

SCOR/IOC/IOGOOS Second International Indian Ocean Expedition (IIOE-2)

Report to SCOR 2019/20

GOAL

The goal of IIOE-2 remains as *to advance our understanding of the Indian Ocean and its role in the Earth System in order to enable informed decisions in support of sustainable development and the well-being of humankind.*

MANAGEMENT

While delivery of IIOE-2 occurs through national activities¹ these are coordinated by a Core Group comprising the following key personnel:

Role	Name	Affiliation
Co-Chair IIOE-2	Peter Burkill ^a	SCOR
	Vladimir Ryabinin	IOC
	Sateesh Shenoi	IOGOOS
Co-Chair WG 1 (Science & Research)	Raleigh Hood	USA
	Hermann Bange	Germany
Co-Chairs WG 2 (Data & Information Management)	Cyndy Chandler ^b	USA
	Harrison Ong'Anda	Kenya
Chair WG 4 (Operational Coordination)	Shailesh Nayak	India
Supported by		
International Project Office (Perth)	Nick d'Adamo	IOC
International Project Office (Hydrabad)	Satya Prakash	IOGOOS
SCOR Office	Patricia Miloslavich ^c	SCOR

a) Marie-Alexandrine Sicre will take over as Co-Chair IIOE-2 representing SCOR in October 2020.

b) Resigned in 2020.

c) Patricia Miloslavich took over from Ed Urban in January 2020

The Core Group has met electronically 4 times: in Nov 2019, in February 2020, in April and July 2020 over the last year to deal with strategic issues. The International Project Offices in Perth, Australia and Hyderabad, India have dealt with a day-to-day issues within IIOE-2.

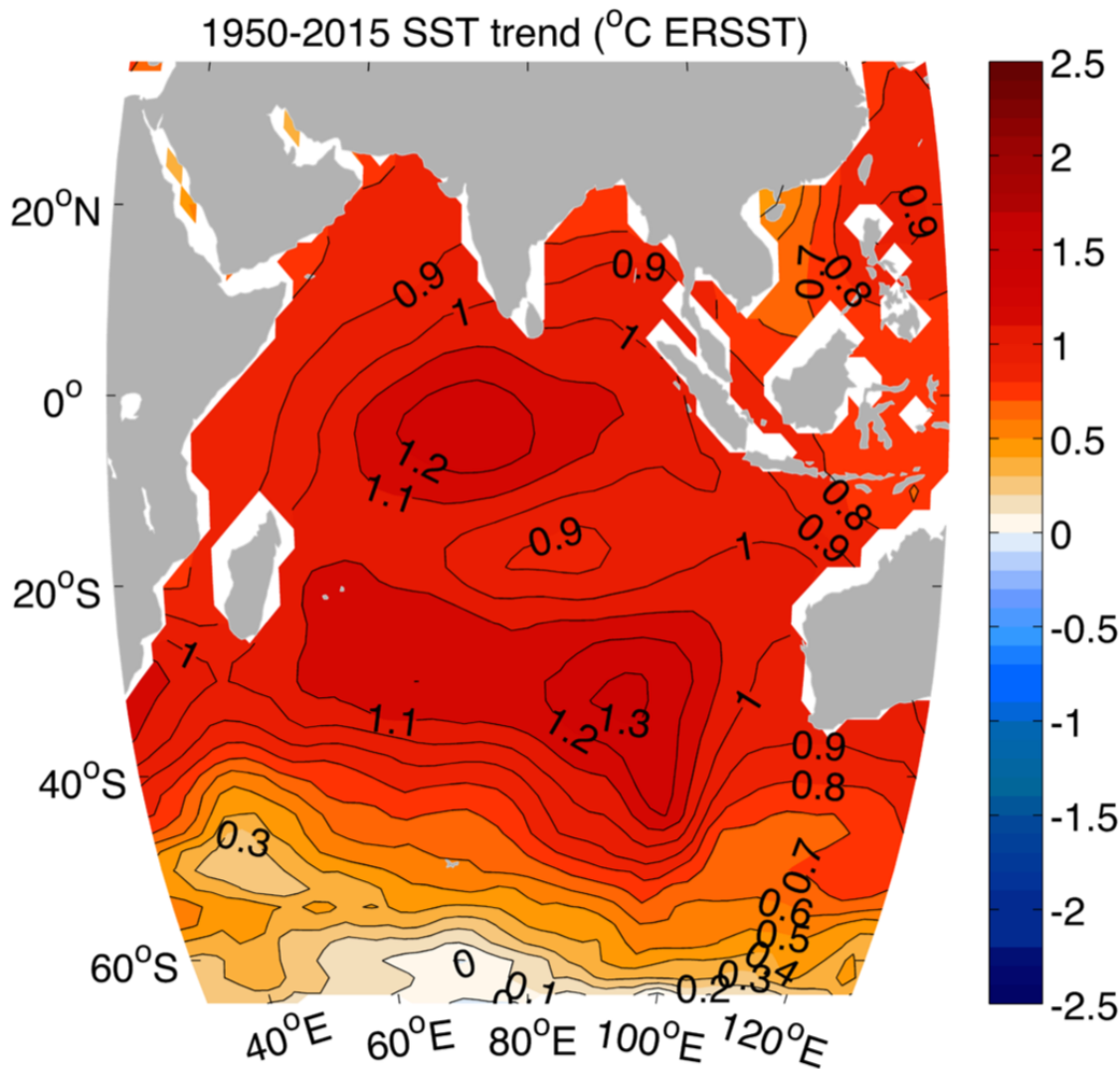
DEVELOPMENTS AS A RESULT OF COVID-19

- The Indian Ocean community was to have met from 16th to 20th March 2020 in Goa, India for the *International Indian Ocean Science Conference 2020*. This open science conference was set up to debate and consider the new understandings gained in first four years of results of IIOE-2; this conference was organized by an International Board. The 2020 IIOE-2 SSC meeting was also scheduled to take place to discuss development and evolution of IIOE-2. One of the main focus of this was how IIOE-2 might best contribute to the development of the *UN Decade of Ocean Science for Sustainable Development*. Sadly, both these key meetings have had to be postponed to a future, and as yet, unknown date because of the Covid problem. It was hoped that the meeting could be rescheduled for later in 2020 but this depends on Indian Government approval and it now looks increasingly likely this will be possible for October 2021.
- IIOE_2 cruises have had to be postponed by countries such as India and Germany. How and when these may be re-planned remains to be determined.
- However, it is not all doom-and-gloom as this enforced 'breather' has given an opportunity to push ahead with other matters reported below.

1: Nations with IIOE-2 committees (chair) are: Australia (Lynnath Beckley), France (Francis Marsac), Germany (Birgir Gaye & Hermann Bange), India (Madhavan Nair Rajeevan), Japan (Yukio Masumoto), UK (Greg Cowie), USA (Raleigh Hood).

PEER-REVIEWED RESEARCH OUTPUTS

Two excellent summaries of the current state of understanding of the Indian Ocean can be found by Hermes *et al* (2019)² and Anon (2020)³. While both these focus on understanding obtained by observational procedures, they encompass almost all aspects of the surface and midwaters of the Indian Ocean. They are particularly relevant to future requirements for research in the IO. Arguably, the biggest single issue they raise is the large quantity of heat taken up by the Indian Ocean and its consequences for global processes. It is noteworthy that the world's smallest ocean has taken up >25% of global ocean heat gain over the last 20 years and perhaps as much as 45% in surface waters in the last 10 years. As a result, since 1950, the Indian Ocean has warmed about 1°C at the surface, compared to a global ocean's average of 0.6°C. The reasons for this remain to be resolved and are crucial for if mankind is to understand and manage climate, sea-level rise, ecosystems and fisheries.



Sea surface temperature change in the past 66 years (reported by Anon 2020 based on Cheng et al 2017).

While the IIOE-2 community publishes its findings anywhere in the open literature, many key publications are to be found in the Special Issues of Deep-Sea Research II Volumes 161 and 166. These are coordinated

2) Hermes JC, Masumoto Y, Beal LM, Roxy MK, Vialard J, Andres M, Annamalai H, Behera S, D'Adamo N, Doi T, Feng M, Han W, Hardman-Mountford N, Hendon H, Hood R, Kido S, Lee C, Lee T, Lengaigne M, Li J, Lumpkin R, Navaneeth KN, Milligan B, McPhaden MJ, Ravichandran M, Shinoda T, Singh A, Sloyan B, Stratton PG, Subramanian AC, Thurston S, Tozuka T, Ummenhofer CC, Unnikrishnan AS, Venkatesan R, Wang D, Wiggert J, Yu L and Yu W (2019) *A Sustained Ocean Observing System in the Indian Ocean for Climate Related Scientific Knowledge and Societal Needs*. **Front. Mar. Sci.** 6:355. doi: 10.3389/fmars.2019.00355

3) Anon (2020). The Recent Decadal Review (2020-2030) of the Indian Ocean Observing System (IndOOS-2) and its Outcomes CLIVAR Special Issue Exchanges 78: Doi: <https://doi.org/10.36071/clivar.78.2020>

by Raleigh Hood who makes appoint of acknowledging IIOE-2 in his introductory MS in each volume. The DSR MSS are summarized below:

Deep-Sea Research II Volume 161:

- Wiles et al. (2019) Submarine canyons of NW Madagascar: A first geomorphological insight. DSR2 Special Issue on IIOE2, 161: 5-15.
- Singh et al. (2019) The community structure of the deep-sea nematode community associated with polymetallic nodules in the Central Indian Ocean Basin. DSR2 Special Issue on IIOE2, 161: 16-28.
- White et al. (2019) Resilience of benthic ecosystem C-cycling to future changes in dissolved oxygen availability. DSR2 Special Issue on IIOE2, 161: 29-37.
- Saalim et al. (2019) Assessing the ecological preferences of agglutinated benthic foraminiferal morphogroups from the western Bay of Bengal. DSR2 Special Issue on IIOE2, 161: 38-51.
- Mao et al. (2019) Mesoscale eddy characteristics in the interior subtropical southeast Indian Ocean, tracked from the Leeuwin Current system. DSR2 Special Issue on IIOE2, 161: 52-62.
- Prend et al. (2019) Impact of freshwater plumes on intraseasonal upper ocean variability in the Bay of Bengal. DSR2 Special Issue on IIOE2, 161: 63-71.
- Yamani and Naqvi (2019) Chemical oceanography of the Arabian Gulf. DSR2 Special Issue on IIOE2, 161: 72-80.
- Baer et al. (2019) Carbon and nitrogen productivity during spring in the oligotrophic Indian Ocean along the GOSHIP IO9N transect. DSR2 Special Issue on IIOE2, 161: 81-91.
- Rigual-Hernández et al. (2019) Diatom species fluxes in the seasonally icecovered Antarctic Zone: New data from offshore Prydz Bay and comparison with other regions from the eastern Antarctic and western Pacific sectors of the Southern Ocean. DSR2 Special Issue on IIOE2, 161: 92-104.
- Beckley et al. (2019) Structuring of larval fish assemblages along a coastal-oceanic gradient in the macro-tidal, tropical Eastern Indian Ocean. DSR2 Special Issue on IIOE2, 161: 105-119.
- Miller et al. (2019) Contrasting biodiversity of eel larvae across the central Indian Ocean subtropical gyre. DSR2 Special Issue on IIOE2, 161: 120-131.
- Dréo et al. (2019) Baleen whale distribution and seasonal occurrence revealed by an ocean bottom seismometer network in the Western Indian Ocean. DSR2 Special Issue on IIOE2, 161: 132-144.

Deep-Sea Research II Volume 166:

- Burdanowitz et al. (2019) Holocene monsoon and sea level-related changes of sedimentation in the northeastern Arabian Sea. DSR2 Special Issue on IIOE2, 166: 6-18.
- Krishnamohan et al. (2019) Is there an effect of Bay of Bengal salinity on the northern Indian Ocean climatological rainfall? DSR2 Special Issue on IIOE2, 166: 19-33.
- Pearce et al. (2019) Marine debris pathways across the southern Indian Ocean. DSR2 Special Issue on IIOE2, 166: 34-42.
- Menezes and Vianna (2019) Quasi-biennial Rossby and Kelvin waves in the South Indian Ocean: Tropical and subtropical modes and the Indian Ocean Dipole. DSR2 Special Issue on IIOE2, 166: 43-63.
- Kämpf and Kavi (2019) SST variability in the eastern intertropical Indian Ocean – On the search for trigger mechanisms of IOD events. DSR2 Special Issue on IIOE2, 166: 64-74.
- Huot et al. (2019) Partitioning the Indian Ocean based on surface fields of physical and biological properties. DSR2 Special Issue on IIOE2, 166: 75-89.
- Bange et al. (2019) Nitrous oxide in the northern Gulf of Aqaba and the central Red Sea. DSR2 Special Issue on IIOE2, 166: 90-103.
- Suntharalingam et al. (2019) Anthropogenic nitrogen inputs and impacts on oceanic N₂O fluxes in the northern Indian Ocean: The need for an integrated observation and modelling approach. DSR2 Special Issue on IIOE2, 166: 104-113.
- Beckmann and Hense (2019) Modelling nitrogen-oxygen dynamics in the central Arabian Sea: Large-scale meridional structure and seasonal variations. DSR2 Special Issue on IIOE2, 166: 114-124.
- Twining et al. (2019) A nutrient limitation mosaic in the eastern tropical Indian Ocean. DSR2 Special Issue on IIOE2, 166: 125-140.
- Noyon et al. (2019) Plankton distribution within a young cyclonic eddy off south-western Madagascar. DSR2 Special Issue on IIOE2, 166: 141-150.

Al-Yamani et al. (2019) The response of microzooplankton (tintinnid) community to salinity related environmental changes in a hypersaline marine system in the northwestern Arabian Gulf. DSR2 Special Issue on IIOE2, 166: 151-170.

Sutton et al. (2019) Habitat associations of cetaceans and seabirds in the tropical eastern Indian Ocean. DSR2 Special Issue on IIOE2, 166: 171-186.

Two further volumes of the DSR-II Special Issue Series on IIOE-2 are pending and these include the following MSS which are in press or under review

Urban (2020) Outcomes of the U.S. Program in Biology of the International Indian Ocean Expedition. DSR2 Special Issue on IIOE2, available online 9 April 2020, 104780, <https://doi.org/10.1016/j.dsr2.2020.104780>.

Cedras et al. (2020) Biogeography of pelagic calanoid copepods in the Western Indian Ocean. DSR2 Special Issue on IIOE2, in press.

Bernal et al. (2020) Mesopelagic fish composition and diets of three myctophid species with potential incidence of microplastics, across the southern tropical gyre. DSR2 Special Issue on IIOE2, in press.

Moffett and Landry (2020) Grazing control and iron limitation of primary production in the Arabian Sea: Implications for anticipated shifts in Southwest Monsoon intensity. DSR2 Special Issue on IIOE2, in press.

D'Asaro et al. (2020) Structure of the Bay of Bengal oxygen deficient zone. DSR2 Special Issue on IIOE2, in press.

Vinayachandran et al. (2020) Maintenance of the southern Bay of Bengal cold pool. DSR2 Special Issue on IIOE2, in press.

Amol et al. (2020) Effect of freshwater advection and winds on the vertical structure of chlorophyll in the northern Bay of Bengal. DSR2 Special Issue on IIOE2, in press.

Sreeush et al. (2020) Biological production in the Indian Ocean upwelling zones - Part 2: Data based estimates of variable compensation depth for ocean carbon models via cyclo-stationary Bayesian Inversion. DSR2 Special Issue on IIOE2, in press.

Sarma et al. (2020) Physical forcing controls spatial variability in primary production in the Indian Ocean. DSR2 Special Issue on IIOE2, in review.

Bernal et al. (2020) Diet composition of myctophid larvae off western Australia. DSR2 Special Issue on IIOE2, in review.

Liu et al. (2020) Eddy-current interaction in the Leeuwin Current off the lower west coast of Australia. DSR2 Special Issue on IIOE2, in review.

Vinayachandran et al. (2020) Processes governing the seasonality of vertical chlorophyll-a distribution in the central Arabian Sea: Bio-Argo observations and ecosystem model simulation. DSR2 Special Issue on IIOE2, in review.

Huang et al. (2020) MJO induced diurnal sea surface temperature variations off the Northwest Shelf of Australia observed from Himawari geostationary satellite. DSR2 Special Issue on IIOE2, in review.

Prakash et al. (2020) Observed variability of monsoon blooms in the north-central Arabian Sea and its implication to deeper water oxygen concentration: A Bio-Argo study. DSR2 Special Issue on IIOE2, in review.

Sprintall et al. (2020) Seasonality of the Somali Current/Undercurrent System. DSR2 Special Issue on IIOE2, in review.

Harms et al. (2020) Particulate matter fluxes reveal no coherence between primary production and organic carbon export in the Indian Ocean subtropical gyre. DSR2 Special Issue on IIOE2, in review.

Ningish et al. (2020) Zonal Current Characteristics in the Southeastern Tropical Indian Ocean (SETIO). DSR2 Special Issue on IIOE2, in review.

A further volume in the DSR II series is planned based on the 2019 IIO degree East cruise on the R.V. Investigator. It current has 23 MSS planned.

There is also a further series of MSS arising from this Australian lead cruise. These are at various stages of development as follows:

Authors	Title/content	Comments	Date expected
Landry et al.	Mesozooplankton biomass and temperature-enhanced grazing along a 110°E transect in the eastern Indian Ocean	Submitted MEPS	Feb 2020
Beckley et al.	Data report overview paper on the 110E voyage	Something similar to Jovane et al. (2019) South Atlantic multidisciplinary voyage paper – still awaiting response from Editor of Frontiers	
Thompson et al.	Long term change along 110E: comparison of 1963 & 2019 observations	Workshop held Sept 2019 at Murdoch. Most required data now processed and some text written – urgently awaiting physical oceanography density layers	June 2020
Phillips et al.	Variability/change of water mass properties near 20S	GRL	Dec 2020
Phillips	Long term variability 1960s to 2019		2021
O'Brien, Seymour et al.	Sulphur cycling (concentrations and qPCRs)	Progress has been made with biogeochemistry & extraction of DNA for qPCR. Hoping to publish the 110E line with not just biogeochemistry & qPCR but incorporation of some community data (amplicons) and metagenomics. This has become a thesis chapter & I would like to aim for a journal like ISME	2021
Focardi et al.	DNA - amplicon 16S and 18S biogeography paper	Maybe in DSR?	
Raleigh Hood	Model biogeochemistry of the IO with a focus on Nitrogen supply pathways to the Leeuwin Current and the SE Indian Ocean	Applied for funding for modelling	
Thompson, Meng Han & Phillips	Triaxus data for nitrate supply to LC	Could make DSR volume	2020
Beckley, Focardi et al.	Synthesis paper on the cold core eddy from cyclone Veronica.	Will need compilation of all eddy biological data & some physical & chemical data & satellite imagery	
Antoine et al.	UVP	UVP data (particle size distributions) has been done	
Antoine et al.	Assessment of the biological pump in the Eastern Indian Ocean	Won't make DSR issue	
Jefferies	Laser experiments on transparent zooplankton		
Antoine et al.	Pigments HPLC	Samples in France not yet analysed	
Antoine et al.	Cytometry	Sorting and determination of phytoplankton carbon on hold.	

There are other special journal issues for IIOE-2 in *Acta Oceanologica Sinica*, the *Journal of Marine Systems* and jointly in *Biogeosciences*, *Atmospheric Chemistry and Physics*, *Ocean Science*, and *Solid Earth* on « Understanding the Indian Ocean system: past, present and future (BG/ACP/OS/SE inter-journal SI), Editor(s): Hermann Bange, Raleigh Hood, Viviane Menezes, Colin W. Devey, and S. Wajih A. Naqvi.

As well as good progress with peer-reviewed publications, the IIOE-2 community also uses informal publications to maintain momentum, to pose ideas and to ensure the community remains informed and cohesive. The IIOE-2 website (see below) is an important repository for this.

INFORMAL PUBLICATIONS

IIOE-2 communications about the project through a monthly newsletter, quarterly publication (*Indian Ocean Bubble-2*), and its website (see below) remains important.

IIOE-2 WEBSITE

This can be found at www.iioe-2.incois.gov.in and is IIOE-2's main interface with the world.

DATA AND INFORMATION MANAGEMENT WORKING GROUP

This Working Group is central to IIOE-2 and was ably led by Cyndy Chandler who sadly resigned on her retirement in 2019. The D&MI Plan she ably led is almost complete and the Core Group is in the process of appointing an interim successor to finish the Plan. The Group will then begin its Implementation. This is an important aspect of developing IIOE-2 in the future.

UN DECADE OF OCEAN SCIENCE

The relationship between IIOE-2 and the DECADE is still evolving and is likely to be a fruitful 2-way street with IIOE-2 projects contributing to the DECADE while aspects of IIOE-2 delivery (e.g. Role of IO in Global Processes) will undoubtedly gain from the DECADE. We are fortunate to have Vladimir Ryabinin, the architect of the DECADE programme, as one of the IIOE-2 Co-Chairs and he will be crucial to the integration of IIOE-2 into the DECADE program

FUTURE

IIOE-2 is now at a turning point in its evolution. There are a myriad of unanswered research questions that remain to be addressed. The biggest, arguably, is what causes the rapid heating of the Indian Ocean? This heating has major knock-on effects including those that directly influence society (sea-level rise). At the same time as addressing these largely research-led questions, IIOE_2 is poised to join up with the DECADE program and this will need some careful thought. The DECADE program will incorporate a closer-to-society focus and this will require some new skills (and probably people) We were due to discuss this at the Goa Meeting in March but that process has been put on hold.

There are also some programmatic issues for IIOE-2 that will need to be addressed in the near future. While the structure of IIOE_2 was simplified in 2019, each of the components remains crucial for the successful delivery of IIOE-2. The component that needs nurturing is the Data and Information Management Working Group. A new leader is being sought and once that person is in place, the community should have more faith in using the IIOE-2 database. As IIOE-2 data will remain as an enduring legacy of the program, that currently remains an important challenge for the near future.