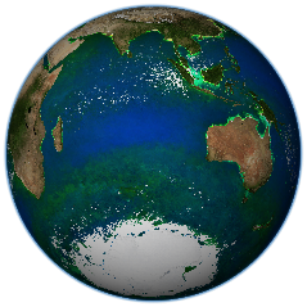

SIBER

Sustained Indian Ocean Biogeochemistry and Ecosystem Research

Report of the 1st Meeting of the SIBER Scientific Steering Committee

12-15 July 2010

Perth Australia

Integrated Marine Biogeochemistry and Ecosystem Research

IMBER Report # 4

IOGOOS:PR:07:SIBER/02

SIBER Report # 2

The SIBER program reflects the importance placed on these issues by the International Geosphere-Biosphere Program (IGBP), the Scientific Committee on Oceanic Research (SCOR) and the Global Earth Observing System of Systems (GEOSS). SIBER has been developed with the approval of the Integrated Marine Biogeochemistry and Ecosystem Research Program (IMBER) and the Indian Ocean Global Ocean Observing System (IOGOOS), providing strong relevancies to the High Level Objectives of UNESCO's Intergovernmental Oceanographic Commission, which span across the generic themes of marine hazards, climate change, ecosystem protection and associated marine natural resource management.

Bibliographic Citation:

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Introduction

The inaugural meeting of the SIBER Scientific Steering Committee was held on 12-15 July 2010 at the Citigate Perth Hotel in Perth, Western Australia. In attendance for the first morning's opening proceedings was the combined membership of the IOGOOS, CLIVAR-IOP and the Indian Ocean Resources Forum (IRF) panels, along with the SIBER SSC. For the opening morning, Dr. Nick D'Adamo (Officer in Charge, UNESCO IOC Perth Office) provided the introduction to the proceedings and acted as Master of Ceremonies.

Dr. Noel Nannup gave the traditional Welcome to Country, with an accompanying didgeridoo performance by Derek Nannup. The Governor of Western Australia, His Excellency Dr. Ken Michael AC, then officially opened the meeting. Welcomes and Keynote Addresses were then given by Julie de Jong (State of Western Australia), Dr. Shailesh Nayak (Secretary, Ministry of Earth Sciences (MoES), India), Dr. Wendy Wright-Watson (Executive Secretary IOC, Asst. Director General UNESCO), and Dr. Neville Smith (Deputy Director, Australian Bureau of Meteorology). These were followed by plenary presentations given by Tim Moltmann (Australia's IMOS), Drs. Yukio Masumoto and Weidong Yu (CLIVAR-IOP), Dr. Raleigh Hood (SIBER) and Dr. Gary Meyers (IRF) that informed all delegates of progress and synergies being developed within and between their programs.

The panels then moved into their individual meetings for the afternoon and the following two days. Of the SIBER SSC membership, Mike Landry, David Vousden and Lynnath Beckley were unable to attend and both communicated their regrets. Richard Matear (CSIRO) was again able to participate as a SIBER delegate, this time as an alternate for Dr. Beckley.

Keynote Speaker (Dr. Shailesh Nayak, Secretary of MoES)

Between his remarks during the opening session of the joint meeting and his keynote address to the SIBER SSC, Dr. Nayak articulated a number of issues regarding research needs for the Indian Ocean, and identified several potential synergies, that are relevant to the interests of SIBER and which are worth exploring as our efforts evolve. These include his recommendation that SIBER develop ties to the Indian Ocean component of the GeoTraces program that India is helping to fund, and that we look to make recommendations to ChloroGIN (http://www.chlorogin.org/) regarding ocean color products that would be of especial interest. In support of the Indian OCM platforms, which should be providing ocean color data to the broader research community by October 2010, Dr. Nayak requested that SIBER consider incorporating spectral optical packages in their moored instrument deployment efforts. In situ optical measurements from these radiometers would address the continual need for calibration and validation data that are a critical component for ensuring that high-quality ocean color data streams are maintained.

Dr. Nayak also noted that the current internationally deployed fleet of remote sensing platforms that are extensively used to study and monitor the world's oceans is aging and that it is uncertain whether the present infrastructure will be replaced in timely fashion. If this is not accomplished, he warned that coverage gaps would begin to manifest. If such gaps were to develop, he stressed that while targeted research could persist the societal benefits afforded by ongoing, well-maintained global coverage of both physical and bio-optical data would be put at risk.

Finally, and perhaps most importantly, Dr. Nayak was supportive of SIBER's request for resources and support that would enable establishment of an International Program Office (IPO) that would be based in India. He requested that we develop a proposal that identified the envisioned needs and submit that to him for consideration. After some discussion among the SSC, it was determined that the most suitable location for a SIBER IPO would be Hyderabad since the IOGOOS IPO is already established there. Thus, mutual leveraging of resources at need (e.g., web site maintenance, logistical support for annual meetings) would be possible.

> **Action Item 1**. A SIBER IPO proposal will be drafted and distributed to the SSC for comments and input. Once finalized, this proposal will be submitted to MoES (Hood and Naqvi).

SIBER Business

With this being the inaugural meeting of the SIBER Scientific Steering Committee (SSC), formalization of the officers of the SIBER SSC was the initial task to be addressed. The acting Chair (Raleigh Hood) and co-Chair (Wajih Naqvi) of the SIBER Interim Steering Committee were nominated and elected to continue in their respective roles on the SIBER SSC. Election of a SIBER Secretary was also put to the SSC. Jerry Wiggert was chosen for this post.

Following the election of SIBER officers, the rotation of SSC membership was established. It was decided that the nominal term would be set as three years in duration. Therefore the first rotation of SSC members is due to occur in 2013. It was further decided that renewal of membership on the SSC would be considered for members deemed to be critical for promoting the ongoing development, expansion and realization of SIBER's agenda and goals as an international program.

The last major agenda item for SIBER business coming into this inaugural meeting was discussion of the additions to the SSC membership that were recommended by the IMBER and IOGOOS steering committees. Four of the five suggested members were in attendance at the combined meeting in Perth and have already accepted our invitation to join the SIBER SSC and are given below.

New SIBER SSC Members

S. Adam	MRC, Republic of Maldives	msadam@mrc.gov.mv
M. Bhikajee	MOI, Mauritius	bhikajee@moi.intnet.mu
S. Khokiattiwong	Thailand	skhokiattiwong@gmail.com
M. Ravichandran	INCOIS, India	ravi@incois.gov.in

SIBER – India

The first national SIBER program has been established in India, which will target six sites for focused time series and process study experiments (Fig. 1). Organization of the SIBER-India Project was the outcome of a workshop held 13-14 April 2009 in Goa, India. Based on the workshop discussions, a comprehensive consolidated 5-year proposal (2010-2015) was submitted to India's Ministry of Earth Science (MoES).

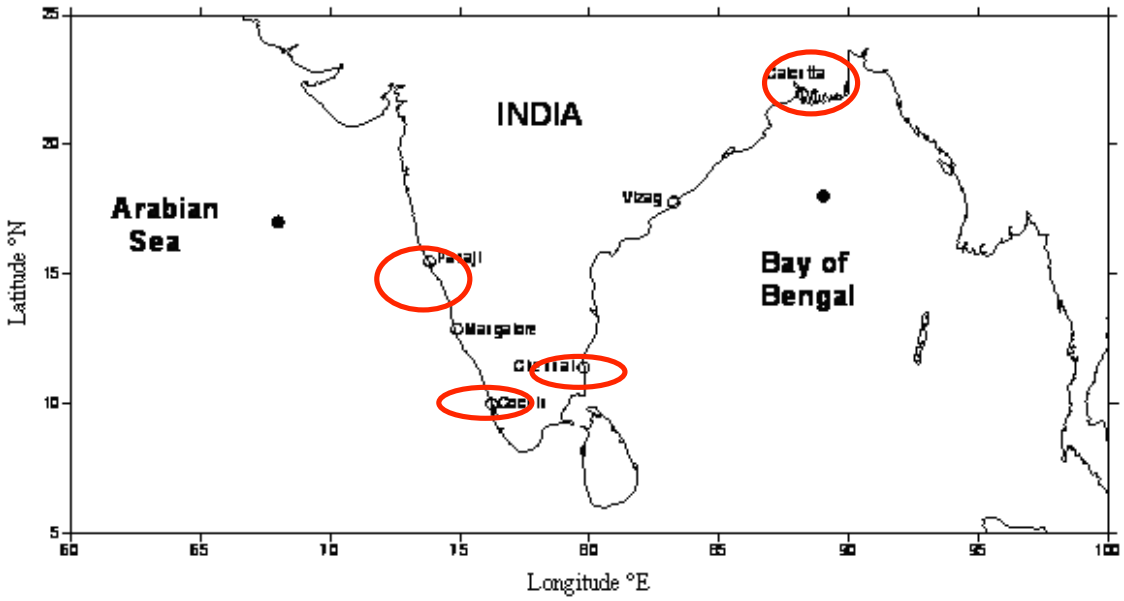

Figure 1. Location of time series sites that will be sampled as part of the Indian National SIBER Programme that will be funded by MoES-India.

The proposed investigations were partitioned between an Open Ocean cluster (6 projects, Table 1) and an Estuaries & Coasts cluster (8 projects, Table 2). Overarching goal of these project clusters is to develop infrastructure through establishment of long-term time series stations at the two open ocean sites (Arabian Sea and Bay of Bengal) and comprehensive/focused time series and process studies at the four coastal/estuarine locations (Goa, Kochi, Sunderbans and Vellar Estuary) (Fig. 1). Naqvi reported to the SIBER SSC that it is expected that these proposals will be approved and that funding should be in hand by fall 2010. Any costs for ship time will be borne by MoES and will not affect the budget of these projects.

Dr. S.W.A. Naqvi, National Institute of Oceanography, Goa.	Long-term monitoring of oceanographic, biogeochemical and ecological processes in the North Indian Ocean through establishment of open-ocean time series stations in the Arabian Sea and Bay of Bengal.
Dr. N. Ramaiah, National Institute of Oceanography, Goa.	Elucidation of long-term changes in microbial communities in intensely denitrifying and oligotrophic environs through metagenomic analyses.
Dr. Sujitha Thomas, Central Marine Fisheries Research Institute, Mangalore.	Flow of matter through trophic levels and biogeochemical cycles in marine and estuarine ecosystems.
Dr. R. Rengarajan, Physical Research Laboratory, Ahmedabad.	Particulate organic carbon export flux from upper Arabian Sea and Bay of Bengal using ^{234}Th as a tracer.
Prof. R. Ramesh, Physical Research Laboratory, Ahmedabad.	The role of anaerobic ammonium oxidation (anammox) in nitrogen-loss from the Arabian Sea.
Dr. M.K. Sharada, C-MMACS, Bangalore.	Modelling of marine biogeochemical cycles in the Indian Ocean.

Table 1. Open ocean SIBER-India projects funded through MoES.

Dr. SWA Naqvi, National Institute of Oceanography Dona Paula-Goa	Dynamics of selected biogenic elements in Indian estuaries – A case study of the Mandovi – Zuari estuarine system.
Prof. C Annapurna, Andhra University, Visakhapatnam.	Assessing macro and meiobenthic diversity off Goa Coast with special emphasis on OMZ
Dr. Vishnu Murty Matta, Goa University	Atmospheric deposition and its influence on nutrients in coastal waters of Goa- West coast of India
Dr. B.R. Manjunatha, Mangalore University	Assessing the Anthropogenic Impact on South-West Coast of India
Dr. A.A. Mohamed Hatha, School of Marine Sciences, Cochin University of Science and Technology, Cochin	Role of Heterotrophic Bacteria and Cyanobacteria in the Nitrogen Cycle in the Cochin estuary and coastal waters with Special Reference to Nitrification, Denitrification and Nitrogen Fixing capabilities
Dr. V.N. Sanjeevan, Centre for Marine Living Resources and Ecology, Kochi	Time-Series studies on the Biogeochemical aspects in the estuarine and coastal waters of Kochi, southwest coast of India
Dr. T. Balasubramanian, Annamalai University, Parangipettai, Tamilnadu	Hydro – Biological studies of Vellar – Coleroon estuarine system
Dr. S. K. Mukhopadhyay, University of Calcutta	Biogeochemical dynamics of the Hooghly-Matla estuarine systems along the northeast coast of the Bay of Bengal, India.

Table 2. Coastal and estuarine SIBER-India projects funded through MoES.

Link to Organizations Focusing on Ocean Carbon Studies

The emphasis of SIBER on both biogeochemical and ecological aspects of the Indian Ocean necessitates that it has a broad scope of research avenues for

which it is necessary to establish and maintain progress. As a means of maximizing the influence of SIBER in critical aspects of marine studies in the Indian Ocean, the SSC has recommended that an effective strategy would be to link in to organizations that have already been established. In particular, the oceans' role in the global carbon cycle has prompted development of key organizations that are well-equipped to address and guide development of the critical scientific and societal needs.

> **Action Item 2**. Determine how to best leverage the linkage that already exists between IMBER and SOLAS (Goyet and Rixen).

Biogeochemical Sensor Deployment on RAMA Moorings

The RAMA moored array is in the process of being deployed at stations that encompass the entire Indian Ocean (Fig. 2).

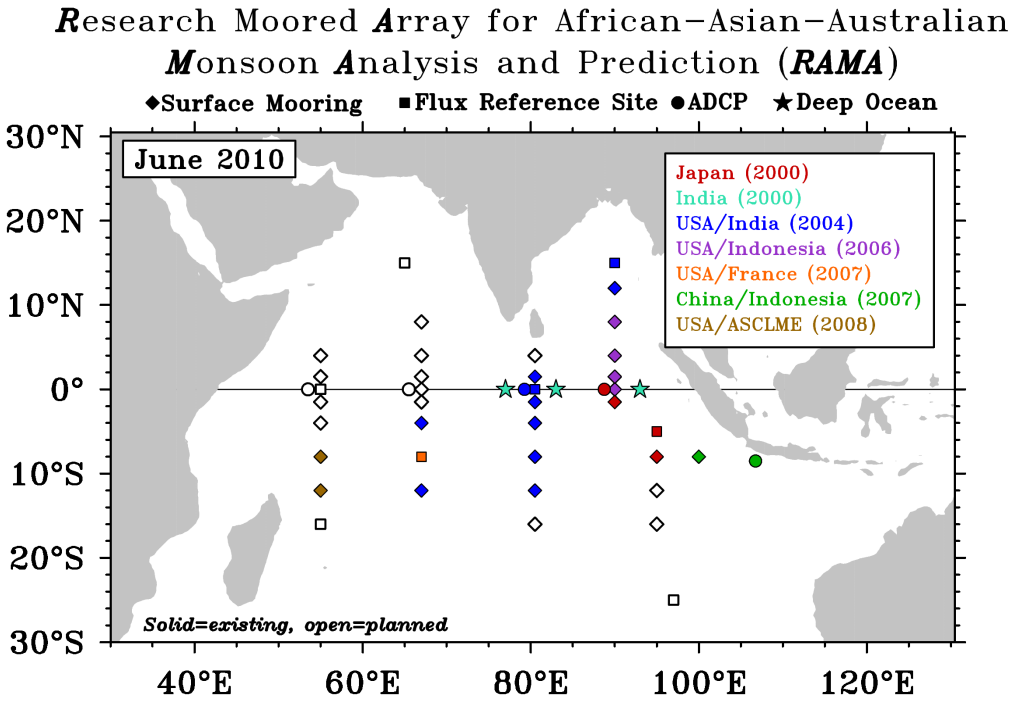

Figure 2. Research moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA). Note that the filled symbols represent assets deployed as of June 2010.

A research goal that materialized during the formative stages of SIBER's development was the possibility of outfitting these moorings with bio-optical or chemical sensors that could be used to obtain time series of ocean properties such as pCO_2, pH, dissolved oxygen, fluorescence, backscatter and air-sea exchange of CO_2. Discussions aimed at developing a deployment strategy have

been ongoing between members of SIBER and IOP. Eight of these moorings are outfitted with comprehensive meteorological sensor packages (identified as Flux Reference Sites in Figure 1). With the added knowledge of air-sea interaction that these flux sites will obtain, they are considered as the ideal platforms for installing biogeochemical sensors.

Due to the constraints imposed by funding, it was necessary to identify the unique scientific interests, deployment hazard, and logistical constraints that would be realized at each location. These factors were then weighed in the process of prioritizing the order in which these sites would be outfitted with biogeochemical sensor packages.

> **Action Item 3**. Members of SIBER and the IOP will determine which site(s) to outfit with biogeochemical sensors. Identifying funding sources to support this activity is a priority (Hood and Meyers).

SIBER Website

A critical mechanism for publicizing the outcomes of the SIBER program is establishment of a website that is actively maintained with the latest information regarding progress and upcoming events. It can also serve as a repository for scientific and programmatic presentations that will be continually updated and accessible to the members of the SIBER SSC, so that as they pursue funding opportunities they are certain to have current information to provide to their agency representatives. These will also serve as a means to promote SIBER to the broader marine community.

Initial hosting of the SIBER website will be through the IMBER IPO in Brest. Once an IPO is established (nominally in Hyderabad, see above), hosting of the SIBER website and responsibility for all of its maintenance needs will be transferred accordingly.

> **Action Item 4**. Establish and maintain initial SIBER website to be hosted by IMBER IPO. Transition website to SIBER IPO once it is established. Implement mechanisms for insuring that content is continually updated (Wiggert/Hood/Beckley/Pradeep Navekar).

Working Groups: Identification and Pursuit of Funding Opportunities

All members of the SIBER SSC were tasked with exploring possible funding avenues in their national or regional locales. These could entail leveraging the SIBER program as a visible venue for enhancing individual projects through the international collaborations it can facilitate. More importantly, development of coordinated proposal clusters with high national and international visibility, as exemplified by the establishment of the SIBER – India activity, is a promising

mechanism that would significantly enhance SIBER's establishment and future prospects. SIBER SSC members have been identified to lead each of these national or multi-national (regional) teams (see below).

An additional charge of these groups is to secure funding that can be used to supplement the travel costs that will required to hold future annual meetings of the SIBER SSC, since the allocations provided by the IMBER steering committee and the IOC-Perth Office are unlikely to be sufficient. It is also suggested that the co-chairs of each regional committee consider recruiting as needed from outside the SIBER SSC to accomplish these goals.

Nation/Region	Co-chairs	Specific Tasks (if identified)
European Union	Cowie/Rixen/Goyet	Recruit other EU members
United States	Landry/Wiggert	Indo – US Science & Technology Forum
Australia	Beckley/Matear	Recruit Waite and Strutton
Western IO	Vousden/Adam/ Bhikajee	Recruit Scott
Northern AS	Al-Azri	Recruit Al-Yamani, Kidwai and Khan
Eastern IO	Susanto/Khokiattiwong	Recruit Zainal Arifin
Japan	Kitazato	Expand group leadership
China	Chai/Zhang	Hood will coordinate recruitment

Working Groups: Evolution of SIBER Plan's Scientific Themes

After some deliberation, the SSC decided to define working groups that would be charged with maintaining and refreshing the scientific themes that are the cornerstone of SIBER's research directives. Through this activity, research pathways that are revealed as the SIBER program evolves and matures would be highlighted and promoted to the broader oceanographic community. These working groups (see below) would be headed by the lead editors of each of the scientific themes that appear in the SIBER Science Plan and Implementation Strategy. Each of the working group leads is recommended to recruit any assistance needed to facilitate maintenance of the relevance and timeliness of her/his theme.

Theme #	Lead Editor	Theme Topic
1	Beckley	Boundary Current Interactions and Impacts
2	Wiggert	Ecological and Biogeochemical Variability resulting from dynamics of the EQIO, STIO and ITF
3	Rixen	Contrasts between the AS and BoB
4	Cowie	Pelagic and Benthic Production in the IO
5	Goyet	Climate and Anthropogenic Impacts on the IO
6	Landry	Role of Higher Trophic Levels

Capacity Building in Indian Ocean Rim Nations

SIBER has a strong potential for making a significant societal contribution in the area of capacity building in the less developed Indian Ocean rim nations. Preliminary discussions on this topic occurred during SIBER-1. One mechanism forwarded within offline conversations of two SSC members (Cowie/Wiggert) was to target countries with less developed ocean research capacity as sites of future SIBER SSC meetings. In doing so, cross-fertilization between the SIBER membership and local/regional scientists would be facilitated and local development of research capacity could be promoted.

> **Action Item 5**. Identify members for a working group to be tasked with determining methods and likely approaches for promoting regional capacity building.

Summary of IRF Discussions and expected SIBER – IRF synergies

The Indian Ocean Resources Forum convened its meeting on July 15th, following introductory presentations and plenary reports from IOGOOS, IOP and SIBER. During the IRF meeting Shailesh Nayak accepted the role of first IRF chairman. His accepting the chair, along with the actions that the IRF is undertaking (see below) and the decision to meet annually indicate that the IRF made a good start. Several participants noted that they are now better informed about the needs of Indian Ocean observing. The meeting ended with a general feeling that all delegates to the IRF will work together to find the ship time and other resources that IndOOS/RAMA and SIBER needs.

The short-term actions emerging from the discussions are:

1. Compile information on how time is allocated for research vessels that operate in the Indian Ocean region, starting with the seven vessels that are already scheduled for 2010/11, and circulate to members. Explore where multiyear allocation processes already exist or might be developed. (Gary Meyers by October).

2. Track all planned research cruises in the Indian Ocean (Howard Cattle by August).

3. Compile a list of sources for biogeochemical research funding (SIBER SSC by September)

4. Develop a strawman plan for using gliders in IndOOS, in particular in the gaps in the eastern and western Indian Ocean (IOP by next meeting)

5. Set date and venue of next IRF meeting in series with next IOP meeting (IOP and SIBER Co-chairmen with convenor by October)

6. Gather information on the new business arrangements between GEF and IOC and consider the potential for supporting the new IOGOOS-SEAGOOS-Westpac project on "Modelling for Ocean Forecasting & Process Studies" (Nick D'Adamo and Wendy Watson-Wright, by October)

Synopses of Presentations on National Perspectives and Research Topics of Interest Given during SIBER-1

Oxygen deficiency in the North Indian Ocean (W. Naqvi)

The Northern Indian Ocean is anomalous in that the most intense oxygen minimum here occurs in the northern basins rather than along the eastern boundary as happens in the Atlantic and Pacific Oceans. Moreover, there exists only a subtle difference between minimum oxygen concentrations in the Arabian Sea and the Bay of Bengal. However, the two regions are very different in terms of redox cycling: reducing (denitrifying, Mn, I-reducing) conditions only develop in the Arabian Sea water column. In the Arabian Sea, there are two suboxic zones: the perennial mesopelagic system and the shallower system that develops seasonally (during the summer monsoon) over the western continental shelf of India (Fig. 3).

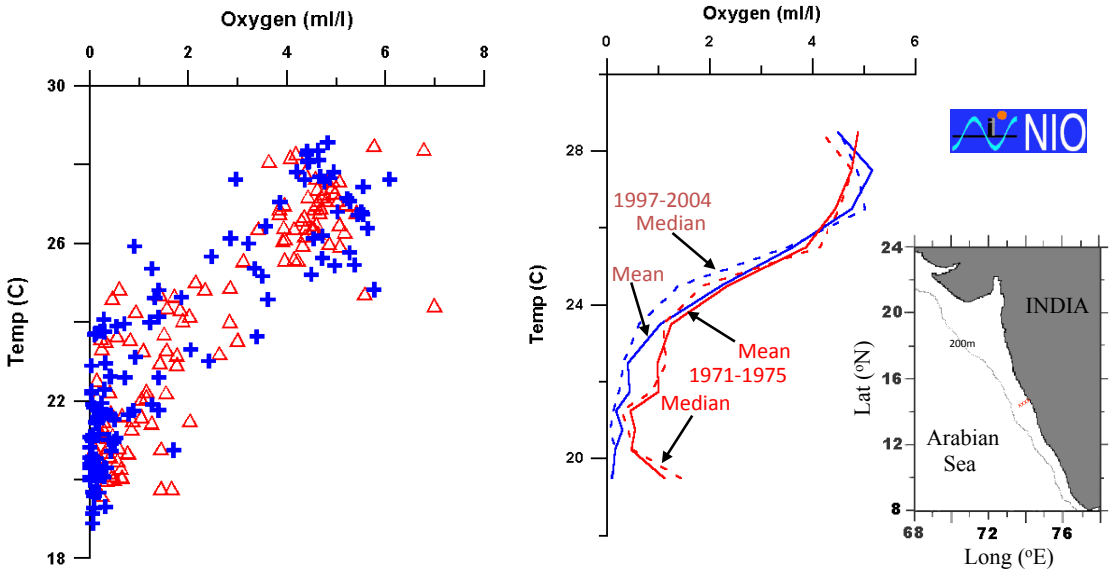

Figure 3. Evidence for intensification of oxygen deficiency apparent in temperature vs. O_2 plots for data sets collected during UNDP/FAO-sponsored Integrated Fisheries Project (1971-1975) and NIO's cruises (1997-2004).

The two are not contiguous. The main characteristics of the two systems were described. These include excess N_2, N_2O cycling, natural isotope abundance and the formation of turbid layers in suboxic zones. The seasonal evolution of the world's largest natural coastal hypoxic zone over the Indian shelf was described in detail using data along fixed transects and at a time series station. The most striking feature of this system is an intense production of N_2O, apparently through denitrification. Unlike its open-ocean counterpart, the seasonal suboxic zone appears to have intensified in recent years in that sulphidic conditions have been

recurring over the inner shelf since 1998. Such anoxic conditions appear to profoundly influence demersal fisheries.

Indonesia and Potential linkages to SIBER (D. Susanto)

There is a direct linkage between Indonesia and SIBER interests, geographically and dynamically. The Indonesian Throughflow (ITF) is the seepage of western Pacific water into the Indian Ocean through the Indonesian Seas, with an annual average net volume transport estimated to be 15 Sv, that has long been recognized as a key component in the global climate system. Understanding the magnitude and variability of this exchange, as well as further developing the ability to estimate it are therefore essential for global ocean circulation and climate in addition to a critical need for characterizing the ITF's role in Indian Ocean biogeochemical processes.

The transfer of mass and heat flux between the Pacific and Indian Oceans is complex. As they pass to the Indian Ocean through the convoluted passages of the Indonesian Seas (Fig. 4), Pacific waters are converted to a distinctly fresh Indonesian Sea profile that is observed streaking across the Indian Ocean within the zonal jet of South Equatorial Current. Within the Indonesian Seas, the rigorous mixing that accompanies strong air-sea interactions, wind driven upwelling, and tidal mixing modify Pacific-sourced waters. Remote forcing associated with ENSO and the Indian Ocean Dipole also contributes to the transformation of the Pacific waters characteristics.

Prior to 2003, ITF measurements were largely uncoordinated, with observations being conducted in different straits at different times. A multinational (Indonesia, USA, Australia, France and the Netherlands) program called INSTANT (International Nusantara Stratification and Transport Program) conducted simultaneous measurement of the ITF in major inflow and outflow passages in 2003-2006 (Fig. 4). Through this effort a previously neglected pathway, an ITF branch via South China-Java, was determined to play an important role in reshaping the upper layer of the main ITF.

Given the dynamical considerations noted above, it is expected that the ITF impacts nutrient exchanges between the Pacific and Indian Oceans. However, even though the ITF has been actively sampled over the last two decades, there has been no integrated measurement of physical-biogeochemical properties in the Indonesian Seas. Consequently, there has been no quantification of the expected biogeochemical fluxes associated with the ITF. Since there are ongoing measurements of ITF in the Makassar, Karimata and Sunda Straits, it would be ideal if we can integrate with biogeochemical observation.

In term of facilities, the Indonesian government has seven research vessels that can be used to support ocean observation within Indonesian Seas and Indian Ocean. In addition, Indonesia is developing a Marine Research Center at

Bungus-Padang, West Sumatra that could potentially be leveraged to serve as a marine station for Indian Ocean observations that would further SIBER interests in the region.

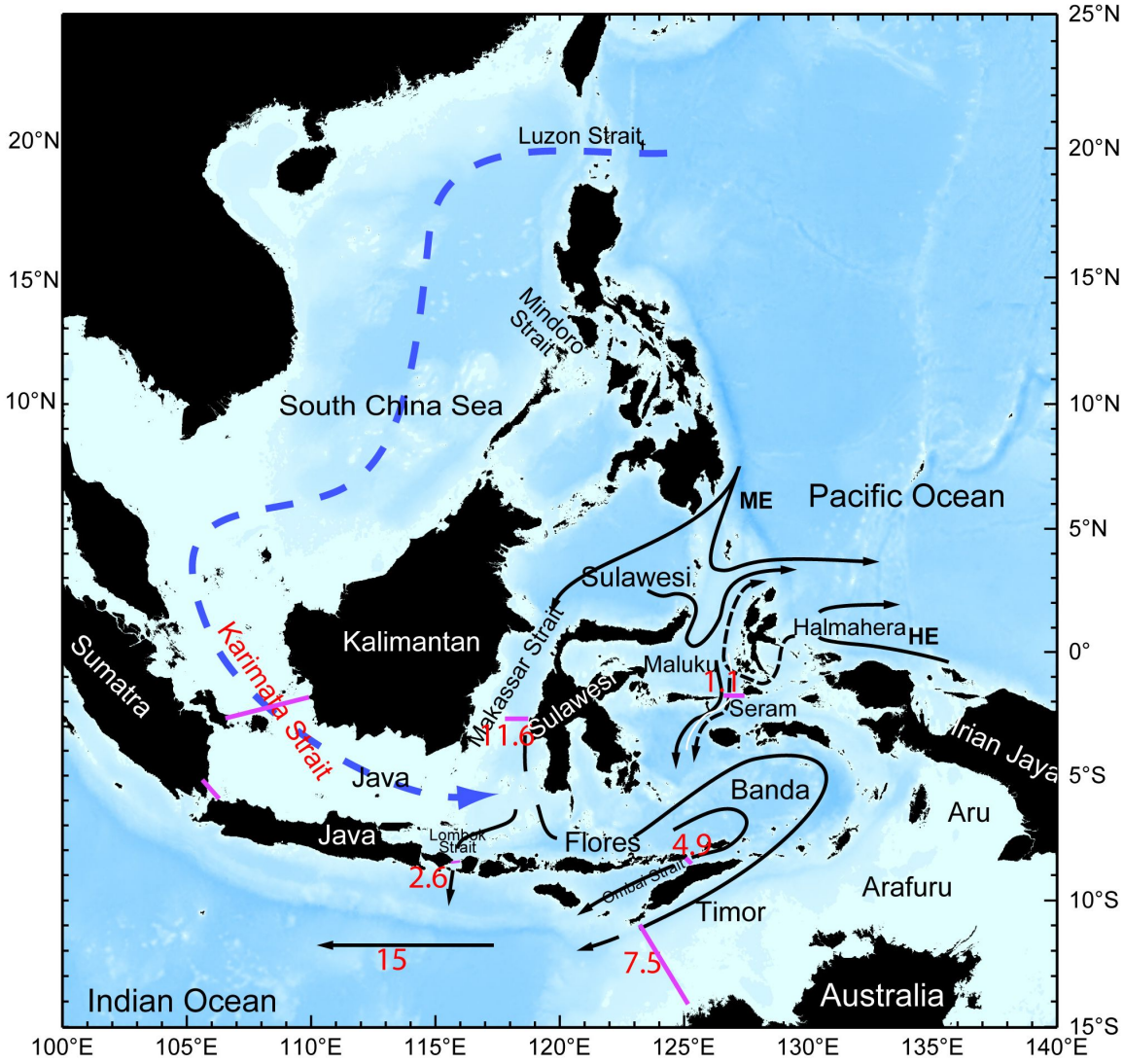

Figure 4. Pathways of the Indonesian Throughflow (ITF). Magenta lines represent INSTANT (International Nusantara Stratification and Transport) and SITE (South China Sea-Indonesian Seas Transport/Exchange) programs' mooring locations. The INSTANT Program (2003-2007) was designed to measure the ITF at 11 mooring sites, with the intention of better quantifying ITF magnitude and revealing time lags between inflow and outflow. Three moorings deployed in the Makassar Strait (2) and the Lifamatola passage (1) measured ITF inflow. Eight moorings deployed in Lombok Strait (2), Ombai Strait (2) and the Timor passage (4) measured ITF outflow. Numerical values represent estimates of ITF mean annual volume transport (in Sv; 1 Sv=10^6 m^3/s) in these Straits during the INSTANT program. The currently on-going SITE program consists of 6 moorings deployed in the Karimata and Sunda Straits.

Oman and Potential linkages to SIBER (A. Al-Azri)

There is a direct linkage between Oman and SIBER. The extensive coastline of the Sultanate of Oman provides abundant food and energy resources and opportunities for tourism and recreation. Unfortunately, the continuous pressure of development threatens this marine environment primarily via over-fishing, global climate change, habitat modification and destruction and land based sources of marine and coastal zone pollution. Furthermore the western Arabian Sea is known for its vigorous field of eddies attributed to the reversal of the monsoon winds.

The densely packed eddy field in this region derives from the seasonal changes of winds that also drive intensive coastal upwelling (Fig. 5). Thus this dynamic oceanographic environment provides opportunities for carrying out studies on these eddies and currents and their impact on the biogeochemical processes in the northern Indian Ocean. Fundamental questions exist regarding how mesoscale physical-biological interactions along the coast of Oman modulate the distribution and intensity of the regional oxygen minimum zone (OMZ), and how this in turn impacts the appearance and intensity of harmful algal blooms (HABs) or the fish kills that have occurred in the Sea of Oman in recent years. The biogeochemical processes associated with these phenomena are complex and intertwined, since the quality of forage for the regional fish populations is linked to the underlying food web that is affected by the nature of the OMZ and its potential for promoting HAB appearance.

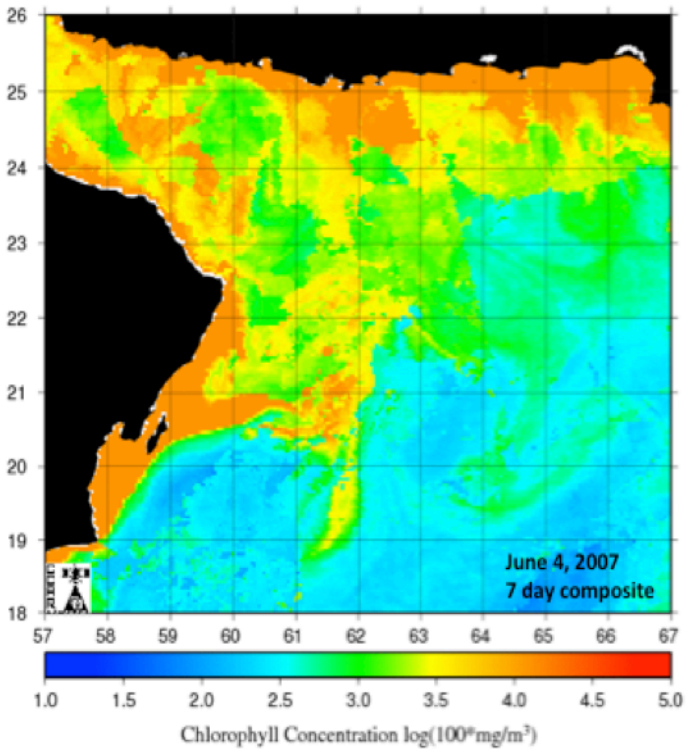

Figure 5. Sea surface chlorophyll distribution associated with the SWM eddy field in the Northern Arabian Sea.

Oman provides great opportunities for carrying out biogeochemical research relevant to SIBER interests. The country has shown more dedication towards ocean and atmospheric research since the impacts of Tsunami and the tropical cyclone Gonu in June 2007 (Fig. 6). A combination of deployment of cabled observatories in Omani waters and the possibility that the country will acquire and outfit a new research vessel, along with the frequent ships of opportunity, all provide good facilities to support and promote SIBER-related research.

German research in the Indian Ocean: in the past and future perspectives (T. Rixen)

Sediment trap experiments were carried out in the framework of bilateral programs and JOGOS between 1986 and 2003 in the Indian Ocean. The results showed the CO_2 uptake efficiency of the biological pump was enhanced in the freshwater influenced waters due to a reduced carbonate production and an enhanced supply of ballast material increasing the export of organic carbon into the deep ocean. The monsoon-driven seasonality was most pronounced in the upwelling systems off Oman in the Arabian Sea and off South-Java.

Due to the large uncertainties regarding to the projected climate change for Asia (IPCC, 2007) the Federal Ministry for Research and Education in Germany (BMBF) was initiating a new research program aiming at a better understanding of monsoon dynamics. Within this initiative, and as contribution to SIBER, it is planned to employ high-resolution marine climate archives in combination with climate modeling in order to study the monsoon dynamics in the Arabian Sea, its feedbacks to the carbon cycle and anthropogenic impacts on this system. Associated cruises with German research vessel are so far suspended to piracy.

French contributions to the study of the Indian Ocean Carbon cycle (C. Goyet)

Over the past 30 years in the southwestern IO, French scientists have maintained long-term time-series programs, mostly within the area between the French islands La Réunion, Crozet, Kerguelen, and La nouvelle Amsterdam (Figure 6). Results from the MINERVE (1991-1995) and OISO (1998-2007) studies in these regions indicate that the trend of pCO_2 increase in the atmosphere is 1.722 (+/- 0.004) ppm/yr from ship measurements and 1.701 (+/- 0.003) ppm/yr from Amsterdam station (located on Amsterdam Island at 37° S the central Indian Ocean). In seawater the positive trend is 2.6 (+/- 1.6) ppm/yr.

A study in the IO sector of the Southern Ocean was performed south of Australia to quantify interannual and decadal variations of CO_2 flux across the air-sea interface between Hobart (Tasmania) and Dumont D'Urville (Antarctica). Results of the analysis of the observations obtained during this ten-year campaign (1996-2006) indicate a weakening of the CO_2 flux within the sub-Antarctic zone. The findings from this study also demonstrate a strong strengthening of the CO_2 flux within the Antarctic zone during summer, and a strong weakening of the flux over both zones during spring, with the Antarctic zone becoming a weak source of CO_2 for the atmosphere.

Although sparse, these observations reveal that the southern IO is responding to increases in atmospheric CO_2 concentrations and likely also changes in ocean temperature, circulation and production in complex ways, which is altering CO_2

fluxes between the atmosphere and the ocean. These fluxes need to be quantified in order to determine the role of the southern IO in the global carbon cycle.

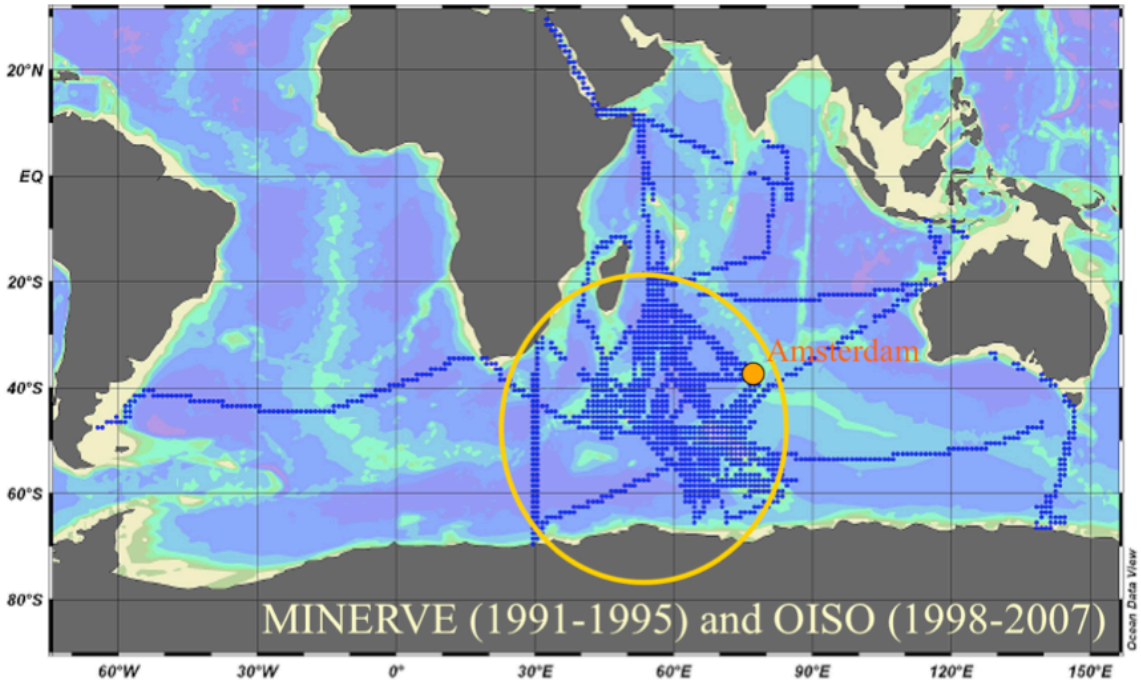

Figure 6. Cruise tracks for MINERVE and OISO programs conducted in the southwestern IO over the period 1991–2007.

In summary, French studies in the Indian Ocean are mainly located in the Southern hemisphere and provide long-term time-series. Most of these programs are ongoing and will contribute to the SIBER initiative to bring insights on the carbon cycle in the Southern Indian Ocean.

India's Mooring-time series, Argo floats and deployment of biogeochemical sensors (M. Ravichandran)

Through the Indian National Centre for Ocean Information Services (INCOIS), India has established, and is continuing to expand, an observational system that is highly relevant to SIBER objectives. New moored buoys, outfitted with surface and sub-surface parameters similar to configuration of the RAMA buoys, will be deployed within one year in the Indian Seas. As part of validation of Oceansat-2 (CALVAL), INCOIS has deployed an optical buoy attached to a moored meteorological buoy for over a year in the Arabian Sea. The Bay of Bengal Observatory and its instrumentation are ideally suited for developing long term measurements of upper ocean temperature, salinity and currents. These moorings will also be a good opportunity as a platform for deploying biogeochemical sensors in the North Indian Ocean.

INCOIS also handles maintenance of Argo floats in the Indian Ocean. There are currently more than 12 floats in the North Indian Ocean with dissolved oxygen sensors that have been operational for more than one year. Recently, two floats with CTD and dissolved oxygen sensors, and one float with CTD, dissolved oxygen and chlorophyll sensor have been deployed in Arabian Sea using FORV *Sagar Sampada*. These three floats were provided by University of Washington, USA. INCOIS has also established and provides logistical support for a number of other physical ocean observational platforms that have been established by India such as tide gauges, XBT lines, equatorial moorings, CODAR to measure surface currents and ADCP moorings along the Indian coast.

JAMSTEC, NOAA and FIO plans for deployment of CO2 and other biogeochemical sensors. (W. Yu, Y. Masumoto and K. Ando)

The motivation for inclusion of CO_2 and other biogeochemical sensors on the RAMA array moorings (Fig. 2) is a priority item that has been discussed above as action item 3 and has several critical scientific components. These are to provide data for: 1) defining biogeochemical variability in key regions of the Indian Ocean and for understanding the physical, biological and chemical processes that govern it; 2) developing models of ocean-atmosphere-biosphere interactions; and 3) assessing the impacts of climate change on oceanic primary productivity and air-sea CO_2 exchange. In addition to CO_2, key biogeochemical measurements of interest are pH, chlorophyll-fluorescence, particle backscatter and dissolved oxygen. Sites that are currently targeted as the initial group of high profile locations are RAMA mooring locations in the Arabian Sea, Bay of Bengal, Equatorial Indian Ocean and the Seychelles-Chagos Thermocline Ridge.

Development/advancement of this observational capability and its deployment as part of the RAMA array is a collaborative effort between NOAA-PMEL, JAMSTEC and FIO. To facilitate this cooperative effort, a joint SIBER/IOP workshop to assess and recommend how best to proceed with sensor evaluation, configuration and data processing will be held.

Use of newly developed ocean color algorithms to assess IOD impact on regional to basin scale biogeochemical fluxes (J. Wiggert)

Characterizing how the Indian Ocean Dipole (IOD) modifies typical basinwide dynamical variability has been vigorously pursued over the past decade. Along with this dynamic response, a clear biological impact is seen in satellite ocean color data. The signature feature illustrating IOD biological impact is a phytoplankton chlorophyll bloom that first appears in September along the eastern boundary of the Indian Ocean in tropical waters that are normally highly oligotrophic (Fig. 7).

A more complete investigation into IOD-related impacts in the ocean color record reveals that positive chlorophyll anomalies are also apparent in the southeastern Bay of Bengal, while negative anomalies are observed over much of the Arabian Sea. Further, the biological response to IOD has clear difference between separate manifestations of this inherent climate mode.

In situ measurements obtained by the Argo float network and the R/V *Suroit* as part of the Cirene cruise during the 2006/2007 IOD also reveal anomalous subsurface physical and biochemical distributions in the southern tropical Indian Ocean that are not captured in the SeaWiFS data. Despite the clear basinwide influence of IOD events on biological variability, the accompanying influence on biogeochemical cycling that must occur has received little attention.

The dynamical signatures (i.e., surface temperature and height) apparent in remote sensing fields for the two positive-phase IODs of the SeaWiFS-era help to illuminate how these events are similar or distinct, and how physical processes unfold as the ocean's seasonal response to IOD evolves. A corresponding comparison of IOD-engendered surface chlorophyll anomalies reveals how the dynamical fields provide the framework of mechanisms that underlie the biological response. The recently developed net primary production (NPP) rate models that capitalize on remotely sensed chlorophyll are one means of gaining an assessment of the basin's biogeochemical state during IOD.

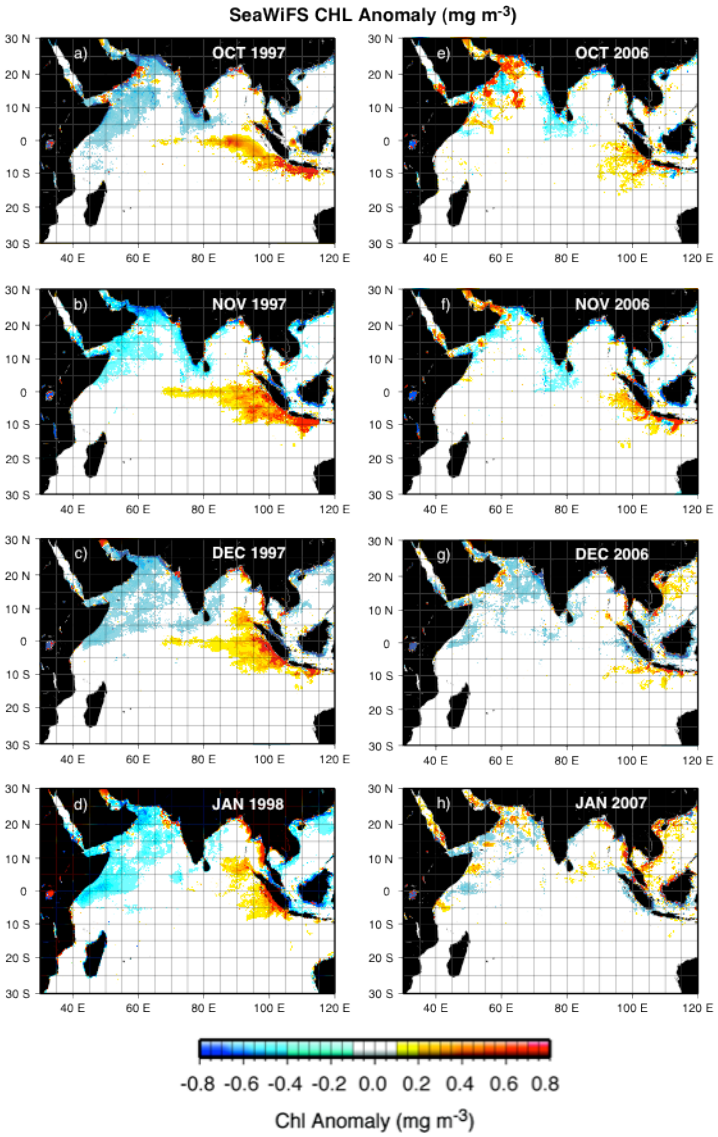

Figure 7. Distribution of chlorophyll anomaly during the 97/98 and 06/07 IOD.

Through combined application of in situ and remote sensing data sets, a picture is emerging that suggests a fundamental alteration of planetary wave

propagation and spatio-temporal evolution of the IO thermocline during IOD. These physical alterations lead to the pronounced modulation of the biological distributions. The NPP estimates indicate essentially a zero-sum impact; however, the redistribution of carbon uptake is profound, which suggests that more complete/consistent coverage of the basin with sediment trap moorings is needed to quantify this redistribution. Further, all regions of the Indian Ocean follow a consistent response between the two SeaWiFS period IODs except for the Arabian Sea which is negatively impacted during the 97/98 event and positively impacted in the 06/07 IOD.

Brief report from the Arabian Sea OMZ dive cruise (YK08-11) and the current research (cruise) plan for the Indian Ocean by JAMSTEC (H. Kitazato)

During September 27 through November 10, 2008, we had a submersible dive cruise at Indian EEZ of the Arabian Sea. The purpose of the cruise was to investigate depositional process, biogeochemical cycle (benthic fluxes) and adaptive ecology of benthic organisms under oxygen depleted environments. This is a joint cruise between JAMSTEC and NIO. It is also carried out under umbrella of both SIBER and COMARGE.

In total 26 dives were performed along the lower boundary of the oxygen minimum zone (OMZ). Three different approaches were taken for these dives. They are 1) observation of sea floor and animals, 2) chemical and biological measurements by both water column and sediments, and 3) in situ feeding experiments by adding food materials labeled with both C-13 and N-15.

Clear depth zonation of benthic organisms were recognized for 2000, 1150~1050, 1000~880, 870~830, 825 ~ 750, 730 ~ 700, 649, 600 ~ 500m respecitively. Faunal composition changes from megabenthos (1150m), macrobenthos (700m) and further to protozoa (500m) according to the depth. The OMZ is a hypoxic world. However, many benthic or nekto-benthic organisms dwell under very low oxygen concentrations (less than 0.4 μM = 0.002 ml / L). Despite the extremely low oxygen concentration, no laminated sediments were seen under the OMZ. This is mainly because distinct tidal flows disturb the sediment surface. Distinct ripple marks are developed in parallel to slope direction.

Both in situ and onboard experiments are going to process and analyze at each laboratories. A lot of measurements were performed during the dives. For synthesizing results from onboard scientists, a post-cruise meeting was held at Edinburgh University in February 2010. The next synthesis meeting will be held during EGU 2011 in Vienna.

Several cruises were carried out by JAMSTEC since FY2008 for different areas at Indian Ocean. JAMSTEC plans to have several cruises by R/V Mirai and Yokosuka/Shinkai6500 at the Indian Ocean during both FY2011 and FY2012.

Benthic process studies in the Indian Ocean: Recent studies in the Arabian Sea, and opportunities for the future (G. Cowie)

In overview, the presentation's objective was to argue for a major benthic component to future biogeochemical process studies in the Indian Ocean (IO). The IO is not just understudied and therefore important in its own right, but is home to exceptional phenomena and conditions that make it of disproportionate biogeochemical importance and likely to yield information that is of far-reaching importance.

The global importance of the IO relates to unique set of key processes and phenomena such as prominent monsoonal forcing, expanses of O2-depleted waters and sediments etc. Secondly, in the IO, benthic processes and benthic-pelagic coupling, especially in margin settings and under O_2-depleted conditions, are of major importance. Yet, the IO has remained grossly understudied, and international process studies such as JGOFS (in all basins), have largely ignored benthic processes. A fundamental conclusion is that future IO studies hold great promise, and should incorporate systematic, basin-wide and integrated benthic and pelagic process studies.

Historical benthic research in the IO (essentially all in the Arabian Sea) – from the Sir John Murray/Mabahiss expedition through to various JGOFS process studies 1990s – largely succeeded in identifying these key phenomena. Observational capability has expanded considerably since these earlier efforts; these new techniques were applied during a UK-led international collaboration that involved four cruises off Pakistan in 2003. The project focused on comprehensive biological and geochemical surveys of sediments at contrasting sites spanning the mid-water O_2 minimum zone (140 to 3200 m), linked to a suite of in situ process studies conducted with benthic landers. Comparative studies were conducted both before and at the end of the summer (SW) monsoon season. Recent Japanese (Indian margin, 2008) and Dutch (Murray Ridge, 2009) expeditions have also occurred, which have also been focused on benthic process studies. Together, these studies illustrate the types of equipment and techniques that are envisaged for future, more comprehensive benthic process studies in the IO.

Comparative benthic process studies in the Arabian Sea and Bay of Bengal would represents a unique research opportunity. Together they represent almost 2/3 of the total expanse of hypoxic waters on Earth, and, notably, it is under these reducing conditions that benthic processes and fluxes are most important. Also, sediment records show that these basins are highly dynamic and have undergone wholesale changes in productivity and hypoxia with fluctuating

monsoons in the past. Moreover, hypoxia is an important and growing phenomenon along both the eastern and western coasts of India, but also in many of the countries lining the Bay of Bengal, with major implications for very large human populations. However, the Arabian Sea and Bay of Bengal represent strongly contrasting regimes, in terms of the monsoons, productivity, extent of hypoxia and riverine influence (etc), which makes comparative study particularly important and attractive.

Recent biophysical research in the Leeuwin Current system (M. Feng)

The strength of the Leeuwin Current (LC) and its eddy field are both strong during the austral winter and weak during the austral summer on the annual time scale, and are strong during the La Niña years and weak during the El Niño years on the interannual time scale. As the LC is a warm current, the sea surface (evaporative) heat loss off the west coast of Western Australia (WA), as well as the upper ocean stratification (mixing) and the nutrient fluxes, is also closely linked to the strength of the current. Mesoscale eddies and air-sea heat fluxes are likely two key factors that drive the biogeochemical processes in the region.

In this talk, recent studies on the temporal and spatial variability of the biophysical properties in the oligotrophic marine environment off the west coast of WA are reviewed. By analyzing recent satellite chlorophyll a data and recent shipboard survey results, possible mechanisms that could be important to the variability of the ocean production off the west coast of WA are identified as: meridional erosion of the seasonal thermocline; vertical motion of the nitracline; horizontal and vertical nutrient advection related to the LC eddy activity; in situ nitrification; and benthic-pelagic coupling.

Phytoplankton biomass and productivity in the Leeuwin Current: The link between physical and bio-chemical parameters (C. Rousseaux, reporting for research team consisting of: Anya M. Waite, Peter A. Thompson, Christine Hanson, Lynnath Beckley)

Research off Western Australia has so far mostly focused on the waters off Perth (32°S). This region with high eddy kinetic energy is also home for one of the most valuable single species fisheries in Australia: the Western Rock Lobster. Previous studies have focused on identifying the key mechanisms driving the recruitment of rock lobster larvae.

Further north the presence of the Ningaloo Reef has been the subject of few studies but has recently been the subject of two major studies. Using chlorophyll *a* estimated from satellite-derived ocean color and in situ field observations, the existence of a seasonal autumn phytoplankton bloom in the waters off Northwest Australia was identified. In autumn, a combination of the accelerating Leeuwin Current and net surface cooling lead to a significant deepening of the mixed layer

depth down to ~100 m. This deepening also coincided with increased nutrient concentrations in the euphotic zone. Future studies should aim at combining field data with satellite and numerical models to resolve the small and larger temporal and spatial scale needed to appropriately understand the dynamics of these so far still fairly unknown ecosystems off Western Australia.

Finally, further north of Ningaloo Reef, the Kimberley region has been the subject of some recent oil and gas development, which have lead to a sudden increase in oceanographic research in this area. The oceanographic conditions in this area are mostly unknown.

Ocean Forecasting Australia Model with Biogeochemical Processes (R. Matear)

CSIRO global ocean modeling effort has been directed at developing a global ocean circulation model that is eddy-resolving in the Australian region (i.e. 90°E to 180°E and 10°N to 70°S). The model, called the Ocean Forecasting Australian Model (OFAM) was originally developed for ocean forecasting. To OFAM, a simple biogeochemical-trophic dynamic module has been added to simulate the BioGeochemical Cycling (BGC) of nutrients carbon and iron coupled to plankton dynamics. The trophic model includes phytoplankton, zooplankton, and detritus compartments and explicitly accounts for organic and inorganic carbon cycling, and iron cycling. The new model system called the World Ocean Model with Biogeochemical And Trophic-dynamics (WOMBAT) provides a new tool for tackling biogeochemical processes in the Indian Ocean region.

The BGC application of WOMBAT is occurring in 3 key areas.

1. Process Understanding. The model provides a valuable tool to explore the bio-physical interactions at eddy-scale resolution to help understand key biogeochemical processes and its capability as a means for developing insight into understanding process linkages has recently been demonstrated in a modeling study of the Indian Ocean off Western Australia. The study used eddy-resolution simulations to answer why the

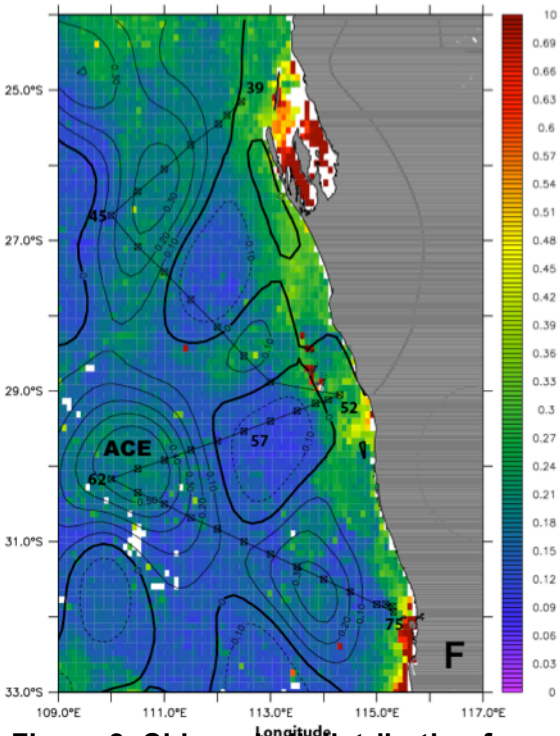

Figure 8. Chlorophyll distribution for 25 September 2000 showing elevated concentration in an anticyclonic eddy off the WA coast.

maximum in observed surface phytoplankton concentrations in the August to December period occur in warm core, anti-cyclonic eddies (Figure 8). These downwelling favorable eddies in oligotrophic waters are usually associated with phytoplankton concentrations less than the surrounding water. However, in its application to the region off Western Australia the model revealed injection of phytoplankton from the shelf into the anti-cyclonic eddies as alternative mechanism to explain the observed phytoplankton concentrations.

2. Climate Downscaling. Following on from the present-day simulations we are using WOMBAT in conjunction with global warming projections to downscale the climate projection to eddy-resolution in the Australian region. The motivation is simply that if eddies and boundary currents are important to BGC then ocean models must resolve eddies and boundary currents if they are to produce realistic climate change projections. We have now developed an approach to ocean downscaling of climate change, which confirms that accurately resolving both mesoscale eddies and boundary currents results in substantial changes in climate change projections for the oceans around Australia.

3. Data Assimilation. Data assimilation provides a method to exploit sparse observations to estimate the ocean state. At present, physical data is assimilated into OFAM to provide both 10-day forecasts and hindcasts of the ocean state. These state estimates provide a consistent 3-dimensional view of the physical state of the ocean to help interpret biogeochemical field data and assist in process understanding. In the near future the data assimilation will be extended to included biogeochemical observations to provide BGC ocean state estimates as well as physical state estimates. The system will assimilate remotely sensed surface phytoplankton concentrations to provide 3-dimensional estimates of phytoplankton and zooplankton concentrations, primary and secondary production, and air-sea CO_2 fluxes.

The present version of WOMBAT provides an exciting tool for advancing BGC understanding in the eastern boundary region of the Indian Ocean. However, we are now working on a global eddy-resolving version of WOMBAT, which will extend the BGC to the entire Indian Ocean basin. It is anticipated that the new version of WOMBAT will provide a valuable tool for the SIBER research and help foster closer interaction between the modeling and observational research effort.

The Western Australia node of IMOS (C. Pattiaratchi)

West Australian Integrated Marine Observation System (WAIMOS) is a node of the Integrated Marine Observation System (IMOS) for Australia funded through the National Collaborative Infrastructure Scheme (NCRIS) (Figure 9). The main area of interest for the West WAIMOS is the continental shelf/slope region offshore of Fremantle extending northwards to Jurien Bay. Within this region there are important topographic features such as the Rottnest Island and Perth Canyon and the circulation is dominated by the southward flowing Leeuwin

Current (LC) with the northward flowing Leeuwin Undercurrent (LU) beneath the (LC) and the wind driven Capes Current (CC) located on the shelf, particularly during the summer months. The IMOS infrastructure located in this region includes HF Radar (CODAR and WERA systems) for surface current measurements at 2 different scales; ocean gliders (Slocum and Seagliders) for subsurface water properties; continental shelf moorings (ADCP, thermistor and water quality loggers); passive acoustic sensors for whale monitoring; and, remotely sensed data products (SST and ocean color). Example data collected from these instruments will be presented in relation to the understanding of different processes operating in the West Australia (WA) region. These include: (1) Interaction between the LC and CC. Here, the warmer, lower salinity southward flowing Leeuwin Current interacts with the cooler, higher saline northward flowing Capes Current creates a region of high horizontal shear and thus intense mixing; (2) Winter cascade of dense water along the continental shelf. The WA region experiences a Mediterranean climate with hot summers and cold winters. During the summer months the inner continental shelf waters increases in salinity due to evaporation. In winter as this higher salinity waters cool its density is higher than offshore waters and a gravitational circulation is set-up where the inner shelf water are transported as higher salinity plumes into deeper waters.

Figure 9. The Integrated Marine Observation System (IMOS) components, including the WAIMOS node.

Appendix A.

Participant List

Panel Members

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Appendix B.

Agenda

Day 1: Monday 12 JULY

1330 SIBER SSC Welcome: R. Hood and W. Naqvi

1345 Keynote Address: Dr. Shailesh Nayak (Secretary, Ministry of Earth Science, India)

1400 National Perspective: SIBER India: (*Wajih Naqvi*)

1415 Discussion: W. Naqvi and R. Hood

How can India help coordinate and implement international SIBER activities? Can a SIBER program office be established in India?

1445 The SIBER Science Plan and research themes, peer review recommendations, and finalization progress (*Raleigh Hood*)

1500 **AFTERNOON TEA**

SIBER BUSINESS: R. Hood and W. Naqvi

1530 Nomination and Election of SIBER SSC Officers (Chair, co-Chair and Secretary).

Discussion of proposed new SSC members and rotations.

1545 Identify and Establish Working Groups, Working Group Chairs and Working Group Goals.

1600 Oxygen deficiency in the North Indian Ocean (*Wajih Naqvi*)

1615 SUMMARY OF DISCUSSIONS, RECOMMENDATIONS AND ACTION ITEMS: J. Wiggert

Day 2: Tuesday 13 JULY

0845 Review of Day's Agenda: R. Hood and W. Naqvi

SIBER BUSINESS: J. Wiggert, W. Naqvi, R. Hood

0850 Establishing a SIBER website and newsletter

0915 National Perspective: Indonesia and potential linkages to SIBER (*Dwi Susanto*)

0945 National Perspective: Oman and potential linkages to SIBER (*Adnan Al-Azri*)

1000 Discussion: D. Susanto and A. Al-Azri

Promoting SIBER in IO rim nations, particularly Indonesia, Africa and Oman. How do we get SIBER established in these countries?

1015 **MORNING TEA**

1045 Discussion (Continued): D. Susanto and A. Al-Azri

Promoting SIBER in IO rim nations, particularly Indonesia, Africa and Oman. How do we establish SIBER programs in these countries?

1100 SCIENCE TALK and NATIONAL PERSPECTIVE: German research in the Indian Ocean: Past and future perspectives (*Tim Rixen*)

1115 SCIENCE TALK and/or NATIONAL PERSPECTIVE: French contributions to the study of the Indian Ocean carbon cycle (*Catherine Goyet*)

1130 Discussion: C. Goyet and T. Rixen

Strategies for tying SIBER into global carbon cycle research programs

1200 **LUNCH**

Convene Joint Session of the SIBER SSC and CLIVAR IOP

1330 SIBER Science Plan recommendations for biogeochemical sensor deployments in the Indian Ocean: Progress since IOP-6 (*R. Hood*)

1345 Report on the status of IndOOS (*Gary Meyers*)

1400 India's Mooring-time series, Argo floats and deployment of biogeochemical sensors (*M. Ravichandran*)

1415 JAMSTEC, NOAA and FIO plans for deployment of CO_2 and other biogeochemical sensors. (W. Yu, Y. Masumoto and K. Ando)

1430 PROGRAM OVERVIEW AND DISCUSSION: G. Meyers and R. Hood

IndOOS/RAMA, the potential for deploying biogeochemical sensors, and establishing linkages with SIBER

Close Joint Session of the SIBER SSC and CLIVAR IOP

1500 **AFTERNOON TEA**

1530 Use of newly developed ocean color algorithms to assess IOD impact on regional to basin scale biogeochemical fluxes (*Jerry Wiggert*)

1545 Brief report from the Arabian Sea OMZ dive cruise (YK08-11) and the current research plan for the Indian Ocean by JAMSTEC (*Hiroshi Kitazato*)

1600 Benthic process studies in the Indian Ocean: Recent studies in the Arabian Sea, and opportunities for the future (*Greg Cowie*)

1615 Discussion: G. Cowie and H. Kitazato

Developing strategies for getting developed nations in Europe, Asia and North America engaged in SIBER

1630 SUMMARY OF DISCUSSIONS, RECOMMENDATIONS AND ACTION ITEMS: J. Wiggert

1900 SIBER Dinner. Cream Restaurant, East Perth.

Day3: Wednesday 14 JULY

0845 Review of Day's Agenda: R. Hood and W. Naqvi

SIBER BUSINESS: R. Hood and N. D'Adamo

0850 Funding availability from IMBER and IOGOOS for future SIBER events and activities. National support needs to be established.

0915 Discussion: N. D'Adamo, R. Hood and W. Naqvi

Strategies for developing meaningful linkages and synergies between SIBER, IOP, IOGOOS and IMBER

0945 Recent biophysical research in the Leeuwin Current system (*Ming Feng*)

1000 Phytoplankton biomass and productivity in the Leeuwin Current: The link between physical and bio-chemical parameters (*Cecile Rousseaux*)

1015 **MORNING TEA**

1045 Impacts of Leeuwin Current eddies on cross-shelf transport of fish larvae (*David Holliday*)

1100 Modeling with BlueLINK in the Indian Ocean (*Richard Matear*)

1115 The Western Australia node of IMOS (*Chari Pattiaratchi*)

1130 Discussion: R. Matear and G. Meyers

Australia, BlueLINK, the IMOS Program and potential linkages to SIBER. Can a SIBER Program office be established in Australia?

1200 **LUNCH**

1330 Discussion: J. Wiggert, R. Hood and W. Naqvi

Formulation of final recommendations and action items and development of SIBER SSC meeting reports and products

ADJOURN 1st SIBER SSC Meeting

1400 Social outing. Caversham Wildlife Park. All groups.

1930 Conference Dinner