Perspectives on future Indian Ocean research from early career scientists*

The first International Indian Ocean Expedition (IIOE; conducted in the early 1960s) was one of the greatest international, interdisciplinary oceanographic research efforts. It involved 46 research vessels (under 14 different flags) that carried out an unprecedented number of hydrographic surveys (and repeat surveys) of the entire Indian Ocean (IO) basin from 1960 to 1965. One key to the successful qualitative and quantitative assessment of plankton organisms across the IO was the unification of zooplankton collections using the IO Standard Net. The IOS net has been used for more than 50 years until now. The Second International IO Expedition (IIOE2; proposed from 2015 to 2020) is motivated by the need to advance understanding of geologic, oceanic and atmospheric processes, and their interactions in the IO to determine how these dynamics affect climate, marine biogeochemical cycles, ecosystems and fisheries at regional and global scale[1].

The 2015 International IO Symposium held at the National Institute of Oceanography (NIO), Goa, India, marked the launch of the Second International Indian Ocean expedition (henceforth, IIOE2) that will be conducted between 2015 and 2020 (http://www.iioe-2.incois.gov.in/). It is an exciting time and opportunity for marine science throughout the IO, especially for early career scientists. The next decade will be a time to push the frontiers of scientific discoveries through multidisciplinary and collaborative approaches. With the goal to give further impetus to marine science in the IO, the Early Career Scientist Workshop was conducted during the symposium. Over 50 early career scientists and academic mentors came together and identified key research topics and knowledge gaps that will be subjected to research during IIOE2 in general and the IIOE2 Early Career Scientist Network in particular.

This Network seeks to develop capacity building amongst the IO rim countries and provide a platform to facilitate interdisciplinary collaborations internationally and within the IO rim. Coordinating working groups within the Early Career Scientist network have been set up, which addressed the six scientific themes of the IIOE2 Science Plan: (1) Human impacts, (2) Boundary current dynamics, upwelling variability and ecosystem impacts, (3) Monsoon variability and ecosystem response, (4) Circulation, climate variability and change, (5) Extreme events and their impacts on ecosystems, and (6) Unique geological, physical, biogeochemical and ecological features of the IO.

Here, we summarize our conclusions and highlight the recommendations for future marine research in the IO of over 46 scientists. The overall aim is to facilitate active participation and integration of early career scientists into the global research efforts that are currently underway and that will be conducted in the IO and its adjacent seas. The main goal of this report is therefore to inform the wider scientific community about our intent. Here we briefly discuss a distilled number of oceanographic research topics related to natural and anthropogenic change in the IO. Along with recommendations for future research, the goal of this report is to increase awareness regarding the upcoming IIOE-2 expeditions and the potential to increase interdisciplinary research collaborations.

We note that while substantial advancement in scientific understanding has been achieved since the first IIOE, we still lack integrated studies linking many scientific processes. For example, eutrophication causes hypoxia which, in turn, affects living resources and biodiversity, thus having a profound socio-economic impact. A holistic assessment of these inter-linked issues needs to be carried out. Below we provide a list of recommendations which could be used as a guideline to accelerate our current and future understanding of the IO.

Recommendations for IIOE2

The Early Career Scientist Network comprises three major subgroups based on the research discipline – anthropogenic stressors, biology/biogeochemistry, and physical oceanography. Each group has provided discipline-specific recommendations and imperative questions for IIOE2.

Anthropogenic stressors

Increase our knowledge on the long-term effects of various pollutants, their environmental fate and set up stringent policies for their proper disposal. Including increased efforts to evaluate their toxicity and ecological risks in marine environments.

- Establish common laboratory procedures for sediment toxicology analysis.
- Quantify the relative contribution of anthropogenic and natural sources of selected constituents.
- A special effort to estimate the extent of marine plastic pollution in the IO; study its impact on the ecosystem, upper ocean heat content, and set up regional monitoring system for the same.
- Quantify the fractional solubility of aerosol iron and assess the environmental factors affecting its solubility.
- Assess the spatial and temporal variability and abundances of ionic species and the isotopic ratios of atmospheric particles.

Biology/biogeochemistry

Develop a world-class time-series station (like the Bermuda Atlantic Time-series Study (BATS) site in the North Atlantic) in the IO.

- Develop base-level datasets on phytoplankton distribution in the northern IO (possibly by combining traditional microscopic methods with molecular taxonomic tools) to increase our understanding of the recent changes in the phytoplankton communities.
- What are the rates of primary production and biological nitrogen fixation,

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including by the cyanobacterium *Trichodesmium* spp. and how are physical–oceanographic controls responsible for configuring plankton food webs?

- Measure the trends of jellyfish and gelatinous plankton swarming episodes. What are the environmental factors triggering their occurrence?
- Develop a database that contains a broad range of information on the benthic species (distribution, functional traits, molecular) that could help address basic research questions.
- To understand the role of benthic bioturbation on the microbial diversity and the corresponding link to oxygen dynamics, nutrient and carbon cycling in sediments.
- Biogeochemistry of (an)oxic sediments in the IO.
- Advanced biogeochemical analytical technologies are under-sourced in Sri Lanka. Increase access and training through collaborative research efforts.
- Increase our knowledge and usage of remote sensing with regard to the management of coastal and marine resources.
- Increase interactive ocean–atmosphere studies to unravel how oceanic and atmospheric processes influence biogeochemistry of the IO.
- How do the thickness and intensified oxygen minimum zone influence the pelagic and benthic biology in the Bay of Bengal?
- Quantify the contribution of the Gulf of Oman to the Arabian Sea oxygen minimum zone through export of organic matter, reduced nitrogen and sulphide compounds, and anoxic water.
- Are oxygen minimum zones (OMZs) connected or isolated to their adjacent habitats via gene flow? Investigate whether fauna present in the OMZs are evolutionarily and functionally distinct or similar to each other. Are OMZ regions of high endemism?
- Develop a coupled biological–physical end-to-end model for the IO and its adjacent seas.
- Quantify keystone species and biogeography patterns (including species range) from various eco-regions across the IO.
- Responses of biological carbon pump to climate change in the IO.

Physical oceanography

- Data availability and accessibility

As mentioned in the earlier sections, the lack of *in situ* data is a limiting factor for many physical oceanographers in developing their models. This paucity in data has been due to sparse field observations or poor coordination among international research groups in making the data available and accessible. We believe that the issue at hand is that there may be an overlap at some research sites but no coordinated agreement among the IO research groups to share the data freely. As a solution, we recommend the development of a shared data portal to archive all *in situ* data for the IO and provide open access for all IIOE2 researchers. This data portal will allow contributors to upload and update their data and quality control of data will be needed prior to data releases. E-mail alerts can also be set up for each relevant discipline whenever new data are uploaded to the portal.

- Multidisciplinary collaborations

As physical oceanographers, we are aware that the physical processes that we attempt to model and observe in our research are only one aspect in understanding the overall IO system. We believe that having more regular interactions among oceanographers, numerical modellers, biologist and ecologists, all parties will benefit in developing more comprehensive and realistic models for the ocean. We are also in favour of implementing a workflow plan to promote multidisciplinary collaborations and that this workflow should have a component using social media and e-mail notifications to update researchers conducting projects at similar sites.

1. Hood, R. *et al.* (eds), The Second International Indian Ocean Expedition (IIOE-2): A basin wide research program – Draft Science Plan, 2015; available from the Scientific Committee for Ocean Research at: http://scor-int.org/IIOE-2/IIOE2_Draft_Science_Plan.pdf

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