Report to CLIVAR SSG-20

Panel or Working Group: Indian Ocean Panel (IOP)

1. Contributions to developing CLIVAR science and fit, where appropriate, to the CLIVAR imperatives

IOP mainly contributes to CLIVAR imperatives through building the ocean observing capability in the tropical Indian Ocean and stimulating related data and model based studies. It has developed the Implementation Plan for the Indian Ocean Observing System (IndOOS) and is coordinating the implementation and maintenance thereof. The RAMA array is at present 67% complete, with 31 of the designed 46 sites occupied with equipment and/or through ship time contributions from the US, Japan, India, China, Indonesia and France, as well as from regional programs such as ASCLME. The field season for October 2011-September 2012 was comprised of 7 cruises on 6 ships from 5 different nations to maintain the array. A total of 27 moorings were deployed using 153 days of ship time. Implementation has been slowed by piracy in the Lloyds of London Exclusion Zone in the northern and western part of the basin, so only one site—a flux reference mooring at 25°S, 100°E—was added during October 2011-September 2012 with Australian vessel support.

Most of the IndOOS data are available through the IndOOS data portal site at http://www.incois.gov.in/Incois/iogoos/home_indoos.jsp. The portal will rely on data serving via a distributed network of data archives. Data archives will be maintained by the individual groups in IndOOS at their institutes. The data and data products will be made available to the central data server and then served to the community via the web portal. Specifically, the RAMA buoy data can be downloaded at http://www.pmel.noaa.gov/tao/rama/ or through IndOOS portal. The data sets obtained from IndOOS are being used to support many of CLIVAR's research challenges such as (a) Intraseasonal, seasonal and interannual variability and predictability of monsoon systems, (b) Decadal variability and predictability of ocean and climate variability, (c) Trends, nonlinearities and extreme events, (d) Marine biophysical interactions and dynamics of upwelling systems, and (e) Dynamics of regional sea level variability. Furthermore, all RAMA data are being assimilated in ocean scale models to provide ocean analysis in real-time. This ocean analysis is being used by India for initialization of coupled ocean-atmosphere system models to provide seasonal predications of monsoons.

The publications arising from information derived from RAMA moorings are listed in http://www.pmel.noaa.gov/tao/rama/ramapubs.html

2. Briefly list any specific areas of your panel's activities that you think would contribute to the WCRP Grand Challenges as identified by the JSC at its most recent meeting

a. Provision of skillful future climate information on regional scales (includes

decadal and polar predictability)

IOP is promoting the implementation of the Indian Ocean Observing System (IndOOS), especially its critical component called the Research Moored Array for Afrian-Asian-Australian Monsoon Analysis and Prediction (RAMA). This will continue to dramatically change the data-poor condition for the Indian Ocean and will without question improve the understanding of the monsoon climate system. It will also improve the generally relatively poor model simulation and prediction skills in the monsoon region.

IOP is working closely with AAMP to realize the maximum scientific contribution from observation to prediction. IOP is working on a review paper on the decadal variability in the Indian Ocean, which will also discuss the further research priorities along this direction.

b. Science underpinning the prediction and attribution of extreme events

- The influences of ENSO and the monsoon seasonal cycle on tropical cyclone activity in the Bay of Bengal are documented. It is reported that during La Nina conditions, the number of cyclones and the intensity of cyclones (referring specifically to super cyclones) are enhanced in the Bay of Bengal (BoB). It is also reported that the monsoon seasonal cycle leads to the bi-modal feature of BoB cyclone behavior and favors the occurrence of the super cyclone during the summer monsoon onset phase. These data will help with prediction of super cyclones.
- The influence of ocean stratification in the Bay of Bengal on the cyclone cold wake was studied. The intense winds associated with tropical cyclones drive strong oceanic mixing, with associated strong cooling of the ocean in the wake of the winds. While the cooling can be related to a proxy of the kinetic energy input of the Tropical Cyclone to the upper ocean, there is a large spread in that relation, and this can be explained by accounting for the ocean state that can modulate the cold wake by one order of magnitude for a given energy input. A twenty year scale experiment with a regional coupled model indicates that the cold wake feeds back negatively on the TC, and both reduces the number of cyclones by 40% and leads to less intense cyclones in the south-western Indian Ocean.
- The structure and mechanisms associated with the first-branch northward-propagating intraseasonal oscillation (FNISO) over the tropical Indian Ocean (IO), which often triggers the onset of the Asian summer monsoon, was investigated using ERA-Interim reanalysis data for the period of 1990-2009. Two possible mechanisms may contribute to the northward propagation of the FNISO. One is the meridional asymmetry of the background convective instability and the meridional phase leading of perturbation humidity in the planetary boundary layer (PBL). This understanding helps improve the monitoring and prediction skill for Asian monsoon onset and its association with climate extremes.
- The impacts of tropical cyclones (TCs) on the Bay of Bengal (BoB) heat budget were examined using the Hybrid Coordinate Ocean Model and it was found that TC winds may significantly alter the interseasonal BoB heat budget through ocean heat transport (OHT) and surface heat fluxes.

- All the above studies have now appeared in research papers. Further, IOP is enhancing its research focus on the monsoon anomalies, and especially related to extreme droughts and severe floods.

c. Intraseasonal, Interannual and decadal variability

- In-situ and satellite data available from the Indian Ocean are being used to understand the intraseasonal and interannual variability. Time series measurements of temperature recorded from RAMA moorings in the Bay of Bengal (BoB) and Equatorial Indian Ocean, along with satellite measurements, are utilized to describe the intraseasonal variability of the thermocline in the BoB. The analysis shows a pronounced persistent intraseasonal variability in the thermocline region with dominant periods in the range of 30-120 days with maximum variation in the southern BoB. The 30-120-day variability primarily concentrated on three distinct periods: 30-70 day, 90-day and 120-day in the thermocline region. The governing mechanisms in terms of local and remote forcing are examined using satellite derived wind, SSHA and D23 data derived from *in-situ* observation. Many other studies are reported to understand and document the Barrier Layer thickness and thermal inversion in the Bay of Bengal on intraseasonal and interannual time scales.

- Regional sea level rise is being studied using Altimeter, GRACE and argo profiling data. Efforts are underway to provide real-time (monthly) sea level anomaly maps (steric and water mass) for the Indian Ocean.

- A review article on "Indian ocean decadal variability" highlighting the importance of observing decadal variability, identifying major decadal variability modes, understanding their causes, and investigating the underlying physical mechanisms will be published soon.

d. Warming event in the southeast Indian Ocean

An unprecedented warming event in the southeast Indian Ocean forced by the 2010-2011 La Nina was observed off the west coast of Australia in the southeast Indian Ocean in February–March 2011. It has locally been referred to as a 'Marine Heat Wave'. Peak sea surface temperatures during a 2-week period were 5°C warmer than the normal long term average for that time of year, causing widespread coral bleaching and fish kills. Understanding the climatic drivers of this extreme event is crucial for predicting similar events under the influence of global warming. The observational data and numerical models associated with the IOP's scientific framework were used to demonstrate that the extreme warming was mostly driven by an unseasonable surge of the poleward-flowing Leeuwin Current during the austral summer, which transported anomalously warm water southward along the coast. The unusual intensification of the Leeuwin Current was forced remotely by both oceanic and atmospheric teleconnections associated with the extraordinary 2010-2011 La Niña. The amplitude of the warming was boosted by both multi-decadal trends of the Pacific climate toward more La Niña-like conditions and intraseasonal variations in the Indian Ocean. This advance in the understanding of the

inter-connections between the Pacific and Indian Oceans, via the ITF, and the coupling between atmospheric and oceanic forcings relevant to the IO, has been a critical outcome of the IOP's work, with both fundamental and direct applied relevance to a globally important conservation 'hotspot' in the East Indian Ocean, sitting at the epicenter of a contiguous East IO system of highly biodiverse marine protected areas.

e. Simulation of atmospheric and ocean variables from regional ocean-atmosphere coupled model

Simulation of surface wind and upper ocean variability associated with the MJO over the Indian Ocean by a regional coupled model (COAMPS) was studied. It is demonstrated that COAMPS realistically simulated surface wind and upper ocean variations associated with the **Madden–Julian oscillation** (**MJO**) event in spring 2009, including the strong eastward jet (~1 m/s) on the equator. The equatorial jet is sensitive to the horizontal resolution of the atmospheric component. The large diurnal warming of SST during the suppressed phase of the MJO is also adequately simulated by the model because of the exceptionally high vertical resolution of the ocean component.

f. Marine biophysical interactions and dynamics of upwelling systems

One of the IOP's unique characteristics in the climate space is its scientific collaboration with **Sustained Indian Ocean Biogeochemical** and Ecological Research (**SIBER**) in the context of characterizing marine biophysical interactions and dynamics of upwelling systems. Key issues underpinning this collaboration include (i) defining and understanding biogeochemical variability, (ii) developing models of ocean-atmosphere-biosphere interactions and (iii) assessing the impacts of climate change on ocean primary productivity and air-sea CO_2 exchange. Efforts are underway to integrate physical and bio-geochemical scientific research in the IOP/SIBER collaborative context, including the incorporation of selected biogeochmical measurements, such as through the addition of CO_2, pH, Fluorescence, Particle Backscatter, and O_2 sensors to RAMA flux reference sites. This objective has already seen the addition of florescence and pCO_2 sensors to two of the equatorial and eastern equatorial Indian Ocean RAMA sites, respectively.

To further develop and enhance this integrating objective between IOP and SIBER, a series of workshop was planned. The first planning workshop of "Eastern Indian Ocean Upwelling Research Initiative – dynamics and ecosystem" to be held at JAMSTEC, Japan during 25-26, April 2013, followed by the second workshop in China during November 2013. The third workshop will be held in Bergan, Norway during IMBER open science conference. The primary objectives of these workshops are to (i) To discuss scientific issues and topics, including observational and modeling strategies, which should be covered by the Eastern Indian Ocean Upwelling Research Initiative, (ii) To discuss observational requirements for this initiative: Whether the existing observations (IndOOS) are sufficient, if not what are the new observations required to meet the above scientific issues, (iii) To make a position paper for the Eastern Indian Ocean Upwelling Research Initiative and (iv) to work out the implementation plan.

3. Key new science findings in the context of the new ocean-atmosphere CLIVAR (1-3 suggestions)

- Air-sea interaction processes during cyclones.
- Intraseasonal variability of the upper ocean (local Vs remote forcing).
- Simulation of surface wind and upper ocean variability associated with the MJO over the Indian Ocean by a regional coupled model (COAMPS).

4. Key science questions that you anticipate your community would want to tackle in the next 5-10 years within the context of the new ocean-atmosphere CLIVAR (1-3 suggestions)

- Eastern Indian Ocean upwelling system: its dynamics and ecosystem impacts.
- The influence of air-sea interactions and climate variability on tropical cyclones.
- Ocean-atmospheric dynamics of monsoon systems with application to improving seasonal and intra-seasonal forecasting.
- Predication of the Indian Ocean dipole from coupled climate models.
- Inter-basin exchanges (via the ITF, Aghulhas system, ACC).
- Indian Ocean decadal variability.

5. Cooperation with other WCRP projects, other global change bodies (e,g. IGBP) and links to applications

Although IOP does not have specific items in its Terms of Reference that address cooperation with IMBER (which is related to IGBP), the panel leadership recognized from its start the importance of establishing meaningful interdisciplinary ties and collaborations aimed at understanding how physical processes impact biogeochemical cycles and particularly air-sea CO_2 exchange and carbon export and also how biogeochemical processes can inform research into the physical dynamics of the oceans. The Panel has supported since the beginning the development of the Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) program (under the auspices of IOGOOS and IMBER and with strong reference to global societal imperatives as aligned with the UNESCO IOC's High Level Objectives). To these ends, several successes have been achieved in the emerging integration between IOP and SIBER, including:

- The SIBER Science Plan and Implementation Strategy which emphasizes interdisciplinary research and IOP/SIBER/IMBER mutual leveraging of effort.
- Motivation for an interdisciplinary modeling study of the physical and biological factors that determine the spatial distribution of the oxygen minimum zone in the Arabian Sea.
- Implementation of bio-geochemical sensors on existing RAMA flux moorings.
- New interdisciplinary collaborations focusing on the biogeochemical impacts of the Indian Ocean Dipole (IOD).

- Several ongoing interdisciplinary studies that are focused on the southern hemisphere boundary currents in both the western and eastern Indian Ocean, with many of these projects fitting into SIBER Theme 1 and being of considerable interest to the IOP.

  IOP and SIBER are discussing and exploring ways to further enhance their collegial linkages, such as through initializing the joint project on Eastern Indian Ocean Upwelling Research Initiative (see above), with the first related workshop planned for April 2013.

  IOP and SIBER are also jointly engaging in the emerging 50th Anniversary initiative for the International Indian Ocean Expedition, with members and associates involved in the 1st IIOE-2 Reference Group meeting and with the 1st workshop (April 2013, Japan) of the Eastern Indian Ocean Upwelling Research Initiative also developing as an initiative with joint IOP/SIBER involvement and with reference to IIOE-2 as a contributing initiative.

6. Activities in the context of scientific capacity building and career support?

Due to limited resources, IOP made important 'contributions' to related capacity building activities under IOGOOS, rather than through a dedicated IOP Capacity Building plan. IOGOOS and IOC Perth acknowledge these contributions as being highly relevant in the CB sphere.

IOP engaged in many capacity building (CB) activities through the tangible engagement of its members, experts, involved agencies and its regional programs. The experience has proved that these are efficient ways for IOP members to provide resources to IOGOOS related CB activities, mainly through personnel from the IOP fraternity, who offer, where and when possible, technical training, with associated links to IndOOS data, science products, modeling and ocean-atmospheric information in general. A major feature of IOP's contribution to CB is the willingness of IOP members to encourage observers to their meetings and also to engage in workshops and meetings outside of the IOP schedule per se with their colleagues from the broader IOGOOS constituency, leading to exchange of ideas, scientific products, information and also promoting and facilitating partnerships with less experienced early career researchers, students, scientists and managers, leading to joint reporting of scientific work, report writing and ultimately publication of research in recognized journals.

IOP members, experts and collaborating colleagues are therefore very active in various capacity building activities, especially in the Indian Ocean rim region. For example, Dr. Sidney Thurston as an IOP expert from NOAA, leads the In-Region Western Indian Ocean Capacity Building Workshop of the WMO/IOC Data Buoy Cooperation Panel (DBCP) and Partners. The latest in this series of workshops was successfully held in Kenya in 2012, with preceding workshops in Mauritius in 2011 and in South Africa in 2010. Some IOP members actively participated in the above capacity building workshops as resource personnel, providing training and insights to IndOOS and related products etc. This particular series of DBCP CB activities primarily aim to encourage and facilitate African and SW Indian Ocean Island countries in participating in building IndOOS in respect to deployment of GOOS components, including floats, drifters, etc., and also in

using the data from IndOOS for their own specific areas and related requirements. Other IOP stakeholders regularly assist Dr Thurston in these DBCP CB workshops (eg Nick D'Adamo of IOC Perth, and by association Dr Gary Brassington of BoM Australia / GODAE OceanView).

Agencies closely involved with IOP / IndOOS also drive or engage in a range of other bilateral capacity building programs, with important benefits to IOGOOS stakeholders. For example, NOAA/USA and MoES/India have developed a collaborative arrangement for CB underpinned by IndOOS. In this context, NOAA trains Indian researchers in the use of IndOOS data for selected areas of ocean forecasting an related modeling and also in the associated generation of ocean analysis products, which provides important utility in initializing conditions for coupled ocean-atmosphere models for prediction of seasonal forecasts of the Monsoon. Furthermore, JAMSTEC/Japan and BPPT/Indonesia, FIO/China and BRKP/Indonesia, have also developed similar CB arrangements. These mechanisms in fact serve the mutual purpose of not only contributing to CB per se but also, by virtue of the relationships, associations and goodwill that thereby develops between and amongst participating countries, in supporting the implementation and enhancement of IndOOS. Such relationships will continue to play an important role in future sustaining IndOOS.

The regional programs affiliated with IndOOS (seen on the annually updated IndOOS implementation maps as ellipses representing process studies) also played important roles in CB in the region. For example, the Monsoon Onset Monitoring and its Social and Ecosystem Impact (MOMSEI) study, as a regional program of IndOOS, organized two summer schools in 2010 and 2011 to train the young scientists from the region in the use of IndOOS data and monsoon knowledge for their own research. Another successful example is the Arabian Sea and Bay of Bengal regional observing system under India's auspices: user interaction workshops are organised every year by India whereby university students and young researchers are invited to attend and learn about the availability and utility of ocean data from the Indian Ocean.

IOC Perth also coordinates, on behalf of IOGOOS, the IOGOOS Pilot Project: Modelling for Ocean Forecasting and Process Studies. This aims to build capacity across IOGOOS stakeholders in the field of ocean forecasting, associated modeling and in its applications for societal benefit. Nick D'Adamo leads the pilot project, and variously many members or associates of IOP engage in related workshops as trainers, experts etc.

Many other examples of how IOP supports and engages in CB initiatives under IOGGOS's framework can be found in IOGOOS annual reports.

7. Activities in the context of knowledge exchange with societal actors?

8. New activities being planned, including timeline, request for endorsements, potential for new funding opportunities

- The Eastern Indian Ocean Upwelling Research Initiative plans two scientific workshops in 2013 and another workshop in 2014, in order to complete its Science Plan and Implementation Strategy. This initiative will involve IOP, SIBER and collegial stakeholders, including global and regional partners such as IOC (including IOC Perth), SCOR, IOGOOS, CLIVAR and IMBER. This new research initiative is expected to transition into an implementation phase for 2015-2020. It will form a contribution to the International Indian Ocean Expedition 50th Anniversary activity (ie IIOE-2), for which an initial Reference Group meeting is planned for 14-15 May 2013, and at which IOP and SIBER will be represented. It will request endorsements of its Science Plan and Implementation Strategy both from CLIVAR and IMBER/IGBP. Then the Science Plan and Implementation Strategy will be distributed to national funding agencies as a call for new funding opportunities.
- Incorporation of biogeochemical sensors on RAMA flux moorings locations.
- Ongoing capacity building activities for western Indian Ocean countries.

9. Workshops / meetings planned

- The First Planning Workshop of "Eastern Indian Ocean Upwelling Research Initiative" during 25-26 April, 2013, JAMSTEC, Japan.
- The first planning workshop of the Reference Group for the International Indian Ocean Expedition 50th Anniversary (IIOE-2) Initiative, at INCOIS, Hyderabad during May 14-15, 2013.
- 10th IOP meeting in association with the annual SIBER, IndOOS Resource Forum (IRF) and Pacific Panel meetings are planned to occur during 8-12, July 2013 at Lijiang, China.
- The second Planning Workshop of the "Eastern Indian Ocean Upwelling Research Initiative" during 25-26 Nov, 2013, at FIO, China.
- The third Planning Workshop of the "Eastern Indian Ocean Upwelling Research Initiative" during 23-27 June 2014, at the IMBER Open Science Conference, Bergen, Norway (presently submitted as a workshop proposal for the conference).

10. Issues for the SSG

The Indian Ocean Panel has a unique role for the Indian Ocean in that is trying to build a sustainable observing system (ie IndOOS) in what is a data-poor basin and also to produce new science outcomes based on new observations under IndOOS. This task is far from complete. In that purpose, IOP experiences some particular difficulties relating to the protocols associated with membership rotations. IOP rotates, with no question, membership as per the CLIVAR rules but believes that whilst encouraging renewal of new skills, opportunities etc in its membership it does on the other result in potential loss of continuity in a program that has a time frame much longer than 2-4 years (the renewal time frames). The negative impact from losing historical knowledge, association with IndOOS, relationships amongst operational components etc is an issue that IOP believes needs to be addressed in the membership context. As a solution, IOP we would like to maintain the meaningful and tangible membership (the actual membership 'categories'

can of course be explored) of some critical members to enable them to stay engaged with IOP for sufficient time so as to maintain the momentum and effectiveness of the panel in implementing and maintaining IndOOS.

We trust that the SSG can appreciate this issue and work with IOP to arrive at a mutually acceptable mechanism by which to achieve the dual purpose of rotation (for all its worthy reasons) and continuity of science, implementation through extensions (of some sort to be agreed) of selected critical members.

Furthermore, at IOP-9 in Cape Town, members expressed a strong desire to find a way to enable a better balance in its membership through finding a mechanism to engage new members according to specific criteria (again through specific membership or new associate membership categories that could be explored and defined to the mutual satisfaction of the SSG). The 'balance' discussed was as follows:

- Strive to increase the gender balance (IOP historically is >80% male comprised), through a concerted effort to identify suitable and willing members in this context.
- Strive to encourage engagement of at least one new member from a country that is emerging and keenly willing to engage in IndOOS/IOP but that may not necessarily have the overall level of ocean science capacity that normally defines the capacity required for IOP membership. The collegial interaction that would be facilitated by the new member working with the IOP as a whole would provide great opportunity for his/her emerging ocean observing country to develop improved networks and skills in related science areas. Furthermore, it would provide bridges for such countries to then become greater contributors to IndOOS (new historical data, observing infrastructure, analysis, modelling and/or vessel support): this sets up a mutually beneficial model.
- Strive to continually indentify emerging sub-basin scale studies that ought to be embedded more explicitly in the IOP framework (eg the emerging Greater Agulhas System study is a case in point).

It is notable here that this membership balance issue and the three points above were strongly submitted and supported through all of the integrated package of meetings held in October 2012 (Cape Town) involving IOGOOS-9, SIBER-3, IRF-3 and IOP-9, and also had the strong support of IOC Perth.

Annex A

Proforma for CLIVAR Panel and Working Group requests for SSG approval for meetings

Requests should be made through D/ICPO (rogbar@noc.ac.uk), against the following headings:

1. **Panel or Working Group: Indian Ocean Panel**
2. **Title of meeting or workshop: 11th IOP meeting**
3. **Proposed venue: TBD**
4. **Proposed dates: around Jan 2015**
5. **Proposed attendees, including likely number: 30**
6. **Rationale, motivation and justification, including: relevance to CLIVAR themes & JSC cross cutting topics and any cross-panel/working group links and interactions involved:**

   IOP is working hard on the implementation of IndOOS and pushing new research initiative, and hence it urgently needs the panel meeting to be conducted on 12-month basis. The proposed 11th IOP meeting will overview the IndOOS development and will push the practical coordination of the ship time sharing. Also, it will push the ITF activities, which is in collaboration with Pacific Panel.

   IOP-11 will address the new Eastern Indian Ocean Upwelling Research Initiative, which is closely related with new CLIVAR grand challenges.

   IOP-11 will be conducted back to back with SIBER-5 and joint session will be planned.

7. **Specific objectives and key agenda items:**

   Objectives consist of:

   (1) Reviewing and coordinating the IndOOS development and relevant science progress

   (2) Promoting Eastern Indian Ocean Upwelling Research Initiative, in close collaboration with SIBER, contributing to the proposed IIOE-2

   Key agenda items consist of:

   (1) IndOOS progress and relevant science

   (2) Ship-time sharing plan to help sustain IndOOS

   (3) Coordinating Eastern Indian Ocean Upwelling Research Initiative

   (4) Collaborating with IIOE-2

8. **Anticipated outcomes (deliverables): coordinated contribution to IndOOS, its science, better preparing Eastern Indian Ocean Upwelling Research Initiatives, close collaboration with IIOE-2 activities**

9. **Format: Report**

10. **Science Organising Committee (if relevant)**

11. **Local Organising Committee (if relevant)**

12. **Proposed funding sources and anticipated funding requested from WCRP: IOP will seek the funding from WCRP and IOC (through its Perth Office). The anticipated funding requested from WCRP is USD20K, which is mainly for the travel support of some members and invited experts.**