoon (NEM). Such a difference is also observed in the δ^{18}O and δD of rainfall over peninsular and north eastern India[5,6]. Besides these seasonal differences, the isotopic compositions of vapour show short term variations (time scales of a few hours to a few days), mainly attributable to cyclonic activity occurring over the sea. Isotopic compositions of water vapour show the lowest values during monsoon depressions and tropical cyclone activity. Such sharp ^{18}O depletions in surface vapour and rain are generally observed in the tropics in large scale organized convective systems[7–9].

We compared the measured δ^{18}O of vapor with Craig and Gordon[10] model, which estimates δ^{18}O and δD from surface water isotopic composition, sea surface temperature (SST) and relative humidity. δ^{18}O of water vapour appeared to be close to the model estimates during non-rainy days of ISM. However, during rain events associated with monsoon depression, vapour δ^{18}O values were significantly lower than the model predicted values. This may be due to the rain-vapour interaction and convective downdrafts in the upstream region. The model assumes that local oceanic evaporation is the only source of vapour (i.e., 'local closure assumption'), while these

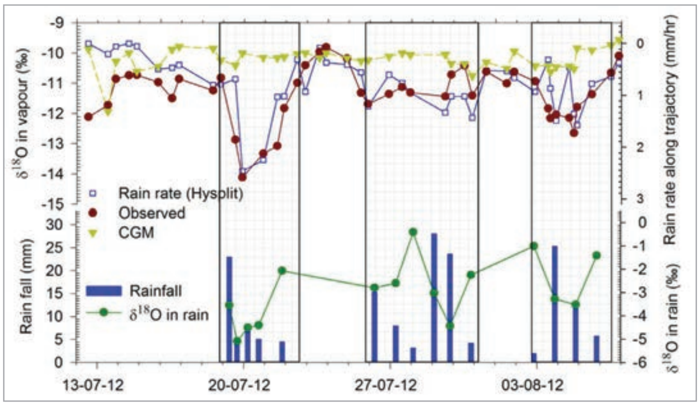

Fig. 2. Comparison of observed δ^{18}O of vapour (filled circles) with Craig and Gordon model results (CGM, inverted triangles). The shaded area shows three rain spells that occurred during sampling. The rain rate (open square) plotted in the upper panel is the average rain rate along the 24h air parcel back trajectory[13]. The accumulated rain amount collected during the cruise (vertical bars) and its δ^{18}O of rain (filled circle) are also shown in bottom panel.

secondary processes make more ^{18}O depleted surface vapour. During NEM season the baseline of vapour δ^{18}O is well below that of Craig and Gordon model estimation, with the lowest values associated with cyclonic activity. The more negative δ^{18}O of the vapour during NEM may possibly be due to multiple factors such as i) change ocean surface conditions (relative humidity and SST), ii) δ^{18}O depletion in the surface sea water due to the increased river runoff by the end of ISM season[6,11] iii) shift in circulation pattern and iv) change in the weather systems (i.e., monsoon storm/ depressions vs. tropical cyclones).

According to the Craig and Gordon model, a negative relation is expected between *d*-excess (δD-8* δ^{18}O) and the relative humidity. This relation arises from the diffusive transport of water isotopologues in air, during evaporation from the ocean. During condensation, which occurs usually under isotopic equilibrium condition, the rain preserves the *d*-excess values of its source vapour. Hence the *d*-excess in ice cores is known to preserve the source vapour signature. This relation was observed earlier over the Southern Indian Ocean[2] and the Atlantic Ocean[12]. We also observe such a relation over BoB, but it appears to be weaker during the ISM, and dominant during NEM.

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The Transporters - Physics: Ocean, Atmosphere

A short perspective on the Mascarene High and the abnormal Indian Monsoon during 2015

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The initiation of the Indian summer monsoon circulation during late May / early June arises through large-scale land-sea thermal contrast and setting up of negative pressure gradient between the Monsoon Trough over the Indo-Gangetic plains and the Mascarene High over the subtropical Indian Ocean. The meridional pressure gradient together with the Earth's rotation (Coriolis force) creates the summer monsoon cross-equatorial flow, while feedbacks between moisture-laden winds and latent heat release from precipitating systems maintain the monsoon circulation during the June-September (JJAS) rainy season (Krishnamurti and Surgi, 1987). This simplified view of the Indian monsoon is a useful starting point to draw insights into the variability of the large-scale monsoon circulation.

In this article, we provide a short perspective on the 2015 Indian summer monsoon season – a period characterized by anomalously weak large-scale monsoon winds and deficient rains over the Indian subcontinent. With pronounced decrease of rains over the west coast and areas in peninsular and north India during 2015, the resultant deficit in the All India monsoon rainfall was about 15% of the long-term average and was accompanied by a significant weakening of the large-scale monsoon cross-equatorial flow (Ref: Fig.s1, 2). The weakened monsoon circulation during 2015 is clearly evident from the low-level easterly anomalies over the Arabian Sea and the Indian region. Further, one can notice a clear weakening of the Mascarene anticyclone as evidenced from the circulation anomalies over the subtropical Indian Ocean to the east of Madagascar and southern Africa (Fig.2b).

The weak Indian monsoon of 2015 happened to coincide with the evolution of another major climatic phenomenon – a relatively strong El Nino event in the Pacific. The westerly anomalies over the tropical Pacific shown in Figure.2b illustrate a weakening of the easterly trades seen during El Nino conditions. The El Nino related variations during 2015 are clearly borne out in the spatial patterns of sea tropical central-eastern Pacific and negative anomalies in the west Pacific depict the classical El Nino pattern. Also notice that the warm SST anomalies in the east extended far northward into the extra-tropics into the west coast of the US and northeast Pacific during 2015. The negative (positive) SLP anomalies over the central-eastern (western) Pacific basically correspond to a weakening of the Walker circulation (Fig.3). The warm SST anomalies in the Northern Indian Ocean and western Arabian Sea are typically associated with weakened monsoon winds, decreased evaporation and reduced upwelling along the Somali and Oman coasts (ex., Rao, 1987, Ramesh and Krishnan, 2005, Scott et al. 2009). It is also noteworthy to mention here that the Pacific SST anomalies in 2015 had resemblance with those during the strong El Nino of 1997 (not shown). Interestingly, it must be pointed out that the strong El Nino of 1997 had little impact on the Indian monsoon which actually turned out to be a near-normal monsoon rainy season (http://www.tropmet.res.in).

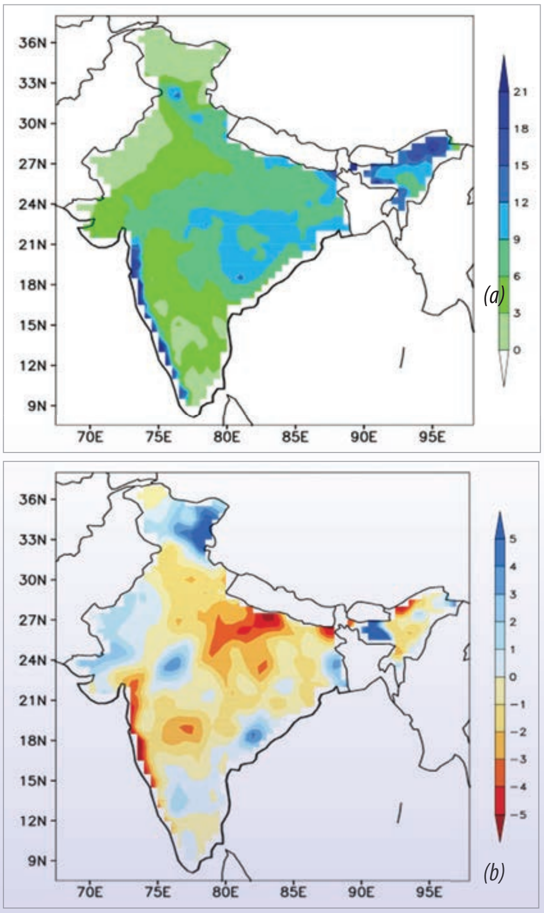

Fig.1. (a) Spatial map of long-term (1979-2015) climatological mean rainfall (mm day-1) for the JJAS season (b) Rainfall anomaly for JJAS 2015. The rainfall dataset is based on the India Meteorological Department (IMD) dataset.

Ref: http://www.imd.gov.in/section/nhac/dynamic/Monsoon_frame.htm

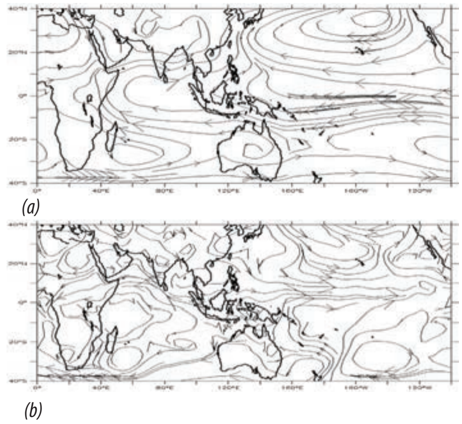

Fig.2. Mean and anomaly map of 850 hPa streamlines for the JJAS season (a) Climatological mean (b) Anomaly for 2015. The wind dataset is from NCEP reanalysis for the period (1981-2014) Ref:http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.html

Although notwithstanding the likely El Nino impact on the Indian monsoon in 2015, the anomalous conditions in the southern Indian Ocean during that period lead us to think about possible non-El Nino factors that might have significantly influenced the large-scale monsoon circulation. For example the Indian Ocean SLP anomalies during 2015 show a weakened Mascarene High along with warm SST anomalies east of Madagascar in the southern Indian Ocean (see Fig.3). These anomalous features during 2015 are suggestive of a likely influential role of the weak Mascarene High on the large-scale monsoon flow and rains over India. Several studies have drawn attention to the role of the southern Indian Ocean SST variability in influencing the Southern Hemispheric climate during the Austral summer (eg., Behera and Yamagata, 2001; Chiodi and Harrison, 2007; Wang, 2010, Morioka et al., 2014, Ohishi et al. 2015). However, aspects of ocean/atmospheric coupled processes in the southern Indian Ocean have received less attention for the Austral winter (or boreal summer) season (Boschat et al. 2011). For example, there is lack of understanding on the basic mechanisms that give rise to persistent SST and SLP anomalies in the southern Indian Ocean during the boreal summer and how they interact with the large-scale monsoon circulation. The boreal summertime teleconnection between the Indian monsoon and the southern Indian Ocean SST/SLP variability assumes greater significance especially given the rapid rate of Indian Ocean warming during recent decades (Copsey et al. 2006). To summarize, a comprehensive understanding of the connection among the Indian Monsoon and the variability of the Mascarene High and the southern Indian Ocean SST is an important scientific problem and warrants further investigations.

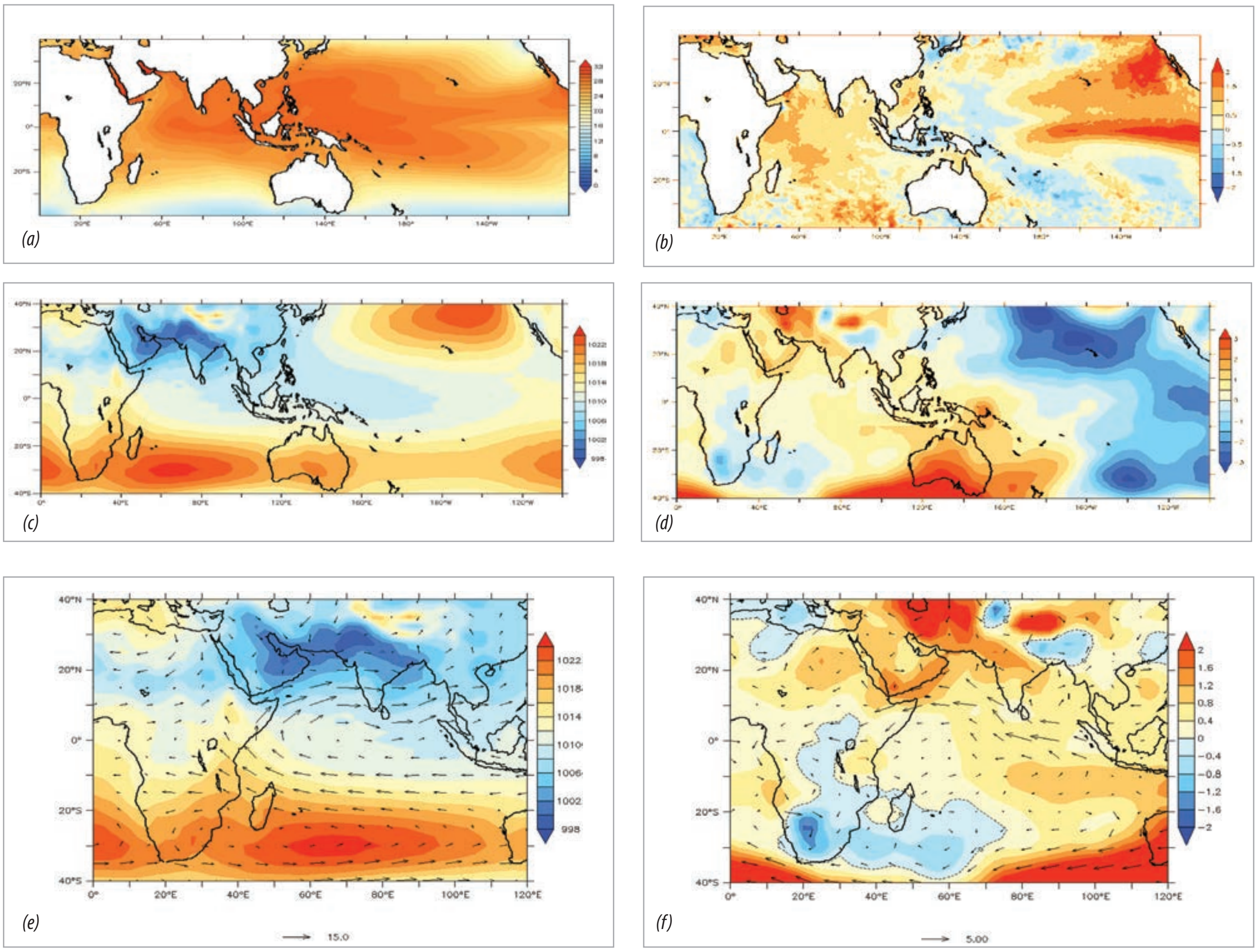

Fig.3. Mean and anomaly maps of SST (°C), SLP (hPa) and winds at 850 hPa for the JJAS season (a) Mean SST (b) SST anomaly during 2015 (c) Mean SLP (d) SLP anomaly during 2015 (e) Mean winds and SLP over the Indian Ocean and monsoon region (f) Wind and SLP anomaly during 2015. The mean fields are for the period (1981-2014) based on the datasets: OISST http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.highres.html and NCEP reanalysis http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.html

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The Barrier Riddle: Exploring the Barrier Layer Thickness in the Bay of Bengal

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Introduction

The oceanic Barrier Layer (BL) is a region of great significance to the upper ocean thermodynamics. Barrier Layer thickness (BLT) is the difference between the Isothermal Layer Depth (ILD) and the Mixed Layer Depth (MLD). In the present study, we have attempted to analyze the seasonal and diurnal variability of the BLT in the northern Bay of Bengal (BOB) at a location 18.18^{0}N, 89.68^{0}E over a year. BLT was observed to be the minimum in April 2013 and the maximum in January 2014. Diurnal variability of Sea Surface Temperature (SST) was observed to be related to changes in wind speed, incoming solar radiation and rainfall, which is well known. Subsequently, it is now intriguing to investigate the diurnal variability of BLT. To find the sensitivity of BLT to surface forcings at different point locations in the BOB is also proposed. In this article, we will present the observations and analysis obtained so far, and the proposed plan. The next section gives information on OMNI buoy data, crucial for this study.

OMNI buoys – Getting to know the data

The BOB, the northeastern limb of the Tropical Indian Ocean is a region strongly coupled with summer and winter monsoons and tropical cyclones. It is a region of strong vertical stratification near the surface due to large inputs of freshwater through rainfall and river run-off. In situ subsurface ocean measurements are sparse both in space and time in this region. Previously, most of the work has been done using assimilated observation datasets and climatology. However, currently available, high temporal resolution, hourly, in situ data, appropriate to study especially the diurnal variability of upper ocean and SST, obtained from OMNI (Ocean Moored buoy Network for Northern Indian Ocean) buoy was used for this study. OMNI buoys enhance the data availability in the North Indian Ocean. So far, we have utilized data from OMNI buoy at 18.18^{0}N and 89.68^{0}E from April 2013 to March 2014. The archived, quality controlled, processed OMNI buoy data was obtained from Indian National Centre for Ocean Information Services (INCOIS). National Institute of Ocean Technology (NIOT) takes care of the deployment and maintenance of these buoys. Venkatesan et al. (2013), gives a detailed account of design and instrumentation onboard OMNI buoys including ranges, resolutions, accuracies, sampling and transmission intervals of the sensors used.

These buoys provide continuous time-series measurements of surface meteorological and oceanographic parameters. Starting with two buoys in October 2010, at present, the OMNI buoy network consists of 12 deep ocean buoys. Data on water temperature and salinity are available at 11 depth levels up to 500 metres depth and data on currents at 21 levels up to 105 metres depth. Air-sea fluxes can be calculated using surface ocean and meteorological data obtained from OMNI buoys, making them an ideal observational platform to study upper ocean processes and air-sea interactions. Apart from this, it can be used to compare with available satellite data, and to validate operational model outputs and reanalysis datasets. An important aspect is that this high temporal resolution, long time range data, makes it possible to explain the variability on different timescales – diurnal and intra-seasonal at selected locations. Also, the real time OMNI buoy data could help in monitoring extreme events like cyclones and help in cyclone prediction and preparation by providing improved initial conditions for operational models. Since no data is discarded (it is flagged on quality checking) it was possible to investigate the anomalies and deviations from the regular trend. In the next section we will view our initial analysis regarding the BLT variability.

Variability of BLT

It is seen that on a seasonal cycle, during summer there is greater heat flux from the atmosphere to the ocean, SST is warmer, stratification increases, Mixed Layer (ML) becomes shallower, BL is thin. Heat flux reverses in winter, ocean cools at surface, ML deepens due to convection, weather is stormier with more wind and precipitation, BL is thick. In this work, daily variation of MLD, ILD and BLT was computed (Fig.1, top panel). Then monthly variability of ILD, MLD and BLT were computed using monthly average of hourly temperature and salinity data as inputs (Fig.1, bottom panel). BLT was observed to be the minimum in April 2013 and the maximum in January 2014 at this location. BLT trend followed the ILD more closely than the trend in MLD. Seasonal buildup of warm water was seen in the upper ocean during the summer period of April to May 2013. During summer monsoons, BLT was the highest in month of June. Further, the BL formed in summer monsoon continued to exist throughout the post monsoon season as well. There was temperature inversion in BL in winter. From the analysis of wind speeds and directions, it was observed that high wind speed in

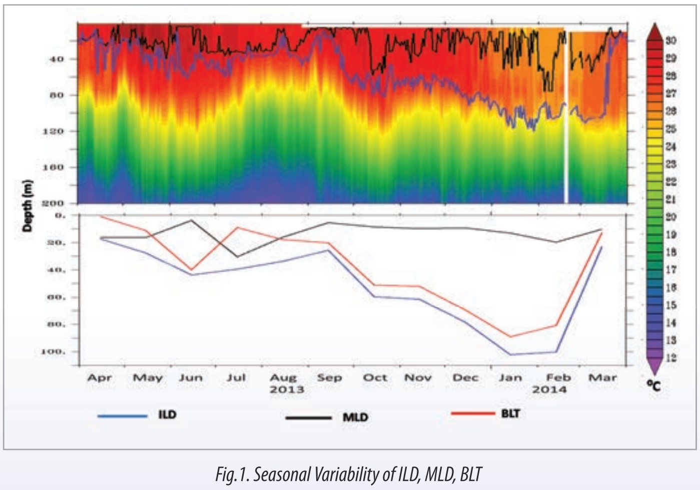

Fig.1. Seasonal Variability of ILD, MLD, BLT

summer monsoon (South Westerly) and winter monsoon (North Easterlies), and low wind speed during spring could be one of the factors responsible for the observed variation in BLT.

Delving into the shorter timescale, diurnal variation of SST, rainfall, incoming shortwave radiation, net radiation, wind speed, humidity and air temperature were analyzed (Fig.2). On a diurnal cycle, after sun rise, gradually the sun heats ocean causing the upper surface to warm and stratify weakly. As sun sets surface water becomes cooler and sinks causing turbulent convection and entrainment of water from below, resulting in a well mixed layer.

It was observed that the wind speed was more around 9 UTC and hence it was dry air. The relative humidity shows the minimum around this time. Thus more water would evaporate (therefore more Latent Heat Flux (LHF)). The wind speed was weakest around 16 UTC, humidity was relatively high at this time. Air was therefore moist, hence less evaporation would take place (less LHF). Rainfall was seen to peak at late noon as there was high evaporation occurring due to high LHF in mid-noon. LHF was least in late-evening. Therefore lesser evaporation took place, which later amounted to lesser rain. Rainfall was least at mid-night. Incoming solar radiation was highest from 5 to 8 UTC (noon). This heated up the air and the sea surface. Thus the SST and air temperature rises at this time and attained peak temperature around 9UTC (2:30pm local time).

Foresight

So far the seasonal variability of BLT and diurnal variability of SST and other met-ocean parameters has been analyzed at this location. Subsequently, with the availability of high temporal resolution OMNI buoy data it will be interesting to study the diurnal variability of BLT in conjunction with the analysis of other variables like sea surface temperature, wind speed, insolation and heat loss to understand the influence of surface forcings on the BLT. This would aid in finding the integrated effect of diurnal variability of BLT on its seasonal variability. Eventually, investigation on the above at the different OMNI buoy locations in BOB would help in understanding the relationship between BLT and the surface and sub-surface dynamics at play at different regions in BOB.

ESSO-INCOIS Diaries: Experience of first author (or Ms. Aurpita Saha)

This work was carried out at ESSO-INCOIS, from May to July 2015 as a summer research student. Throughout my duration at the Centre, the data repository unit and all the scientists I interacted with from the Data and Information Management Group were very welcoming and approachable. My interaction with the fellow research students, PhD students, junior and senior researchers and scientists from all groups there was an enriching experience, which will be cherished. We attended some of the seminars held here. One of them was by Prof. Raghu Murtugudde (University of Maryland, College Park), this helped us expand our scientific thoughts. The most fascinating aspect was, that my workstation was in the library, and the library was captivating! Particularly, books on oceanography, upper ocean processes and air-sea interactions interested me- those which explained the history and the very basics of oceanography in a beautiful manner – which the internet still cannot parallel! From an early age, I admired and liked oceanography, and getting this opportunity to work as a research student at ESSO-INCOIS has helped me delve deeper.

Acknowledgement

The first author sincerely thanks the Director of ESSO-INCOIS for allowing this work to be carried out. She is also grateful to Head, Data and Information Management Group, for providing the data and with deep acknowledgements extended to ESSO-NIOT for the OMNI buoys. She also sincerely thanks Dr. K. Suprit, her guide at the Centre and also Mr. Rohith Balakrishnan for his kind support. Timely support from her guide Dr. D. Swain (IIT Bhubaneswar) is acknowledged. She also expresses her gratefulness to the Indian Academy of Science (IAS) for providing this opportunity and requisite financial support .

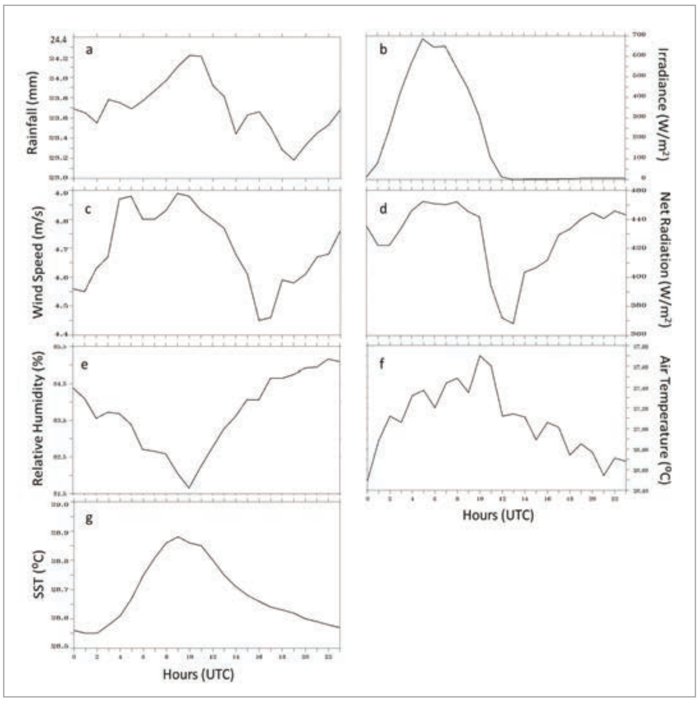

Fig.3. Diurnal Variability of :- a) Rainfall, b) Irradiance, c) Wind Speed, d) Net Radiation, e) Relative Humidity, f) Air Temperature, g) SST

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Dare to Care - Conservation Awareness

Occurrence of Cetacean bycatch in high sea gillnetting and status of mitigation measure in India

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Fig.1. Courtesy. www.wildlifetrusts.org

For harvesting large pelagic fishes, large mesh drift gillnet is the most popular fishing gear in all the coastal states of India. Recently high sea gillnet fishermen have started changing their fishing operations to deeper and distant waters by conducting multi-day operations extending up to 45 days. Conventionally , polyamide (PA) multifilament are used for fabrication of gillnets in India and High Density Polyethylene (HDPE) has become popular for large mesh gillnets along with PA. Gillnets are also considered to be the main gear responsible for cetacean bycatch in the country. An All India survey was conducted for craft and gears during 2012-2013, to document design and operational aspects of mechanised fishing sector. The survey team interviewed fishermen of all coastal villages and landing centres. The incidental mortality of marine mammals in fishing gear was observed along the coastal belt of Tamil Nadu, Gujarat and Odisha, where the maximum concentration of high sea gillnetting occurs. The study indicated that, increase in size of the fishing gear, especially in gillnets and changing pattern of operational area where marine mammal abundance is more are the two factors responsible for cetacean bycatch. Simply put, Cetacean bycatch is expected to occur in areas where gillnets are dominant.

However the study did not elaborate on techniques for reducing the incidental catch of marine mammals in gillnet fisheries.

Fig.2. Banana pingers

Paucity of information available on bycatch associated with gillnet fisheries throughout the Indian coast also does not allow accurate quantification of bycatch that can be attributed specifically to gillnet vessels targeting tuna and tuna like species, though a previous estimate says that artisanal coastal gillnet fisheries catch approximately 9000--10000 individual cetaceans each year (Yousuf et al, 2009). This study proposed tthe use of active sound emitters ('pingers') in several gillnets fisheries throughout the world to reduce bycatch of small cetaceans, and/or to reduce depredation by dolphins in gillnets. The pingers either deter the animals from the nets or alert them to the nets. In either case, the pingers have been shown to reduce entanglement and death of several dolphin and porpoise species. Marine mammals have excellent hearing and use sound in various ways in the ocean to navigate and communicate.

It is high time to implement bycatch reduction through the coast, since fishermen are not ready to disclose the exact number of mortality of cetaceans encountered in the high sea gillnets in all survey centres especially since cetaceans such as dolphins may be utilised by the fishers for food and bait to attract sharks to the net. It is intended that researchers and policy makers may utilize the information provided here to prioritize and inform research, management, and mitigation of marine mammal bycatch in the high seas of the Indian EEZ. Graphical representation of typical pinger proposed is indicated in Fig.2 and high sea gillnet is illustrated in in Fig.1.

Bottom Trawling – A Menace to Benthic Fauna in the Tropical Indian Ocean

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The coastal waters of the maritime states are under constant threat of pollution from a number of sources. The intensified use of marine biosphere with footprints of man almost everywhere has brought considerable changes leading to the loss of biodiversity and damage to coastal ecosystems. Therefore protection of marine biosphere from the menace of pollution at local, regional and global scales have been strongly urged upon to ensure the sustainability of marine resource.

Over the past two decades, intensive research on the effects of bottom-fishing gearon marine benthic communities (Collie et al.,2000, Kaiser,2006) has led to the recognition of bottom trawling as one of the greatest and most widespread causes of anthropogenic change in shelf seas (Bergman and Santbrink, 2000). Understanding the impacts of fishing activity to the seafloor is a key element in the development of sustainable ecosystem-based marine resource management. It is only recently that we have begun to appreciate the extent of this variability and to initiate research aimed at understanding how disturbance caused by fishing, affects ecosystem

Fig.1. (A, B and C) Exploitation of fishery resources by fishermen in Indian Ocean.

function, biodiversity, productivity, vulnerability and resilience. There is growing need to develop indicators of ecological status. The impacts of bottom trawling on seabed habitats is a concern for ecosystem managers because such activities alter the structure and function of benthic marine ecosystems (Tillin et al., 2006.).Chronic disturbances by bottom trawling represents a significant threat to the diversity and composition of the three dimensional benthic structure (Hinzet al.,2009) and lowering of the structural complexity of benthic environment (Asch and Collie,2008). This recognition is now begging to be acted upon by policy- makers and authorities.

Two cruises were carried out in the tropical Indian Ocean(9°39'19"N&76°17'23"E) in Kerala in 2012 and 2013 during monsoon as a part of a major project funded by the Kerala State Council for Science,Technology and Environment, Govt. of Kerala (Fig. 1). Sampling was carried out from five stations (station I,II,III,IVandV)

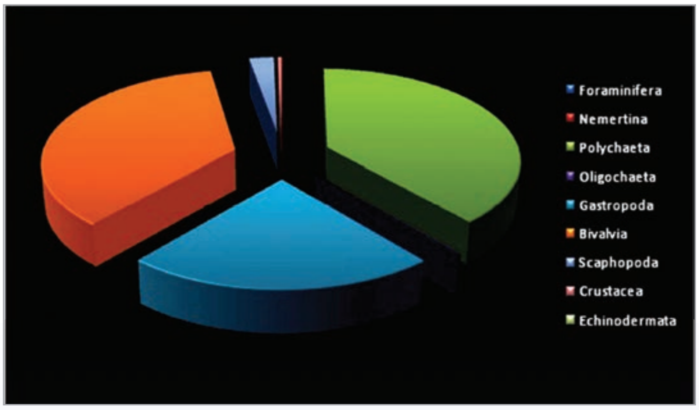

Fig.2. Seasonal average of macrobenthos during monsoon (2012-13).

representing depths of 5m, 10m, 15m, 20m and 30m from the shoreline along one transect. Samples were taken using a stainless steel corer (1 m long and 7 cm diameter) and a Van veengrab (0.1 m^2 mouth area).Macrobenthic samples consisted of 8 major groups (Fig. 2) with polychaetes predominanting. Macrobenthic polycheate composition consisted of indicator species at all stations which included *Paraprionospio sp., Nephtys sp., Lumbrineries sp., Asychis sp., Nicomache sp., Cossura sp., Sternapsis sp.,Glycera sp., Capitella sp., Nereidae sp., Aricidea sp., Polydora sp.* and *Ophiodromus sp.* (Sinu J. Varghese and Miranda , 2014).

Trawls scrape or plough the sea bed, resuspend sediment, destroy bed forms and remove or scatter non-target species (Gilkinson et al.,1998).The abundance of polychaetes declined in 2013 when compared to the previous year indicating the detrimental effect of habitat alteration caused due to fishing (Fig.3). Commercial exploitation involves multiple trawling events in the same area and the disturbance is cumulative (Pranovi et al.,2000).Cumulative effects of repeated hauls may produce long term changes in benthic communities (Jennings and Kaiser,1998). The investigation revealed the abundance of more stress tolerant r-selected species which survive in an unstable environment. Bottom trawling alters the seafloor habitat complexity leading to increased predation on infaunal species which in turn drastically alters the total ecosystem productivity. The presence of *Sternapsis sp.*, *Cossura sp.* and *Lumbrineries sp.* during monsoon season indicates the negative impact that might have occurred after trawling due to disturbances on the top layer of the sediment. Most of the polycheates observed throughout the study were of smaller size clearly indicating the extreme disturbance imposed on the sediment.(Sinu J.Varghese and Miranda, 2014).Observations revealed the deleterious effect of bottom trawling on benthic resources due to over exploitation of fishery resources. Fishing, the most

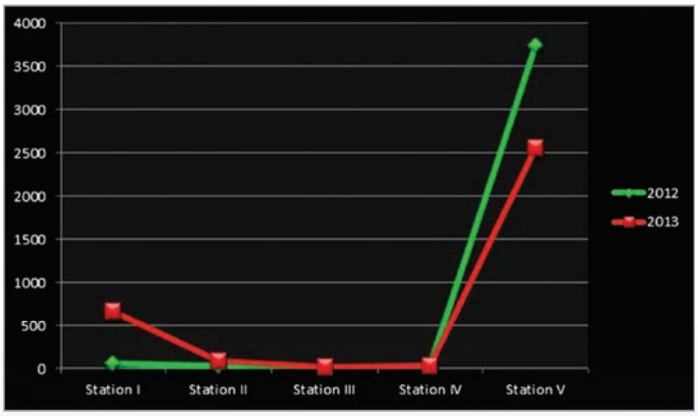

Fig.3. Macrobenthic Polychaete abundance during 2012 and 2013 monsoon

widespread human activity in exploiting marine environment, is an ubiquitous agent in changing the marine biodiversity (NRC, 1995). Extensive fishing activity by trawling has resulted in tracks on the sea bed and cumulative trawling activities have gravely disturbed the sea bed in this region of the Arabian Sea.

Since benthic fauna act as a connecting link between the biotopes of substratum and water column in the aquatic ecosystem, their distribution highly depends on the physical nature of the substratum, nutritive content, degree of stability and oxygen content.

As bottom trawling stirs up the sediment at the bottom of the sea, commercial fishing with mobile bottom- contact gear such as bottom trawls and dredges and the physical disturbances that ensure, is widespread in continental shelf areas (Connaughey et al.,2000).

In the present study, macrobenthic diversity revealed marked increase in instability indicators among polychaetes .The direct physical impact of bottom trawling causes varying levels of impact by altering sea bed morphology, removing ,damaging or killing biota ultimately leading to substantial changes in benthic community structure (Kaiser et al.,2002).

Bottom –contact gears were found to change the community structure leading to changes in average sizes of organisms and removal of ecosystem engineers especially burrowing forms which inturn alter nutrient cycling, increase in vulnerability to stress and decline in productivity of the ecosystem. In order to preserve benthic bioresources in their pristine form, bottom contact gears should be restricted and if permitted trawling activities should conform to eco-friendly strategies so that cumulative long-term disturbances causing profound changes in benthic communities do not take place.

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IIOE-2 Symposium

Port Louis, Mauritius

Promoting Marine Research

A Half-Day Symposium in the context of IIOE-2 will be held on the 23rd of December 2015 at Port Louis, Mauritius under the aegis of the Department of Continental Shelf, Maritime Zones Administration and Exploration of the Prime Minister's Office.

A team of multi-disciplinary research scientists will present the preliminary findings of the Scientific Expedition that will be undertaken by 'Sagar Nidhi', an Indian research vessel, along the leg Goa to Port Louis.

This event will be graced by the presence of representatives from UNESCO, IOCAFRICA, the Mauritius Oceanography institute, Mauritius Meteorological Services, Ministry of Housing and Lands, Ministry of Ocean Economy, Marine Resources, Fisheries, Shipping and Outer Islands, Mauritius Research Council and the University of Mauritius.

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