INTERNATIONAL INDIAN OCEAN EXPEDITION

Issue No. 12
February 2020

The Indian Ocean Bubble 2

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Conference and Integrated Meetings

The 4th International Indian Ocean Science Conference (IIOSC) is scheduled to be held during 16-20 March 2020 at the National Institute of Oceanography (NIO) Goa. It is sponsored by Ministry of Earth Sciences (MoES), Govt. of India and co-hosted by NIO, National Centre for Polar Ocean Research (NCPOR) Goa, Goa University and the Indian National Centre for Ocean Information Services (INCOIS) Hyderabad, India. The conference aims at assessing the progress and scientific knowledge gained during the last 4 years of IIOE-2 (during 2016-2020). There will be presentations focussing but not limited to all six themes of IIOE-2 Science plan (i.e., human impacts and benefits; boundary current dynamics and ecosystem impacts; monsoon variability and ecosystem response; circulation, climate variability and change; extreme events; and discovery of unique physical, geological, biogeochemical and ecological features of the Indian Ocean). It will provide an opportunity for the scientists working on different facets of the Indian Ocean to present their ideas and discuss the outstanding issues, identify the knowledge gaps and plan a way forward to address such issues.

Full Speed Ahead - Cruises, Research Vessels

The significant contribution of the RV Dr Fridtjof Nansen to research in the Western Indian Ocean

Jenny Huggett[1], Johan Groeneveld[2], Bernadine Everett[2]

[1] Oceans & Coasts, Department of Environmental Affairs, Cape Town, South Africa

[2] Oceanographic Research Institute, South African Association for Marine Biological Research, Durban, South Africa

jenny.huggett@gmail.com

The Norwegian marine research vessel (RV) Dr Fridtjof Nansen, commonly referred to as "the Nansen", has been exploring the Western Indian Ocean (WIO) since its first expedition to the Arabian Sea in 1975. In fact there have been three versions of the vessel, with the latest launched in 2017. The vessel is owned by the Norwegian Agency for Development Cooperation (Norad), but an agreement with the Food and Agriculture Organization of the United Nations (FAO) enables the Norwegian Institute of Marine Research (IMR) to operate the vessel under a UN flag.

Dr Fridtjof Nansen himself, after whom the vessels are fittingly named, was a Norwegian explorer, scientist, diplomat and humanitarian, who lived from 1861-1930. Apart from his legendary polar exploits, he participated in many oceanographic surveys in the North Atlantic and developed the "Nansen reversing bottle" to obtain samples of seawater at specific depths. He also helped found the International Council for the Exploration of the Sea (ICES) in 1900. After the First World War (WW1) he served as the High Commissioner for Refugees for the League of Nations. He introduced a passport for stateless persons, known as the "Nansen passport", and was awarded the Nobel Peace Prize for his work on behalf of displaced victims of WW1 and related conflicts.

The activities of the RV Dr Fridtjof Nansen in the WIO between 1975 and 2016 are comprehensively reviewed in a book edited by Groeneveld and Koranteng (2017). The first Nansen was commissioned to assess and map the living resources available for fisheries development in the Indian Ocean, and was active in the western sector between 1975 and 1990, with 27 surveys conducted as part of the "Nansen Programme", the majority in the Mozambique and Somali Coast subregions. A primary objective was to test whether the high primary productivity documented in the Arabian Sea during the International Indian Ocean Expedition (IIOE) would

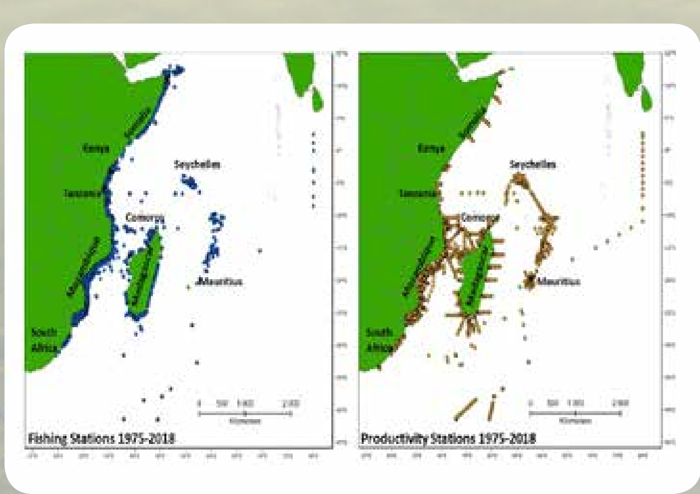


Fig. 1: Maps showing all stations visited by the RV Dr Fridtjof Nansen in the WIO between 1975 and 2018. Productivity stations include those where CTD profling and plankton net tows were conducted.

support a high abundance of small coastal pelagic fish, similar to those observed in eastern boundary current upwelling systems. Exploratory surveys by the Nansen confirmed high fish production in the Arabian Sea, but mostly of mesopelagic fish, which do not form sufficiently dense aggregations to support economically viable fishing operations. Surveys in the Southwest Indian Ocean (SWIO) indicated far lower productivity than in the north, and fish biomass along the East African coast was estimated to be an order of magnitude lower than in the Arabian Sea. In its first ten years at sea, the Nansen spent nine years surveying the Indian Ocean, covering the Exclusive Economic Zones of most coastal countries in the WIO as well as the Gulf of Aden, the southern Red Sea and the island States of Maldives, Madagascar and Seychelles.

After a long gap, the Nansen returned to the WIO in 2007, this time within the framework of the EAF-Nansen Project, in support of the ecosystem approach to fisheries (EAF) concept. This coincided with implementation of the large marine ecosystem (LME) projects supported by the Global Environment Facility (GEF). In the WIO, surveys by the new (second) version of the RV Dr Fridtjof Nansen were conducted in support of the Agulhas and Somali Currents LME (ASCLME) project and the Southwest Indian Ocean Fisheries Project (SWIOFP). Multidisciplinary surveys were conducted in the Mozambique Channel, off Mozambique, Madagascar, the

Fig. 1: Maps showing all stations visited by the RV Dr Fridtjof Nansen in the WIO between 1975 and 2018. Productivity stations include those where CTD profling and plankton net tows were conducted.

Comoros, Mauritius and Seychelles, as well as off a number of seamounts of the Southwest Indian Ocean Ridge, and one further north at Walters Shoals. These surveys generated new data on mesoscale eddy circulation and localised upwelling, primary and secondary productivity, food web interactions, fish biodiversity and genetics. The data confirmed that nutrients from terrestrial sources were of a greater importance than upwelled sources for demersal organisms over soft sediments in the southern part of the WIO – hence demersal fisheries and those for small pelagic fishes were concentrated near areas of riverine influence. Unfortunately the deteriorating security situation in the region after 2007, with piracy threatening shipping off Somalia, Kenya, Tanzania and Seychelles, led to an embargo on the operation of the Nansen in areas north of 10 °S in the WIO.

In anticipation of the 2nd International Indian Ocean Expedition (IIOE-2), a demonstration survey was undertaken across the southern part of the Indian Ocean in 2015, and included participants from six WIO countries. The first leg of the survey started in Jakarta, Indonesia and ended in Port Louis, Mauritius; the second leg continued from Port Louis to Durban, South Africa. The survey investigated ecological features of the southern Indian Ocean, and habitat studies were carried out on the Mascarene Plateau and Madagascar Ridge using the new Video-Assisted Multi Sampler (VAMS). Sampling for microplastics was also initiated during this survey, across the southern Indian Ocean gyre, which revealed plastic particles to be present in almost all water samples, with higher densities along the gyre edges, especially the eastern edge.

In 2017 the third RV Dr Fridtjof Nansen was launched, and is considered to be one of the most advanced research vessels in the world. In 2018, this vessel undertook a series of surveys along the east coast of Africa from South Africa to Tanzania, across to the Seychelles, and finally further northwards towards India, as part of the new EAF-Nansen Programme "Supporting the Application of the Ecosystem Approach to Fisheries Management considering Climate and Pollution Impacts", which will run from 2017 to 2021. The Science Plan of this new Programme outlines three priority research areas: (1) Fisheries resources, distribution, abundance and structure; and dynamics of key bycatch species; (2) Understanding the impacts of oil and gas activities, and land-based pollution, including marine debris and microplastics; (3) Measuring the impacts of climate change on coastal and marine resources, including the use of long-term monitoring systems. In combination, these priority areas are expected to promote an ocean (or "blue") economy, using mechanisms such as ecosystem-based management, marine spatial planning and regional collaboration.

Capacity development remains a key objective of the EAF-Nansen Programme, with over 400 participants from WIO countries included in the regional surveys from 2006-2016. In addition to on-board training, opportunities in the form of short-term training courses, long-term degrees and scholarships have been provided. Alongside capacity development, partnerships with governments, fisheries research and management authorities, regional and international organisations, and non-governmental organizations have played a key role in the successes of the EAF-Nansen Programme to date. Many thanks to all involved, and we hope to see you on-board one day!

For further information: http://www.fao.org/in-action/eaf-nansen/en
Reference: Groeneveld, J.C. & Koranteng, K.A. (Eds). 2017. The RV Dr Fridtjof Nansen in the Western Indian Ocean: Voyages of marine research and capacity development. FAO. Rome, Italy.

One Ten East voyage of the IIOE-2

Professor Lynnath Beckley
Murdoch University
L.Beckley@murdoch.edu.au

Figure 1. Captain Adrian Koolhof, scientists and MNF support staff, wearing their fluoro vests and red beanies, form IIOE 2 on the foredeck of RV Investigator. Photo: Micheline Jenner AM.

Four thousand nautical miles, thirty-three days and twenty-five very busy oceanographic stations later, the forty scientists and MNF support staff on board the RV Investigator (Figure 1) returned to Fremantle, Western Australia on 14th June 2019 armed with huge amounts of data and biological samples obtained from temperate to tropical waters in the south-east Indian Ocean. We had completed an ambitious bio-physical, ecosystem-scale examination of the International Indian Ocean Expedition 110°E line last visited in May/June 1963 by Australian scientists aboard the HMAS Diamantina.

The 110°E voyage is Australia's main contribution to the second International Indian Ocean Expedition. Our objectives were to examine ecosystem-scale change from the 1960's benchmark, characterise microbes that contribute to the regional biogeochemistry (especially related to nitrogen), determine pelagic food web structure and relate information on phytoplankton and particles to bio-optical quantities derivable from satellite radiometry. We achieved this, and much more, almost without missing a beat, thanks to the remarkable multi-disciplinary, multi-institutional, international scientific team and Marine National Facility (MNF) technical support on board the ship.

The 54 CTD deployments were at the heart of operations with nearly half of them to

Figure 2. In the CTD lab, several scientists retrieve water samples from the Niskin bottles for nutrients, microbes, phytoplankton and micro-zooplankton. In the foreground from left, Amaranta Focardi (Macquarie University) documenting the details and James O'Brien (University of Technology Sydney) and Dr Peter Thompson (CSIRO) taking water from the rosette. In the background, Dr Helen Phillips (University of Tasmania) prepares samples for the hydro-chemists. Photo: Micheline Jenner AM.

depths exceeding 5,000 m. This is a long way down into the abyss and the physical and chemical measurements made, and the seawater obtained from the 12L-Niskin bottles fired at about 20 different depths, were the life blood for the on-board experiments on nutrients, genetics, microbes, phytoplankton and micro-zooplankton (Figure 2).

Figure 3. The Indian Ocean Standard Net (IOSN) is the one of the original nets used in the International Indian Ocean Expedition in the 1960s. This one being deployed from the RV Investigator on the 110°E line is a replica allowing for interesting comparisons of zooplankton biomass and composition across the decades since the 1960s. Photo: Micheline Jenner AM

Various netting operations ranging from tiny 20-micron mesh nets to large, coarse 1 mm mesh nets provided samples of the plankton. The samples from the Indian Ocean Standard Net, a replica of one used in the original IIOE, will serve as a direct comparison with the zooplankton collected in the 1960s (Figure 3). Forty deployments of the opening and closing EZ net collected stratified samples of zooplankton and mesopelagic fishes from 500m depth to the surface (Figure 4).

We made various measurements of optical properties and mixing in the water column, recorded acoustics from sonobuoys, towed a continuous plankton recorder between stations and deployed 14 weather drifters, two JAMSTEC deep ARGO floats and one IMOS ARGO float. On the return leg of the voyage, we towed the undulating Triaxus with CTD (Figure 5) and other sensors for 50 hours assessing the flow of the

Figure 4. Freshly caught larval meso-pelagic fishes, Margrethia sp., with their stomachs full of orange copepods visible through their transparent bodies. It's not always so easy to see what fish have eaten! Photo: Dr Pilar Olivar (CSIC, Barcelona).

Eastern Gyral Current and crossing a large eddy generated nearly three months earlier by Tropical Cyclone Veronica.

All the while, the 20-strong ship's complement kept the ship running smoothly, the deck crew assisted us with various winching and crane activities, wrestled with nets and expertly deployed and retrieved valuable scientific gear whilst the chefs and their team kept us exceptionally well fed. We even had a World Oceans Day celebration with our post-graduate students competing in the first ever "3-minute thesis" competition afloat in the Indian Ocean!

Whilst packing up our gear for demobilisation in Fremantle, we had many fruitful discussions about our data, sample processing, integration and how we will relay our findings to the world. We expect to have a good showing at the International Indian

Figure 5. Dr Helen Phillips (University of Tasmania) and Earl Duran (University of New South Wales) eagerly awaiting deployment of the Triaxus so that they could gather oceanographic data across the Eastern Gyral Current. Photo: Micheline Jenner AM.

Ocean Science Conference in Goa in March 2020 and look forward to the wonderful Indian hospitality we experienced at the 2015 conference.

The voyage was led by Professor Lynnath Beckley of Murdoch University and the research was supported by a grant of sea time on RV Investigator from the CSIRO Marine National Facility. Our sincere thanks to all who contributed to making the RV Investigator voyage IN2019_V03 so successful. Daily reports from the voyage are available at https://iioe-2.incois.gov.in/

Ocean Voice - Opinions/Discussion

Is the Unique Indian Ocean Warming Related to the Southern Ocean Warming?

Prof. Raghu Murtugudde

University of Maryland

mahatma@umd.edu

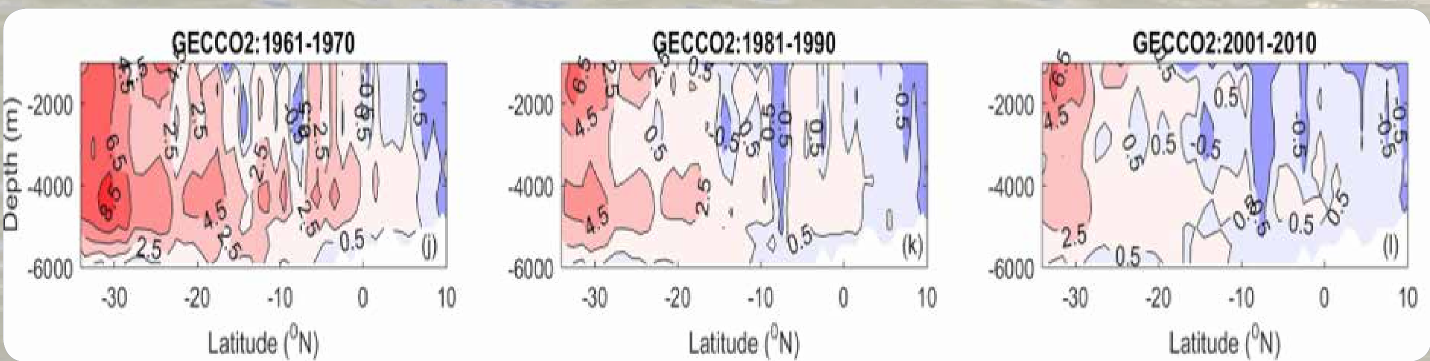
Prof. Murtugudde specialises in Earth System Modelling and Predictions and specifically focuses on Climate Impacts and the Ocean's Role in Climate Variability

Thermocline theories are not easy to grasp because of the hairy math involved. But the simple idea of a balance between high latitude heat loss and the low latitude heat gain can be used understand the impact of high latitude warming on the tropical thermocline response (see Fig. 2 of https://science.sciencemag.org/content/312/5779/1485). Especially since the high latitude warming in the regions of deep water formation or deep mixing of surface warming can pump the warming signal into the tropics via the Meridional Overturning Circulation or the MOC.

Two unique oceans may be offering an early indication of how this theory may work in reality. The Southern Ocean is unique because of its channel configuration which allows winds to churn the ocean and put much more wind energy into the ocean compared to the other oceans. This allows the Ekman currents to extend much deeper and along with it the surface warming which is also uniquely faster due to the polar amplification and wind changes.

Indian Ocean is unique because it is shutoff to the north by the Asian landmass which short-circuits its MOC and forces the deep and intermediate waters to rise and return south at multidecadal timescales – a relatively rapid flushing timescale compared to the other oceans. Indian Ocean is also unique because of the heat transport from the Pacific via the Indonesian throughflow. But what is the role of the Southern Ocean warming and the MOC on the upper ocean response in the Indian Ocean to the increase in greenhouse gases? This question will need further data and model analysis. Do the ocean reanalyses help? A comparison of three ocean reanalysis products raise more questions than provide answers.

A recent study published in the Geophysical Research Letter (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL084244) contrasts three ocean



reanalysis products to show that one of them GECCO2, has a trend in the MOC unlike the other two, viz., ORAS4 and GFDL. Validation of the products indicates that ORAS4 may be the most realistic and thus the trend in GECCO2 may be spurious. However, this trend such as it is in the deep northward inflow can be used to elicit the impact of deep ocean warming on the upper ocean.

Simply put, reduced inflow of colder deep water into the low-latitudes results in a reduced southward upper ocean return flow leading to an accumulation of heat at mid-depths in GECCO2. This can be used as a proxy for the invasion of warmer deep waters and its impact on the upper ocean. Clearly, the available data and the reanalysis products leave much to be desired in terms of a complete understanding of the Indian Ocean MOC.

Model experiments have reported on the impact of abyssal warming around Antarctica on the Atlantic MOC (https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2014GL059923).

Wind-driven changes in the Subantarctic Mode Waters are also argued to affect the ocean heat storage and play a role in the much-discussed Global Warming Pause (https://www.nature.com/articles/s41558-017-0022-8).

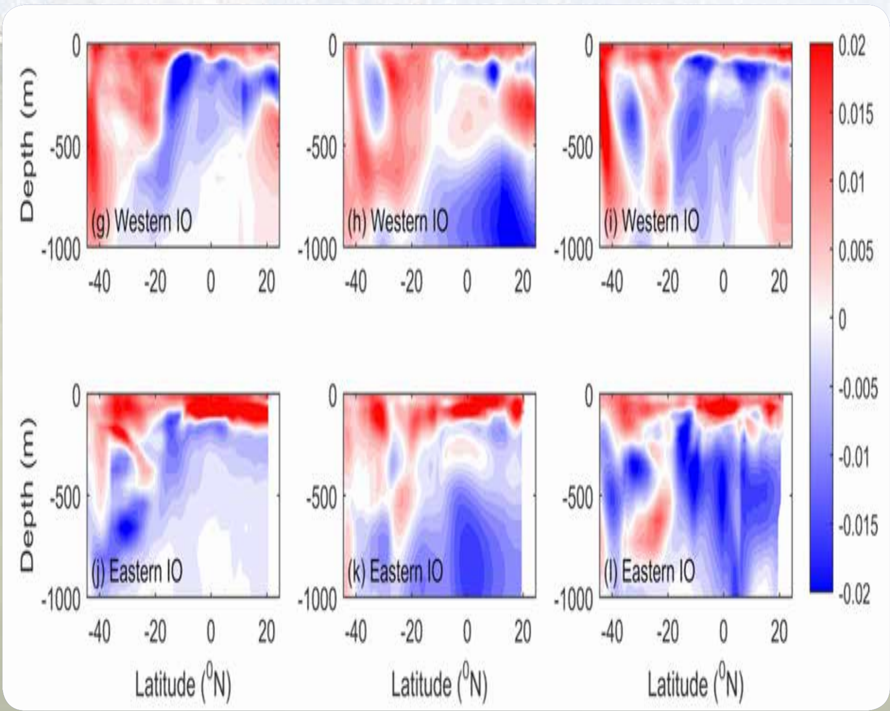
Clearly, the Southern Ocean is undergoing rapid changes in response to anthropogenic warming and those changes are invading the Indian Ocean relatively quickly. The monotonic warming of the Indian Ocean has been argued to have impacts on the monsoon as well as the Atlantic MOC and the Pacific Ocean

(https://www.nature.com/articles/ncomms8423; https://www.nature.com/articles/s41558-019-0566-x?proof=true&draft=marketing and https://www.pnas.org/content/109/46/18701).

Needless to say that there is an urgent need for enhanced observational and modeling efforts to advance the process understanding of the Indian Ocean MOC and its response to Southern Ocean warming and the net impact of the Southern Ocean warming and the MOC on the Indian Ocean warming. A cautionary note is also warranted against assuming reanalysis products to be reality.

GECCO2 is the only reanalysis which shows a decline in the MOC from 1961 to 2010 among the three products analysed, viz., ORAS4, GFDL and GECCO2.

Trends in temperatures in ORAS4, GECCO2 and GFDL ocean reanalyses during 1961-



2010. The impact of the trend in MOC seen above in GECCO2 leads to the mid-depth warming trend in the western and eastern IO. The role of MOC changes driven by the Southern Ocean warming on the upper ocean are critical for future projections of tropical climate modes and the monsoons.

Ocean Vision

Census - Marine Biology

New Species Described from Specimens Collected by the U.S. Program on Biology of the International Indian Ocean Expedition

Ed Urban

(Former Executive Director, Scientific Committee on Oceanic Research)

University of Delaware

ed.urban@scor-int.org

Dr. Urban has recently retired from his position as SCOR Executive Director at the end of January, but will continue to support SCOR in various capacities.

Introduction

The first International Indian Ocean Expedition (IIOE-1) was conceived by the Scientific Committee on Oceanic Research (SCOR) at its first meeting in 1957; the Intergovernmental Oceanographic Commission because a co-sponsor of the project in 1960. A major goal of the IIOE was to study the biology of the Indian Ocean, to develop a basic understanding of the productivity of the region and its potential for feeding the developing countries surrounding the ocean basin, but also to understand how the seasonally reversing monsoon winds affect ocean biology. The United States funded a U.S. Program in Biology, which was primarily conducted from the ships R/V Anton Bruun and R/V Te Vega, and from field stations in India and Madagascar. The Bruun hosted many Indian scientists on its cruises.

The Bruun and Te Vega used a variety of equipment to sample organisms from plankton to large pelagic fish, including plankton nets of various types, trawl nets, dredges, long-line fishing gear, hook-and-line fishing, and collection by hand in shallow-water and onshore. U.S. scientists sent 3.6 million specimens from IIOE-1 to the Smithsonian Oceanographic Sorting Center (Wellen and Fehlmann, 1974). IIOE-1 had a major impact on determining what organisms lived in the Indian Ocean, not surpassed until the time of the Census of Marine Life (Wafar et al., 2011). Specimens collected during IIOE-1 are still being used to describe new species and understand how species fit within higher taxa; papers using IIOE-1 specimens were published as recently as 2018 (e.g., Baker et al., 2018), 54 years after the specimens were collected.

The Bruun made 10 cruises as part of the IIOE and the Te Vega made 4 cruises. A complete station list and other information from these cruises is given in Urban (2019a,b,c,d). This article will present information about the role of the U.S. Program in Biology in the discovery of new species in the Indian Ocean.

Specimens from the IIOE were used to describe at least 113 new species (Urban, 2020) and to revise genera for several different types of organisms. Several new species described from materials collected by the Bruun were named for the ship and/or the namesake Danish biologist, including amphipod (*Deutella antonbruuni*) and isopod (*Gnathia antonbruunae*) crustaceans, a myctophid fish (Diaphus antonbruuni), and an octocoral (*Protodendron bruuni*, now *Corymbophyton bruuni*). Sixty-four percent of the described species are crustaceans.

The most typical time from collection to description (the statistical mode) was 3 years. Fifty percent of the descriptions (the statistical median) were accomplished in 10-11 years, and the mean time between collection and description was 19 years. In several cases, many new species were described in a single publication, as the author reexamined an entire genus or family. Two species described from specimens collected by U.S. scientists are shown below.

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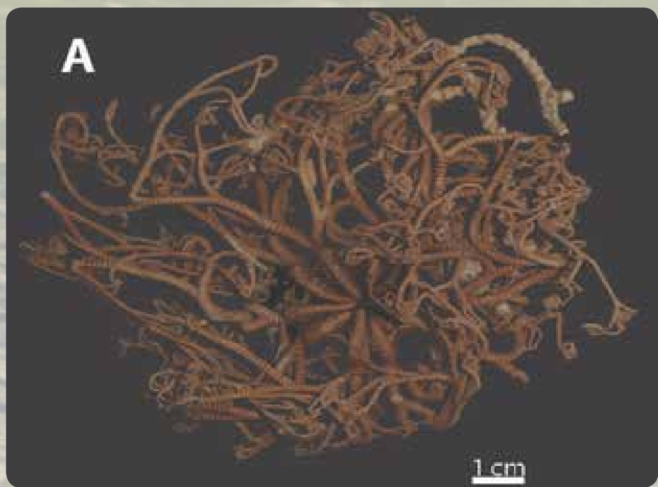
Curious Wormfish, Gunnellichthys curiosus. Source: Andrey Ryanskiy / Fishbase. License: CC by Attribution-NonCommercial-ShareAlike (Bray, 2016). Named by Dawson (1968) based on specimens collected by James E. Böhlke at the Seychelles Islands on 23 February 1964.



Brittle star Astrrocyclus somaliensis.

Source: Baker et al. (2018), Euryalid brittle stars from the International Indian Ocean Expedition 1963 - 64 (Echinodermata: Ophiuroidea: Euryalida), Zootaxa 4392 (1), pp. 1-27. Copyrighted material used with permission from Zootaxa (https://www.mapress.com/j/zt). Specimen collected on Anton Bruun Cruise 9, Station 463 on 18 December 1964 off the coast of Somalia.

The Transporters - Physics: Ocean, Atmosphere

Role of currents and eddies in shaping ocean thermal response to TC Phailin

Lingala Jyothi [1,2], Sudheer Joseph [1] and Suneetha P [2]

[1] Indian National Centre for Ocean Information Services

[2] Department of Meteorology and Oceanography, College of Science and Technology, Andhra University, Visakhapatnam,India

jyothi.l@incois.gov.in

This article summarises a remarkable finding with clear implications on the physical and biogeochemical processes along the east coast of India and the exchanges between BoB and Arabian Sea . The first author is pursuing her PhD at INCOIS.

Tropical cyclones (TCs) are one of the most extreme cases of air-sea interaction where a lot of heat and momentum exchange takes place. The strong atmospheric winds associated with the TCs can greatly influence the underlying ocean as a result of which the ocean responds. The primary response with the TC passage is the reduction in SST underneath the storm core which generally ranges from 1- 6°C (Price 1981; D'Asaro 2007). The magnitude of upper ocean cooling is generally a function of initial ocean conditions, intensity of the storm and its translation speed. Past studies that estimated the mixed layer heat budget have emphasized the relative importance of various physical processes in governing the rate of temperature change. i.e.. temperature tendency. They have quantified that 70-90% of mixed layer cooling is dominated by vertical mixing in the surface and ~5% is accounted for upwelling in the subsurface. Although there is a good understanding about these aspects in the open ocean, the TC-induced ocean thermal response in the presence of pre-existing oceanic features such as coastal boundary currents and eddies is still not explored in the Bay of Bengal basin. Therefore, our present study aims at investigating how the thermal responses associated with the pre-existing oceanic features are going to be different from the open ocean responses. To achieve this objective, a storm case, Phailin (8–12 October 2013) has been considered in the BoB basin. The HYbrid Coordinate Ocean Model (HYCOM) simulations having a horizontal resolution of 1/16º together with the observational data sets are used.

SST Response at Distinct Locations Along the TC Track

To investigate the role of pre-existing oceanic features on the TC-induced SST response three sample point locations are considered along the TC track as shown in Figure 1. Location A, B and C represent the regions away from the coast and eddy, inside eddy and near to the coast respectively. The common element for the three locations is that they are under similar wind forcing (115 knots) associated with TC. The basic question arising under such a scenario is whether the SST response to TC at these locations with different oceanic conditions is going to be same?

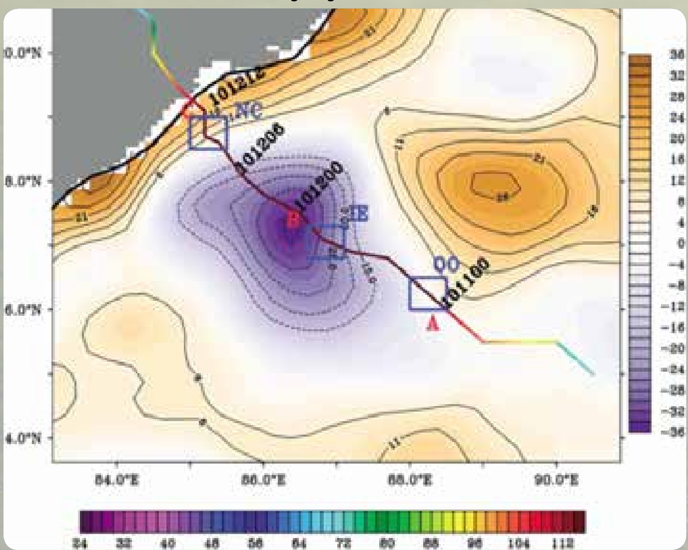
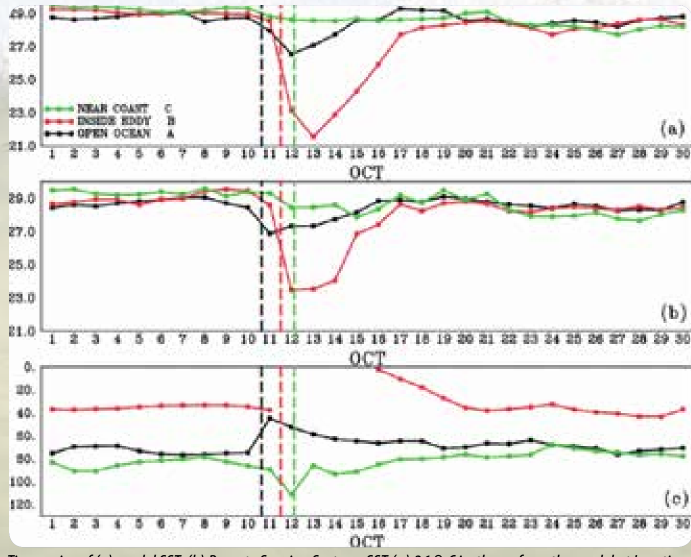


Figure 1: Sea surface height anomaly (SSHA; cm) pattern on 12 October 2013. Dashed and solid contours represent negative and positive SSHA. OO (A), IE (B), and NC (C) are three sample boxes (point locations) open ocean, inside eddy, and near coast, respectively. Numbers along the track represent the TC locations. Color along the track denotes the intensity of the storm in terms of maximum wind speed (horizontal color bar.)

The time series of TC-induced SST response at A, B, and C is displayed in Figure 2. SST cooling is stronger (nearly 7˚C) inside the cold-core eddy (B) due to the presence of a shallow thermocline (Figure 2c). Even though the wind forcing over region A is similar to B, only 2˚C (Figure 2a) cooling is visible, as the thermocline is not as shallow as in the former case (Figure 2c). At Location C (Figure 2a) only 0.5˚C cooling is observed in contrast to the other two regions (B and A) despite the passage of an extremely severe cyclonic storm. The possible mechanism behind the weakened SST cooling near the coast is explored with the help of mixed layer heat budget analysis.

Mixed Layer Heat Budget Analysis

Three-box averaged regions along the track (Figure 1) are considered to carry out an in-depth analysis of the physical processes. The first box selected is in the open ocean (OO) to elucidate the changes in thermal response in comparison with the other two locations described below. The second location is within an eddy (IE) to explore the TC-induced thermal response under its influence. The third location is selected to



Time series of (a) model SST, (b) Remote Sensing Systems SST (c) 26 ° C isotherm from the model at Locations A, B, and C. The gap in the 26°C isotherm (red curve in c) is due to its outcropping. Dashed lines represent the time of TC passage.

understand the influence of boundary current, EICC on TC induced thermal response near the coast (NC).

The analysis of heat budget in the mixed layer from the three selected regions under similar wind forcing demonstrates that preexisting oceanic features such as EICC, and eddies have more influence on the thermal response in the region as compared to an open ocean region without any such major oceanic features. The heat budget analysis from the three distinct regions considered along the storm track shows that entrainment plays a dominant role in deciding the thermal signature at IE and OO regions with IE having higher-temperature tendency during the passage of the cyclone. However, in the NC region, the total thermal response is low with dominant horizontal advection, which is associated with the presence of EICC. Earlier studies by D'Asaro et al. (2007), Jacob et al. (2000) and Price (1981) suggest that entrainment mixing accounts for about 70–85% of the SST drop, which is not true at least in case of locations like NC where horizontal advection dominates the temperature tendency

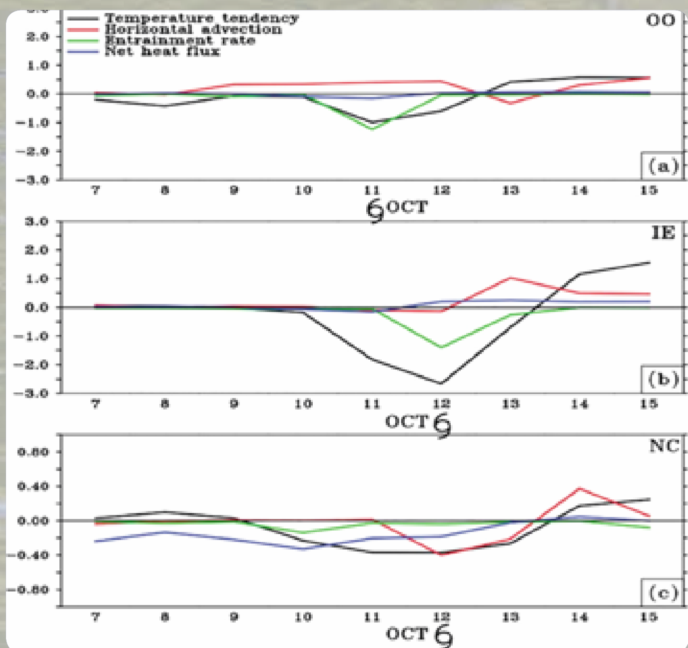


Figure 3: Time series of various mixed layer heat budget terms across box averaged regions of (a) open ocean, (b) inside eddy, and (c) near coast as denoted in Figure 1.

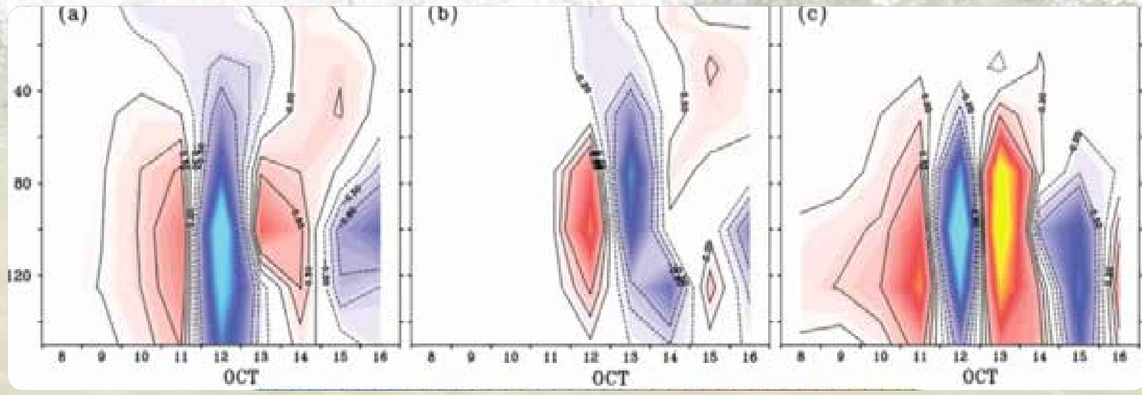


Figure 4: Model (a) temperature tendency (°C/day), (b) horizontal advection, (c) vertical advection considered over near coast region from surface to 150 m depth during 8–16 October. The cyclone symbol represents the location of the tropical cyclone.

Subsurface Responses

It is evident from Figure 3c that the TC did not induce significant cooling at the NC region despite the passage of an intense storm like Phailin. However, the cooling exists from 80 m to deeper depths, contrary to the surface. The differences in cooling between the surface and subsurface depths is examined and presented in Figure 4. The surface layer (0-40 m) cooling is dominated by the horizontal advection (Figure 4b) and below 50 m the cooling (>2.5° C) is mainly due to the vertical advection (Figure 4c) on 12 October. Thus, in the NC region, the horizontal and the vertical advection dominates the TC-induced surface and subsurface thermal responses, respectively. However, there are other processes that contribute to the total temperature changes (Figure 4c).

Evolution of Cold Wake Driven by Local Circulation

The role of oceanic features in transporting the TC induced cold wake from its origin is shown in Figure 5. The vertical movement, in conjunction with the horizontal movement of the cold wake is examined by sampling the temperature data along a circle which encloses the feature of the eddy. Figures 5a–5d and Figures 5i–5l shows the SST responses overlaid by TC track and model-simulated currents. Figures 5e–5h and Figures 5m–5p demonstrate the vertical section of temperature along the circle from 0-200m depth. The movement of the surface cold patch along the circle of sampling can be traced down to the subsurface in the shoaling peak of 23° C isotherm (Figures 5i–5l and Figures 5m–5p). The cyclonic eddy circulation and the southward flow of EICC contributed to the transport of this cold wake toward to the coast from its origin (18° N, 86° E).

Thus, the cyclone-induced cold anomalies can be advected to other locations under the influence of local circulation and can contribute to the faster restoration of thermal signatures to pre-storm conditions. This finding is remarkable given its implications on the physical and biogeochemical processes along the east coast of India and the exchanges between BoB and Arabian Sea (Durand et al., 2008; Shetye et al., 1996).

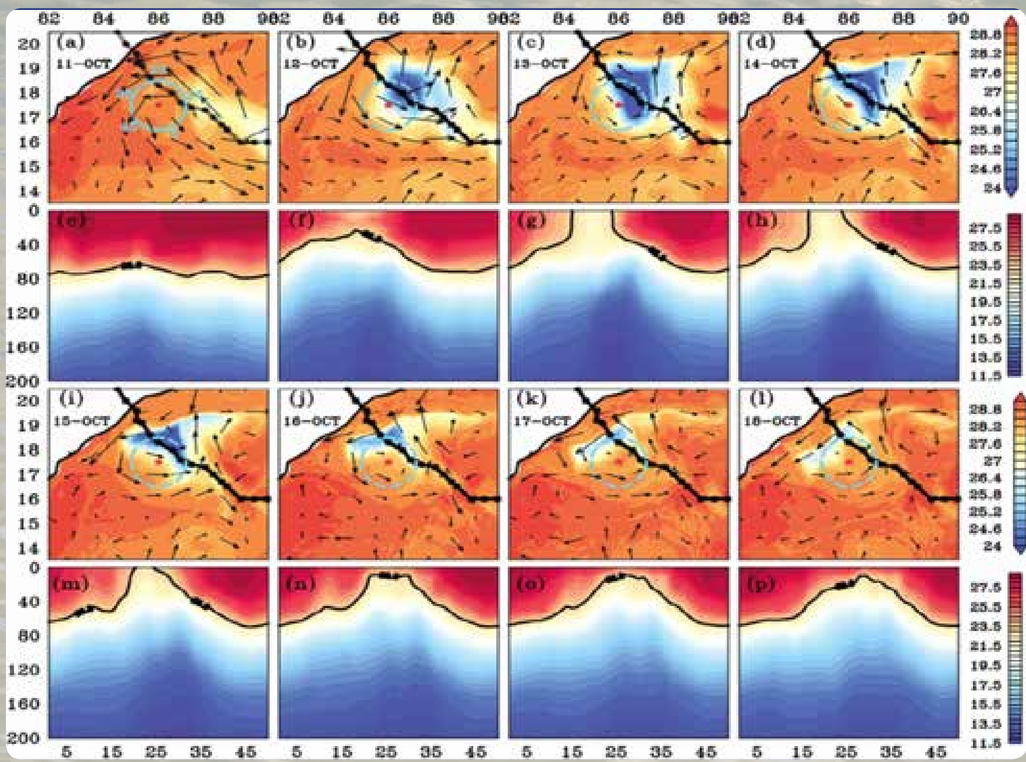


Figure 5: Panels (a)-(d) and (i)-(l) indicate the surface temperature overlaid with current vectors, and panels (e)-(h) and (m)-(p) indicate their corresponding responses in the subsurface along the rim of the circle during 11-18 October 2013. Sampling locations along the circle are numbered in the counterclockwise direction. Black contours indicate 23 °C isotherm.

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Investigation on water mass mixing and dominant oceanic processes in the eastern Arabian Sea: insights from geochemical and isotopic composition of water

Tripti Muguli [1], L. Sheela Nair [1], Gurumurthy G.P [2], Prakash T.N. [1], Mahboob Alam [2]

[1]National Centre for Earth Science Studies, Thiruvananthapuram - 695011, India
[2]Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow - 226007,
tripti.muguli@ncess.gov.in; tripti87jan@gmail.com

Dr. Muguli focusses on research in fog dynamics using geochemical and stable isotope tracers, investigating water, carbon and nitrogen cycles, and understand ing the inter-link between land surface processes and climate change in humid tropical mountain ecosystems as well as elemental fluxes from the west flowing rivers of India to the Arabian Sea.

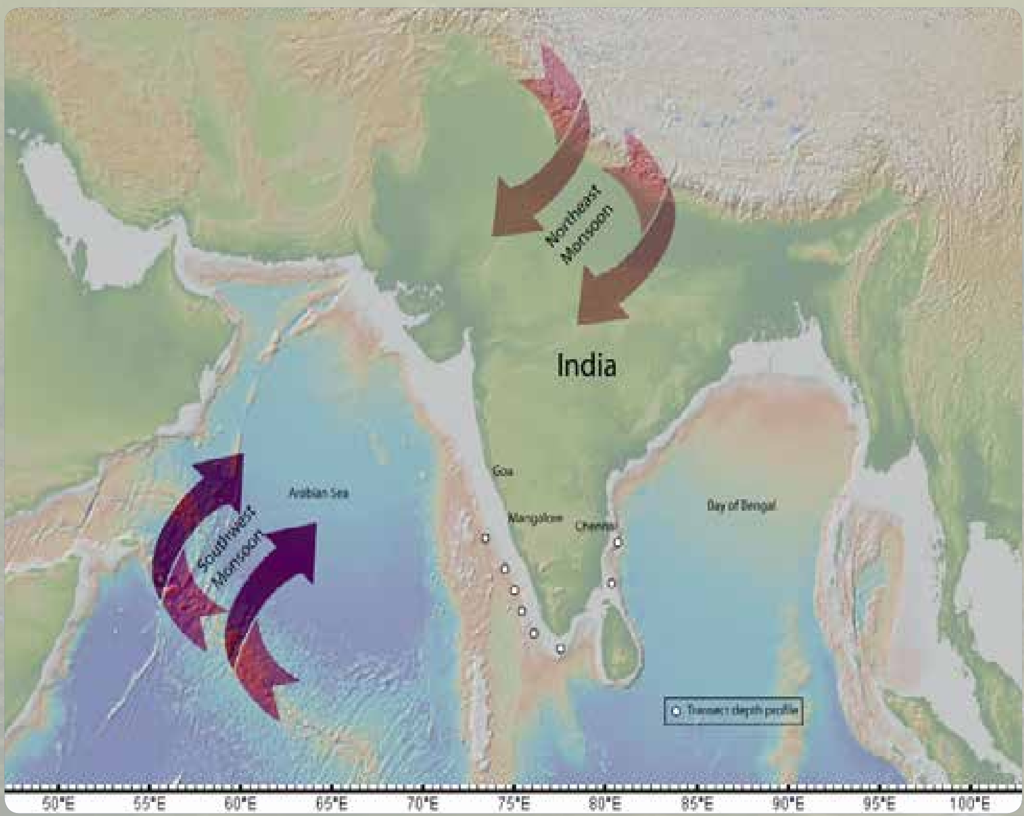

Figure 1: Study area map showing water sampling locations during SK-362 expedition on board ORV Sagar Kanya.

The northern Indian Ocean exhibits a characteristic salinity difference between the eastern and western part due to differences in the supply of freshwater fluxes from the sub-continental region. The seasonal reversal of winds during the summer and winter monsoon, and differences in salinity aids the mixing of water masses in the Indian Ocean. The water mass mixing and its circulation in the oceans are critical in the functioning of the coastal system and ocean biogeochemistry. Geochemical and isotopic tracers have proven to be useful in tracing the sources, mixing pathways and circulation of water masses both in the terrestrial and oceanic systems. Water circulation in continental shelf and open oceans is complex because several secondary factors like evaporation, continental runoff, upwelling and larger water mass influx from adjacent oceans together act as a key controller of water characteristics. The functioning of such complex water mass system has been addressed with the knowledge on physico-chemical observations like conductivity-temperature-depth (CTD), dissolved oxygen of sea water, depth-wise current profile and wind (speed/direction) data. The isotopic and geochemical tracers coupled with physical observations in a modelling system will improve the present understanding on water mass mixing in the marine environment.

The present study aims to i) investigate the geochemical and isotopic behaviour of redox sensitive elements and their distribution in the northern Indian Ocean to trace sources of water mass and its mixing pattern in the eastern Arabian Sea, and ii) model the mixing pattern of water mass in the eastern Arabian Sea to better understand and predict the redox condition, upwelling, coastal flooding and storm effect over South India, and palaeoceanographic reconstruction (palaeo-salinity, palaeo-redox, etc). Samples have been collected from continental shelf region (50-500 m water depth) of northern Indian Ocean covering eastern Arabian Sea and Bay of Bengal (Fig. 1) during October-November 2019 on board ORV Sagar Kanya, SK-362 expedition. Sample collection involved rain water (35 samples), sea water (180 samples) and surface sediments (5 samples). Standard protocols recommended by the International Atomic Energy Agency were followed for sample collection and handling. Meteorological and physical data are obtained from onboard AWS station and rosette CTD setup respectively. The proposed work explores questions pertaining to $\delta^{18}O$ - salinity relation, prevailing redox condition and the extent of water mixing from the Bay of Bengal in the continental shelf region of eastern Arabian Sea during the early winter monsoon season. The laboratory approach includes measurement of i) geogenic elemental water column profiles in the coastal and deep oceanic environment, ii) isotopic composition of oxygen ($\delta^{18}O$), hydrogen ($\delta^{2}H$), carbon ($\delta^{13}C$) and redox sensitive elements, and iii) modelling using MIKE 3D software/ROMS/Isotope based models. The generated data will be discussed in line with earlier observations in the eastern Arabian Sea and water influx from tropical river basins in India.

Acknowledgements: We thank the Director, National Centre for Earth Science Studies and the Director, Birbal Sahni Institute of Palaeosciences for encouragement and financial support to carry out this research in the northern Indian Ocean. This work is also supported by the funding from DST-INSPIRE Faculty grants to TM. Thanks to Dr. Anil Kumar, National Centre for Polar and Ocean Research, Goa for his constant support. The onboard support from the Captain and his officers, Norinco engineers, the Chief Scientist and scientific team during the SK-362 expedition is acknowledged

The Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia will host the 15th Pan Ocean Remote Sensing Conference (PORSEC2020) from 20 - 22 September 2020 in Johor Bahru, Malaysia.

The deadline for abstract submission for PORSEC-2020 has been extended to 29 February, 2020.

The 5-day Tutorial Capacity Building that will be held prior to the conference from 15-19 September 2020 will focus on existing instruments in space and on methods of analysis and visualization. Participants will be given following exposure such as :

1. **Theoretical information as well as practical exercises along with a variety of data and software.**
2. **Fundamentals of visible, thermal and microwave remote sensing, satellite wind and wave data, satellite altimetry, ocean colour data, fisheries applications, and data assimilation.**
3. **Demonstrations on how to access all of these datasets from a variety of different software.**
4. **How to write scientific manuscript.**
5. **Giving a scientific presentation in English to an international audience.**
6. **Experience live field data collection and sampling at the ocean facilitated by the experienced local facilitators.**
7. **Related instruments used for ocean water sampling are demonstrated and students will get opportunities to operate them**
8. **Tutorial Application deadline for the pre-conference tutorial program is also extended to 15 February, 2020.**

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

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