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TABLE of CONTENTS

Action Items

1) Write a brief report on the feasibility of maintaining a mooring array at 80E for 3 years and circulate to IOP members for comment

(M. McPhaden)

2) Write a position paper on the need of setting up a IndOOS resources board, including list of potential members

(M. McPhaden, VNS Murty, Y. Masumoto and W. Yu)

3) Write an overview/user guide of the IndOOS data portal

(Ravichandran with assistance from P. Hacker and J. Potemra)

4) Link the IndOOS data portal to the CLIVAR website

(R. Boscolo)

5) Consider if further action is required to develop research plans for studies of surface layer heat budget (seasonal interannual time scales) and ocean processes at decadal time scales.

(Y. Masumoto, G. Meyers, T. Lee and G. Vecchi)

6) Comment on the Agulhas monitoring proposal

(all members)

and assess the proposal based on comments

(G. Meyers and Y. Masumoto)

7) Determine the feasibility and organize a 2nd IOP High Level Progress Review at IOGOOS-IV (~ November 2007), potentially including names for the resources board

(S. Thurston and D'Adamo)

8) After confirmation with K. Yoneyama and J. Vialard, engage the interest of AAMP, VACS and GSOP in a multi-national experiment in 2012 following from MISMO/Cirene

(G. Meyers and Y. Masumoto)

9) Draft a brief paper on the basin array and potential collaborations and submit it to all the groups interested in studying intraseasonal timescale, including AAMP, YOTC, the US CLIVAR, MJO WG and THORPEX

(Y.Masumoto, K. Yoneyama and G. Meyers)

10) Find a replacement for co-chair G. Meyers

(G. Meyers and Y. Masumoto)

11) Invite W. de Ruijter to become member of IOP

(G. Meyers, Y. Masumoto and R. Boscolo)

12) Investigate dates and venue for next IOP meeting in Bali, Indonesia

(F. Syamsudin and R. Boscolo)

1. Introduction

The 4th IOP meeting was hosted by the South African Weather Service (http://www.weathersa.co.za/) in its head office in Pretoria. Mr M. Majodina, senior manager of the SAWS Regional Weather O§ffices welcomed the participants (see Appendix A). Gary Meyers, co-chair of IOP, introduced the new co-chair, Yukio Masumoto, and accepted the apologies from Fritz Schott, Peter Hacker, Weidong Wu and Yoshi Kuroda for being unable to attend the meeting. Gary Meyers also thanked the panel members who fully support themselves for attending this meeting and welcomed the numerous guests. Finally Chris Reason was thanked for the local arrangements. The agenda (Appendix B) was adopted by the meeting participants.

1.1. Welcome from the Sponsors: GOOS and CLIVAR

Nick D'Adamo, director of the IOC Perth Regional Programme Office, welcomed the IOP meeting attendees on behalf of GOOS, one of the IOP sponsors. The IOC Perth Office maintains its strong advocacy and support for the IOP of the Indian Ocean Global Ocean Observing System (IOGOOS), as a successful and active collaborative entity that continues to produce significant advances in the characterization and modeling of the dynamics of the Indian Ocean and of the interconnectivity between the Indian Ocean and its adjacent seas. The IOC Perth Office underwent a change in staffing earlier this year, with N. D'Adamo replacing Bill Erb as Head of the Office. N. D'Adamo took this opportunity to wish Bill Erb well and also congratulate him on the legacy he left in the IOC network, referring to this panel as well as the many other significant achievements Bill championed across the Indian Ocean, South East Asia, Pacific Island and Western Australia GOOS domains.

The welcome from CLIVAR, the other IOP sponsor, was given by Roberta Boscolo, science officer of the International CLIVAR Project Office. She reminded participants that the World Climate Research Programme (WCRP, http://wcrp.wmo.int/) published its Strategic Framework: 2005-2015: Coordinated Observation and Prediction of the Earth System in August 2005. The document reiterates the WCRP objectives to determine the predictability of climate and the effect of human activities on climate. The strategic framework seeks to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. The key issues are:

Move from physics-only to Earth-System models (with IGBP, http://www.igbp.net/)

Prediction across all timescales: "seamless predictions"

Development of the sustained climate observing system with GCOS, GEOSS etc…

Integration of models and data: 1) use of data assimilation to initialize models over widest range of climate prediction timescales possible; 2) synthesis through reanalysis (atmosphere, ocean, coupled)

Link to applications through existing mechanisms (e.g. START http://www.igbp.net/ and the World Climate Applications Programme) and new ones

R. Boscolo informed the IOP that the 28th session of the WCRP Joint Scientific Committee was held in Zanzibar, Tanzania, from 26 to 30 March 2007. The meeting aimed to determine the future of the WCRP and review progress in implementing its Strategic Framework 2005-2015 (see report at http://wcrp.wmo.int/documents/jsc28report.pdf).

Particularly relevant to CLIVAR is the outcome of the JSC Task Team on implementing the WCRP Strategic Framework which recommends WCRP to focus on cross-cutting issues aimed at meeting society's and stakeholder's needs. The cross-cutting activities identified by the JSC are:

- Anthropogenic Climate Change
- Atmospheric Chemistry and Climate
- Monsoons and the Year of Tropical Convection
- Decadal Prediction
- Extreme Climate Events
- International Polar Year
- Sea-level Rise
- Seasonal Prediction

R. Boscolo also informed the meeting that as result of introducing cross-cutting activities within WCRP, the total budget allocated to CLIVAR activities will be reduced considerably (to about 1/4) for the period 2008-9. In this financial framework the SSG co-chairs and the ICPO feel urged to consider reorganization of CLIVAR and introduce a new modus operandi.

The IOP expressed concerns on the emphasis on the cross-cutting themes. The panel members highlighted the importance of regional activities as a way to address local climate phenomena with huge societal impacts in the Indian Ocean rim. G. Meyers urged the IOP members to develop a solid research plan in order to position the work of the IOP in the WCRP framework.

1.2. Intersessional Activity and Future Meetings

G. Meyers listed the relevant meetings/events occurring in the period 2005-2006 as part of the intersessional activity:

- THORPEX/WCRP workshop (March 2006). The study of convection was recognized as coupled ocean-atmospheric process; the TAO array have provided new insights into high-frequency air-sea interaction processes in the tropical Pacific but our understanding of similar processes in the Indian Ocean is much more limited.
- CLIVAR SSG-14 (17-19 April 2006). G. Meyers submitted a report for IOP and M. McPhaden attended the meeting and made a presentation.
- OOPC-11 (16-20 May 2006). F. Schott attended and made a presentation on behalf of IOP
- Integrated Marine Biogeochemistry and Ecosystem Research—Indian Ocean (SIBER) (3-6 October 2006). G. Meyers, J. McCreary and M. McPhaden attended
- AAMP-8 (19-21 February 2007). J. McCreary attended

Reports and publications:

- Mail out of the Indian Ocean Observing System (IndOOS) Implementation Plan—positive feedback
- *CLIVAR Exchanges* No.39 – special issue on Indian Ocean climate
- Journal of Climate special issue on Indian Ocean Climate, Volume 20, No. 13.

The 2006 featured a big IOD event with some devastating societal impacts e.g. 300,000 left homeless by Kenya floods

2. Science talk: Impacts of Indian Ocean variability on southern African climate *(Chris Reason)*

A review of the impacts of Indian Ocean variability on the climate of Africa south of the equator was given. Focus was placed on three examples (the Indian Ocean Dipole, co-evolving dipole-like SST anomalies in the subtropical South Indian and South Atlantic oceans, and the potential modulation of the Benguela Nino impacts on southern Africa by these subtropical anomalies in the South Indian Ocean.

The main rainy season over most of southern Africa is austral summer and this season is when the subtropical dipole-like SST anomalies and the Benguela Nino express themselves. It is also the season when ENSO has the strongest impact on southern African climate. There also appears to be a relationship between ENSO and the subtropical dipole-like SST anomalies. The latter evolve through modulations of the midlatitude wave 3 or 4 pattern in the atmosphere which lead to anomalies in the surface anticyclones and hence changes in surface heat fluxes and Ekman heat transports.

The well known impact of the Indian Ocean dipole on the short rains (OND) over equatorial East Africa appears to have a less well known (and weaker) opposite signed rainfall impact over subtropical southeastern Africa. It should be noted that ENSO also shows opposite signed rainfall impacts for southeastern Africa and equatorial East Africa.

Indian Ocean variability as well as ENSO impacts on rainfall measures that are of great interest to user groups (agriculture, health, water resources, tourism) include the onset of the main rainy season and dry spell frequencies within it. The CLIVAR VACS panel is keen to explore the potential predictability of these rainfall impacts given their strong societal applications. VACS is also very keen to engage further with IOP on the design of research and observing system programmes for southern and eastern Africa.

3. Progress and Plans for the Moored Buoy Components of IndOOS *(Mike McPhaden)*

This presentation reviewed PMEL-related activities associated with development of the moored buoy component of IndOOS. Emphasis was on 1) progress since the Third Session of the Indian Ocean Panel (IOP-3) in March 2006 and 2) plans for the coming year. The moored buoy array design, including scientific motivation, implementation time line, and ship time requirements, was published in *CLIVAR Exchanges* in October 2006.

As of April 2007, 15 sites in the array have been occupied, representing 32% of the 47 sites in the array (Figure 1). Since March 2006, eight ATLAS moorings and one ADCP mooring were deployed on three separate cruises. The cruises were on the *ORV Sagar Kanya* (Sept-Oct 2006), *RV Baruna Jaya* (Nov 2006), and the *RV Suroit* (Jan-Feb 2007). The latter cruise was carried out in support of the VASCO-CIRENE program. Also, the *RV Mirai* replaced vandalized meteorological sensors on the 1.5°N, 80.5°E ATLAS mooring during the JAMSTEC MISMO cruise (Oct-Dec 2006). Likewise, in April 2007, the *RV Roger Revelle* replaced damaged meteorological sensors on the 8°N, 90°E ATLAS mooring during the course of a U.S. sponsored Repeat Hydrography cruise.

Fishing vandalism continues to be a concern. Most ATLAS moorings were vandalized in the months following deployment and two were set adrift. Four were either not transmitting at all or not transmitting valid data by the time of IOP-4. Data return for ATLAS and TRITON moorings combined was 68% for the period October 2004 (when the first ATLAS were deployed) to March 2007. This measure of data return does not include loss of data after moorings had been deployed for more than their design lifetime of one year. Data return will diminish with time until the next servicing cruises because of those moorings that are presently not transmitting data. On the other hand, the JAMSTEC and PMEL ADCP moorings at 90°E and 80°E respectively have returned 100% good data.

PMEL is building and testing a low-profile (LP) ATLAS that will initially transmit ocean data in real-time from a buoy that has a tamper resistant design. PMEL is also changing the hardware (nuts, bolts, screws) on existing ATLAS moorings to require specialized tools for removal of instrumentation. These efforts may discourage but are not likely to completely eliminate problems with vandalism.

Ship time remains a concern since there is no systematic framework for planning cruises on a regular basis. The mooring at 8°S, 67°E for example was deployed without any guarantee for a return cruise for recovery (though possibilities exist and are being pursued). Likewise, the first two cruises to ATLAS sites along 80°E and 90°E were separated by nearly two years; the third cruise to service moorings along these lines in 2008 will most likely occur after an interval of 18 months or more. These servicing intervals are far in excess of the ATLAS mooring design lifetime of 12 months and contribute to both equipment and data loss. Promising efforts are underway to develop formal partnerships between NOAA and institutions in India and Indonesia that would ensure more regular ship scheduling in the future.

In the coming year, PMEL intends to maintain all existing ATLAS sites as well as expand along both 80°E (adding 4°N and 4°S) and 90°E (12°N and 15°N). These expansions would be carried out in collaboration with institutions in India. If successful, 12 ATLAS mooring sites will be occupied by early 2008.

PMEL also proposes an array of ADCP moorings along 80°E to measure prominent transport variations in the central basin on intraseasonal to interannual time scales. These transport variations, which play an important role in the development of the IODZM, are linked to Wyrtki Jet and equatorial wave processes. The array would also have extension east and west of 80°E to allow for estimation vertical velocity via the continuity equation and would complement the array of NIO and JAMSTEC ADCP moorings stretching along the equator between 77°E and 93°E. Data on the velocity field in this region would provide a valuable constraint for the development of ocean models used in climate forecasting.

The plan would be to maintain the 80°E ADCP array as a process study embedded in the broad scale observing system for three years beginning in 2008. The moorings would consist of upward looking ADCPs to provide velocity measurements in the upper 300-400 m. Some moorings would be equipped with a string of temperature-conductivity sensors to provide definition of water mass properties in the thermocline. These subsurface moorings will be less subject to fishing vandalism and so data returns are expected to be very high. Possible refinements to the array design based on discussions at IOP-4 will be explored and reported to the panel in a separate document.

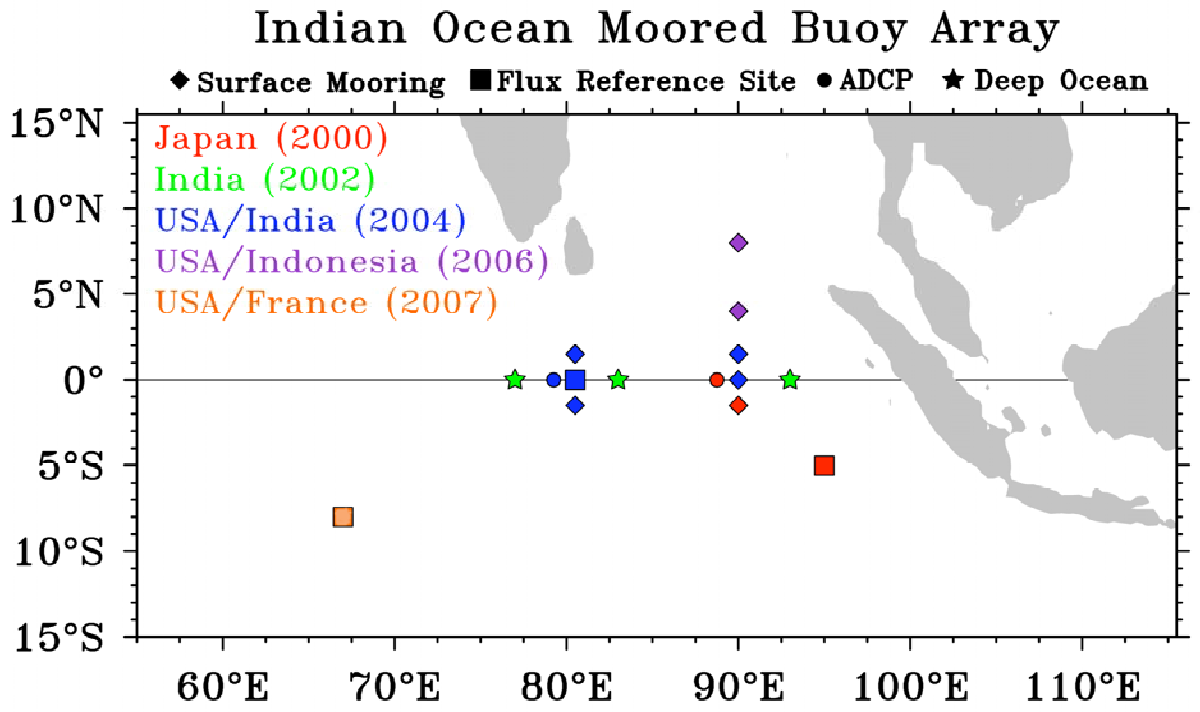

Figure 1. Status of the deployed moored buoys as part of IndOOS as of April 2006. Colours show national support by site with dates in parentheses indicating the year of first occupation.

ACTION ITEM 1. Write a brief report on the feasibility of maintaining a mooring array at 80E for 3 years and circulate to IOP members for comment (M. McPhaden)

4. Upper Ocean Variability of Measured Currents from ADCPs along the Equator in the Indian Ocean during Nov. 2004 – July 2006 (*VNS Murty)*

The semi-annual variability of zonal currents in the equatorial Indian Ocean from ADCP measurements and model simulations was presented. The ADCP data were collected in the upper 150 m at the three mooring locations, viz., 77ºE, 83ºE and 93ºE during 20 October – July 2007. The ADCP data were collected at 8 m bins. The topmost bin of the ADCP data is 16 m at 93ºE. The observed zonal currents showed the strong Equatorial Jets – both spring jet and fall jet. The strength of the fall 2005 jet was relatively strong compared to the spring jets of 2005 and 2006. The Indian Ocean Regional Model simulations (provided by Dr. Raghu Murtugudde, University of Maryland, US) were compared with the measured currents. The comparison was very good at 77ºE but the model zonal current, particularly the spring 2007 jet, was overestimated in the model simulations. The matching of the observed and simulated currents was good in the central Indian equatorial basin, the region of strong surface wind forcing. However, the mismatch at 93ºE might be due to the importance of thermodynamics playing a major role to be considered in the model. Possibly, the model wind forcing might be in error or the model southern boundary may be too close to the equator.

Both the measured and model simulations (both of weekly data) are fitted with the semi-annual wave (SAW) harmonics and the amplitude and phase of the semi-annual harmonics are obtained. In both the observed and model simulations, the SAW harmonic showed upward phase propagation suggesting the vertical propagation of equatorial waves. Further, the amplitude and phase of the SAW harmonic in the observed currents agreed with the model simulations at 77ºE. The differences in the amplitude and phase of the SAW harmonic at each observed depth were presented.

The work is being prepared for publication.

5. Review of TRITON and JEPP-IOMICS Projects *(Yukio Masumoto)*

The present status and issues of the TRITON and JEPP-IOMICS projects were reviewed. Two TRITON buoys deployed by JAMSTEC at 1.5ºS, 90ºE and 5ºS, 95ºE are continuously observing and sending their meteorological and surface/subsurface ocean data, though one buoy has a significant period of missing meteorological data. To prevent vandalism, we adopted a new tower design for the buoy at 5ºS, 95ºE, which is covered by a cylinder with minimum exposition of the sensors to the open air. So far, the data have been safely obtained, suggesting a possibility to reduce the meteorological data gaps, although the cover itself may affect the data quality.

A new, small and light weight TRITON buoy, named m-TRITON, has been developed under the JEPP-IOMICS project, with a new A/D converter board installed. Two m-TRITONs were deployed at 79ºE and 82ºE on the equator during the MISMO program, as the final field test. The buoys successfully collected all the data during the one-month observation period, with the sensor drifts similar to the one for the TRITON buoy. One of the two m-TRITON is now deployed side-by-side with the TRITON at 1.5ºS, 90ºE for a year-long comparison, which currently shows promising performance of the new buoy system.

There is, however, large uncertainty of the ship-time for maintaining the buoys in the eastern Indian Ocean. Active participation of any institutes/groups from the rim countries of the Indian Ocean to IndOOS to secure the necessary ship-time in the near future would be highly appreciated.

6. Progress and Plans for the Java Subsurface Mooring under IndOOS *(Weidong Yu)* – contribution from a non-attending panel member

This short report reviewed the First Institute of Oceanography China (FIO)-related progress on the planned Java subsurface mooring. It emphasized 1) progress since the Third Session of the Indian Ocean Panel (IOP-3) in March 2006 and 2) plans for the coming years.

On 11 Dec. 2006, the Implementation Agreement on the Java Upwelling Variation and Impacts on Seasonal Fish Mitigation was signed between FIO/China and AMFR/Indonesia, which will permit the FIO to deploy the Java subsurface mooring in collaboration with the Indonesian scientists using their *R/V Baruna Jaya VIII*. This agreement resolves the technical problems with the deployment in the Indonesian EEZ. The deployment has been scheduled during 25 Sep. and 5 Oct. 2007. The originally planned site is at (8.5ºS, 160.75ºE). The actual deployment location may move a little northward, to around 8ºS, where the water depth is about 3000m and the topography is much smoother.

In association with its industrial partner, FIO has designed a new generation subsurface mooring system (Figure 2). The shape of ADCP buoy is optimized to have very small resistance against the current and allows for the installation of 5 satellite transmitting mini-buoys. One mini-buoy will be released to the surface shortly after the deployment of the mooring system in order to test its working status. The other 4 mini-buoys are programmed to be released to the surface every three months and to transfer the daily mean data through satellite, within the one-year lifetime of the subsurface mooring. This technical advancement enables us to receive the data periodically and to significantly reduce the risk of lost data. The full high resolution data will be obtained after the recovery of the mooring system.

FIO is discussing with AMFR to maintain the Java subsurface mooring for the long-term and to carry out the process studies. These activities will be defined at the second China-Indonesia Workshop on Cooperation of Marine Science and Environmental Protection to be convened in Indonesia in May 2008.

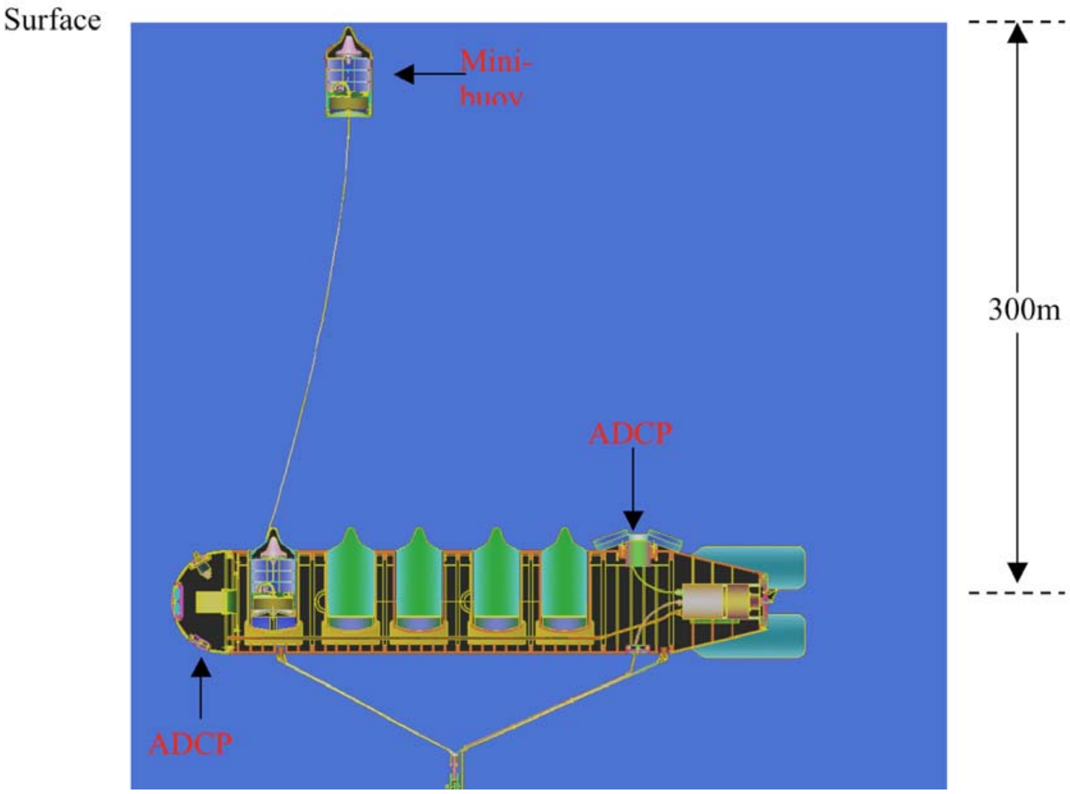

Figure 2. Schematic plan of the Java subsurface mooring

ACTION ITEM 2. Write a position paper on the need of setting up an IndOOS resources board, including list of potential members (M. McPhaden, VNS Murty, Y. Masumoto and W. Yu)

7. Progress and Plans with Argo floats *(M. Ravichandran)*

Presently there are 389 Argo profiling floats in Indian Ocean (north of 40ºS) and 551 floats in the entire Indian Ocean. In order to reach a 3x3 degree array north of 40ºS, 420 floats are required. The main gaps persist in the areas where there is no shipping route. However, efforts are underway fill these by air deployment. Most of the countries deploying floats in Indian Ocean have secured funds for maintaining a 3x3 degree array. About 6 floats were deployed with Oxygen sensors and 12 floats deployed with Iridium communications in the last year. Using objective analysis from available floats, monthly data products from Argo floats such as temperature and salinity at different depths, depth of 20º and 26º isotherm, mixed layer depth, isothermal layer depth, geostrophic currents, heat content up to 300 m depth, and dynamic height are available for the Indian Ocean at http://www.incois.gov.in/Incois/argo/products/argo_frames.html.

All the float data are gridded and made available in the live access server http://www.incois.gov.in/Incois/argo/las.jsp, wherein user can download and/or plot required parameters. Amongst other things, the data show that the Argo floats capture the IO dipole signal and reveal that the maximum temperature difference (temperature difference between western and eastern parts of the dipole) occurs at about 100m depth and not at the surface.

8. Introducing an Integrated Marine Observing System for Australia – IMOS *(G. Meyers)*

The Minister for Education, Science and Training, the Hon Julie Bishop MP announced the Integrated Marine Observing system (IMOS) [http://www.imos.org.au/] on 27 November 2006. The Department will contribute

$A50 million new funding toward development of observational capabilities, to be matched by an almost equal amount by contributing partners, comprising most of the agencies and Universities in Australia with capability in coastal or bluewater oceanography. The IMOS Office is located at the University of Tasmania. Dr Gary Meyers is the first Director of IMOS. IMOS is an initiative of the Australian Government being conducted as part of the National Collaborative Research Infrastructure Strategy.

Highlights of the observational program include:

- A fleet of 220-240 Argo floats
- A fleet of 10 ocean gliders for open ocean and shelf deployments
- An array of shallow water moorings around the country to measure physical and biogeochemical variables
- The introduction to Australia of high frequency coastal radar technology to observe inshore currents the the wave environment
- A 'curtain' of acoustic listening stations on the continental shelf in Queensland, New South Wales, South Australia and Western Australia to detect fish movements
- Sensor networks on the Great Barrier Reef to detect reef responses to climate and ocean phenomena

9. The IndOOS Data Portal (*M. Ravichandran)*

During IOP3 meeting, it was decided to create a central website, wherein data from all the IndOOS observing system will be made available at one central web site. Accordingly a website http://www.incois.gov.in/Incois/iogoos/home_indoos.jsp was set up. All the primary data such as Moorings, Argo profiling floats, XBT, drifting buoys, etc are available through the links to data providers. The web page contains primary data, secondary data and products for the Indian Ocean region. Also, made available from the live access server are satellite derived sea surface temperature, sea surface height anomaly and wind vectors in gridded format. Meta data information and quality control procedures adopted by each PI are not available but are here requested to be provided the same to INCOIS who will make them available on the website. A white paper regarding IndOOS data management will be prepared jointly by INCOIS and APDRC and will be circulated to all members before publishing it.

ACTION ITEM 3. Write an overview/user guide of the IndOOS data portal (Ravichandran with assistance from P. Hacker and J. Potemra)

ACTION ITEM 4. Link the IndOOS data portal to the CLIVAR website (R. Boscolo)

10. Science talks by the new members: What future research-directions should IOP take? (*Convenor: Y. Masumoto*)

10.1. Mixed-layer temperature budget (and upper-ocean heat balance) in the Indian Ocean as a future research direction of IndOOS (Tony Lee)

The sustained measurements from the TAO moorings have allowed quantitative analysis of the mixed layer temperature (MLT) budget in the tropical Pacific from intraseasonal to interannual time scales and improved the understanding of mixed-layer physics in relation to ENSO. The MLT budget for the Indian Ocean is poorly documented but the emerging INDOOS mooring system begins to make such analysis possible.

Some of the key **science questions** that need to be addressed for the MLT budget of the Indian Ocean include:

- What are the dominant processes controlling MLT balance from intraseasonal to interannual time scales in different regions of the IO?
- Are there similarities in the physics of the IO MLT balance on different time scales?
- How does the balance vary among different IOZM events?
- How does the balance vary spatially (e.g., eq. vs. thermocline-ridge areas)?

- To what extent can one use MLT balance from a mooring location to infer large-scale MLT balance (e.g., associated with the patterns of IOZM)?
- Is the current mooring adequate and efficient in capturing dominant processes controlling MLT balance?
- Where are the areas where the air-sea heat flux works against increasing MLT (potential areas of active air-sea interaction)? What is the ocean dynamics involved?
- What is the main difference between the IO and tropical-Pacific MLT budgets? What is its implication to intermediate coupled models for the IO?
- How does the barrier layer affect MLT balance on different time scales?

The **approach** to address these questions:

- Observational analysis of MLT balance based on mooring data and satellite-derived SST & surface currents.
- Comparison with modeling and data assimilation products (both for measured quantities and for term balance).
- Provide a complete budget of MLT mooring locations using validated model/assimilation products.
- Assess the spatial (in)homogeneity of MLT balance **-** local vs. large-scale balance.
- Examine difference in MLT balance between temperature and density criteria of defining MLD – effect of barrier layer.
- Make use of a suite of assimilation products to get an assessment of uncertainty in MLT balance (be aware of issue of budget closure in some assimilation products).
- Evaluate MLT balance in coupled models (a validation process).

The study by Du et al. (2005)[1], one of the few examples of quantitative MLT analysis in the Indian Ocean, highlighted the difference in the regime of seasonal heat balance in the southeast Indian Ocean and the effect of the barrier layer. The on-going work of Indian-Ocean MLT budget using an ECCO assimilation product by D. Halkides and T. Lee of JPL show that the point-wise balance near the eastern node of the IOZM/IOD is different for the 1994 and 1997 events in terms of the role of surface heat flux, zonal advection, and vertical diffusion. The balance at 4.8ºS, 101ºE has some substantial difference from that at 0ºN, 97ºE, reflecting the spatial dependence of the interannual MLT budget.

Technical issues of MLT budget analysis:

1) Problem with budget closure due to:

- incomplete observations
- ad-hoc estimate of entrainment temperature (both in observational & model analyses)
- failure to include "detrainment" (both in observational & model analyses)
- statistical correction in assimilation.

2) Quantification of directional pathways of heat.

To quantify the pathways of heat that goes into and out of a certain region, one cannot simply average the local temperature advection in that region because the averages correspond to internal transfer of heat within the region, not external process that control the heat content. A boundary-flux formulation is needed by removing the dependence of boundary-temperature flux on temperature scale (e.g., using the formulation by Lee, Fukumori, and Tang 2004).

Expanding the scope of analysis to multi-decadal upper-ocean heat balance:

The utility of data assimilation products to analyze MLT balance can be extended to the analysis of upper-ocean heat budget in general, and for longer time scales, e.g., to address questions related to the multi-decadal warming of the upper Indian Ocean. Some ocean reanalysis products, e.g., the ECCO products based on the adjoint method and the Kalman filter smoother methods, satisfy heat conservation and have outputs of various terms contributing to temperature tendencies. These outputs greatly facilitate heat budget analysis. However, these

[1] Du, Y., T.-D. Qu, G. Meyers, Y. Masumoto, H. Saskai, 2005: Seasonal heat budget in the mixed layer of the southeastern tropical Indian Ocean in a high-resolution ocean general circulation model. *Journal of Geophysical Research-Oceans* **110** (C4): Art. No. C04012 Apr 28 2005

two products are only available for the period of TOPEX/Poseidon and JASON-1 altimeters (1992 onward). On multi-decadal time scales, the only reanalysis product that satisfies heat conservation is the 50-year ECCO reanalysis based on the adjoint method (the Germany ECCO, or GECCO product). At present, this product has not archived the budget terms like the other two ECCO products for the altimeter period. Nevertheless, IOP could convince the GECCO system developers to implement the output of budget terms for the 50-year run in the future.

There are other multi-decadal ocean analysis/reanalysis products available, e.g., the SODA product. These products are generated using sequential assimilation methods that involve tendency terms associated with incremental correction of the model state by the assimilation. Such corrections pose a major difficulty in analyzing the physical term balance of heat budget. The utility of these products for analysis of multi-decadal heat balance is possible only if the assimilation corrections and diffusive tendencies are much smaller than the advective tendencies, which is not very likely on multi-decadal time scales.

IPCC-type climate models are potentially useful to gain insight of multi-decadal heat balance as their outputs satisfy heat conservation. For these models to become useful for multi-decadal heat budget analysis, a complete output of tendency terms (those associated with advection, diffusion, and surface heat flux) would need to be archived.

*10.2. Bay of Bengal Studies (*VSN Murty)

A new observational program in the Bay of Bengal during September – October, 2007 consists as of now, of coast-coast long zonal sections and time series measurements from a moored buoy in the northern Bay. The observations to be carried out are the surface-bottom temperature and salinity data at 0.25° intervals. The possibility of occupying stations in the EEZ of Mynamar / Bangladesh is still to be worked out.

The cruise track, sampling strategy and parameters to be measured will be intimated to the IOP members soon. The possibility of participation of PMEL/NOAA technicians for deployment of Atlas moorings and flux mooring was discussed.

*10.3. IOP future directions: Dec-Cen to Climate Change? (*G. Vecchi*)*

In addition to substantial and socially-relevant intraseasonal to interannual variability, the Indian Ocean exhibits – in models and observations – changes on longer timescales, from decadal to climate change. The decadal and inter-decadal timescale variability remains to be fully documented and understood, and the extent to which it acts to modulate variability on shorter timescales is still an open research question. Further, the detection of radiatively-forced trends is limited by the presence of this decadal variability. Finally, the potential predictability of these decadal variations has begun to be explored using coupled modeling experiments, although more efforts should likely be expanded.

Questions on decadal/inter-decadal variability are:

0) What are the basic characteristics of the decadal variability of the Lee (2004)[2] type of variations (done already or underway)?

1) How does the decadal change/variability similar to that identified by Lee (2004) – c.f. also Lee and McPhaden (2007 pers. comm.) – impact modes of variability of Indian Ocean? E.g. by modifying thermocline depth in thermocline dome and other mean conditions.

2) What historical datasets are available in the Indian Ocean to help characterize the decadal and interdecadal modes of variability? What model data are available?

3) Are there paleoceanographic data that could help characterize the decadal and interdecadal variability?

4) What are the mechanisms for the decadal variability c.f. Lee (2004)? To what extent does the Indian Ocean play an active role in it? What role does the ITF play? Atmospheric bridges?

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[2] Lee, T. 2004: Decadal weakening of the shallow overturning circulation in the South Indian Ocean, Geophys. Res. Lett., 31, L18305, doi: 10.1029/2004GL020884

ACTION ITEM 5. Consider if further action is required to develop research plans for studies of surface layer heat budget (seasonal interannual time scales) and ocean processes at decadal time scales? (Y. Masumoto, G. Meyers, T. Lee and G. Vecchi)

11. Indian Ocean impacts on Africa: science talks (convenor: C. Reason)

11.1. The 2006/07 summer season over South Africa, rainfall anomalies, regional SST anomalies, forecast and verification (W. Landman)

The South African Weather Service (SAWS) issues rainfall and temperature forecasts at various time ranges, including the seasonal-to-interannual time scale. A number of forecast systems of various complexities are used by the seasonal forecasters of the SAWS to produce probabilistic forecasts for 3-month seasonal rainfall and surface mean temperature. These forecast systems include statistical models, atmospheric general circulation models (AGCMs) and AGCM forecasts downscaled to station level. In 2006, the SAWS has expanded its operational modelling capacity by introducing a nested system whereby a fine resolution regional climate model is forced by a coarse resolution AGCM. Presently, the forecasters at the SAWS consider each forecast produced by the various systems and then subjectively decide on the best estimate of the forecast probabilities assigned to three categories of below-normal, near-normal and above-normal. In addition, the SAWS has recently started to issue probabilistic forecasts of extremely dry/wet and hot/cold conditions. The SAWS is busy developing a multi-model forecasting system that will include various general circulation models of which the forecasts are first downscaled and then optimally combined to produce objective probability forecasts at station level.

The SAWS was successful in predicting high probabilities of dry and hot conditions over South Africa during the 2006/07 austral summer season. This season coincided with an El Niño event, and the various models used by the SAWS to compile a seasonal forecast were in strong agreement that the main summer season would in all likelihood be dry. Even though the season did not start poorly, dry conditions set in towards the end of December 2006 and very little rain was received over the larger part of the summer rainfall region for the remainder of the season.

11.2. Indian Ocean variability and east African climate (A. Kijazi and A. Mafimbo)

There are two main rainfall seasons in the East African region, March-April-May and October-November-December in association with the north-south movement of the ITCZ. However southern Tanzania has one long rainfall season extending from November to May. Studies have shown that the Indian Ocean is the main source of moisture for the bimodal region. Increased moisture fetch from the Indian Ocean leads to wet conditions while reduced moisture leads to dry conditions

ENSO and IOZDM have direct influence on East African rainfall variability. El Niño and positive IOZDM coincide with above average rainfall while La Niña and negative IOZDM coincide with below average rainfall. The increased rainfall during El Niño is associated with warming and easterly moisture flux convergence over the western equatorial Indian Ocean. Decreased rainfall during La Niña is associated with cooling and westerly moisture flux divergence.

Extreme climate events such as drought and floods have devastating impacts on vulnerable communities in the region ranging from loss of life, food shortages, energy crisis, disease outbreaks etc. Hence climate monitoring is crucial to minimize these impacts.

Institutions in the region have planned a number of activities for the improvement of climate monitoring. These include improvement of regional climate models and products, downscaling of global climate products to regional and national level, installation of observing platforms over the Indian Ocean and establishment of a modeling system for the region consisting of various dynamical models.

To achieve the afore mentioned activities there are number of challenges to be addressed. These include improvement of modellling data retrieval and storage, upgrading of internet connectivity with international centers for model data transfer and enhancement of observation platforms particularly in the western Indian Ocean.

The region hopes to benefit much from IOP in the achievement of the above goals through active participation in its programs and activities.

11.3. Indian Ocean and Madagascar climate variability (N. Raholijao)

The topography, North West monsoon/ trade wind circulations and the ocean are the key determinants of Madagascar climate. Mean annual and seasonal rainfall patterns reflect the prominent role of the interaction between these systems.

On the interannual time scale, Madagascar summer climate variability is a crucial issue for it can have high socio-economical impacts. The North West monsoon, the Intertropical Convergence Zone (ITCZ), the South Indian Convergence Zone (SICZ) and tropical cyclones are the main summer rain bearing systems. Investigations of the correlations (Jury et al, 1995) between the summer rainfall over the agriculturally important central highlands and the surrounding SSTs and winds highlight that January/February rainfall is enhanced by:

- Warm Sept/Oct Indian Ocean SSTs (6ºS/16ºS-52ºE/70ºE)
- Warm Jan/Feb Indian Ocean SSTs to the NE of Madagascar
- Cool Jan/Feb Indian Ocean SSTs to the south of Madagascar
- Stronger low level NW monsoon
- Upper easterlies in the tropics to the NE of the island.
- Stronger trade winds to the south of the island
- An active ITCZ and low level cyclonic vortex
- An upper trough over the Mozambique Channel to the west
- More tropical cyclones hitting the island, favoured by above normal Indian Ocean SSTs to the NE of Madagascar (5ºS-15ºS, 50ºE-70ºE) in the preceding spring, upper level easterly anomalies and QBO in east phase.

Correlation across the region also demonstrates that the interannual variability of summer convection over Madagascar is opposed to that of southern Africa owing to the existing dipole pattern in convection over the South Western Indian Ocean. In Cook (2000) the dipole pattern is interpreted as the movement of the SICZ. It is one of the determinants of rainfall spatial distribution over Madagascar during the core summer, December to February.

The 2006/2007 summer season illustrated most of the above mentioned findings. The Madagascar 2006/2007 summer season was one of the most devastating over the last decade in terms of losses in lives, infrastructure and agriculture. Drought prevailed in the south west semi arid region during the early summer (OND06) and most of Madagascar experienced flood in January/February 2007.Four tropical cyclones hit the island and among them, intense tropical cyclone Indlala (March 2007) was the most destructive . Peak rainfall amounts were recorded in January over the western coast, the central highlands and the southeastern coast. January 2007 OLR anomalies show negative values oriented NW/SE over Madagascar with minimum values observed both sides of the island in January week1 corresponding to the period of maximum rainfall amounts. Positive SSTas were observed in the Indian Ocean to the NE of the island, in the Mozambique Channel and to the south of Madagascar. Low level and upper level January 2007 vector winds anomalies in the South West Indian Ocean were typical of Madagascar above normal rainfall conditions.

Sea surface temperature anomalies are commonly used as predictors in seasonal rainfall forecasting. Madagascar summer rainfall statistical prediction models use Indian Ocean, Atlantic and Pacific SSTa as predictors. Preliminary net assessment of the 2006/2007 SARCOF (Southern Africa Climate Outlook Forum) forecast products using July 2006 SST anomalies as predictors , shows failure in predicting the early summer (OND06) rainfall and success for the late summer (JFM). These products give mean seasonal expected rainfall conditions but no indication on the associated high impact weather or extreme event. The predictability of high impact weather at seasonal time scale remains a challenge.

11.4. The Influence of the Agulhas Current on SA Weather (S. Mkatshwa)

The Agulhas current was initially studied because its location is along a major shipping route. However these studies uncovered the role of the current system in weather and climate. Statistical results demonstrate that heat losses from the Agulhas current system play an important role in regulating the weather and climate of the

Southern Africa. The average latent and sensible heat fluxes of the Agulhas current exhibit a considerable seasonal variation and the deep cumulus clouds tend to develop over the current during certain conditions especially if the wind direction is parallel to the current. The mechanism of interaction between the oceanic current and the atmosphere is not fully understood. The surface moisture fluxes within the marine boundary layer over the Agulhas current are twice those observed over the colder inshore water leading to an intensification of fronts. The proximity of the core of the current to the land further influences rainfall along the south east coast of South Africa.

The Agulhas current plays a significant role in the storm events in South Africa. It contributes to the increase of the moisture transfer and latent heat release to atmosphere. Due to the interaction between the continental low and the south Indian ocean anticyclone, heavy rainfall and tornados take place in various locations. Accounting for the Agulhas current can improve weather forecasts.

11.5. Numerical Weather Prediction at the SAWS, short and medium range and THORPEX link (W. Tennant)

A brief overview of numerical weather prediction at the South Africa Weather Service (SAWS) was presented. Emphasis was placed on the locally implemented Met Office Unified Model regional domain (SA12) covering southern Africa and adjacent oceans. The benefit of doing local data assimilation in the SA12 domain was also shown. Examples of model and human forecasts was shown for a tropical cyclone (Favio) and a strong cut-off low over the SW Indian Ocean using the SA12 and ensemble forecasts downloaded from NCEP.

11.6. Activities in Oceans surrounding South Africa (J. R. van der Merwe)

The SAWS maintains manned weather stations in Gough, Marion and Antarctica as well as a couple of automatic weather stations on remote islands. SAWS participates in the international drifting weather buoy program by contributing to 3 action groups covering the region of South Atlantic, Indian Ocean and Antartica. The majority of the drifters are from NOAA/AOML with barometric upgrades by SAWS. Given this activity, the SAWS can offer deployment opportunities on relief voyages, services at ports Durban and Cape Town, assistance with deployments of SVPs, Argo floats and XBTs.

The SAWS has up to now concentrated on deployments in the South Atlantic, mainly for weather forecasting. Buoys generally drift into the Indian Ocean. However if additional deployments are required for climatologic research, then SAWS would like to be informed. The challenges are:

- Lack of offshore wind data along west coast.
- Cost of moored wind buoys.
- Logistical support to maintain moored buoys.

SAWS is involved in regional capacity building:

- A guest from Tanzania Weather Service was invited to participate in a voyage to Gough in October 2005.
- A guest from Namibia Weather Service was invited to participate in a voyage to Antarctica in December 2005 ~ January 2006.

12. Circulation of the SW Indian Ocean and Rationale for Monitoring the Agulhas Current system (*W. de Ruijter)*

Monitoring the Agulhas Current is a powerful way to keep one's "finger on the pulse" of intraseasonal to long-term variability across the Indian Ocean. As the western boundary current of the South Indian Ocean, the Agulhas accumulates, and effectively integrates, signals of circulation and water mass variability from around the basin. For instance, there is evidence to suggest that tropical variability, related to monsoons and Indian Ocean Dipole (IOD) events and shifting of atmospheric wind patterns associated with climate change can cause variability in the Agulhas Current. In addition, heat and freshwater fluxes of the Indian Ocean, as well as its overturning circulation, are linked to the vertical structure and strength of the Agulhas. Finally, variability in water masses related to changes in atmospheric forcing may be best detected within the Agulhas Current, where waters from disparate sources converge, such as Red Sea Water, tropical waters, and mid-latitude mode waters.

Among the world's western boundary currents the Agulhas Current has a uniquely global significance. It feeds an inter-ocean transport of warm and saline waters into the South Atlantic which directly impacts the strength of the Atlantic meridional overturning circulation. This makes Agulhas monitoring of importance not just for Indian Ocean variability, but for global climate. Despite its significance, the Agulhas Current remains poorly measured, such that its annual, interannual, and longer-term variability remain unknown.

Satellite altimeter observations of sea surface height variability over the Indian Ocean show a region of maximum variability in the Agulhas retroflection and a return current that appears connected to the north with the variability in the Mozambique Channel and that around the southern tip of Madagascar. These regions connect to two zonal bands of variability across the Indian Ocean around 12ºS and 25ºS. These are the major routes along which anomalies of tropical and subtropical origin propagate. On reaching the western boundary current region these anomalies in turn may trigger instabilities that eventually lead to Agulhas retroflection loop occlusion, Agulhas ring shedding and 'leakage' into the South Atlantic.

Among the world's western boundary currents the Agulhas Current has a uniquely global significance. By direct leakage and ring shedding it feeds an inter-ocean transport of warm and saline waters into the South Atlantic, which directly impacts the strength and stability of the Atlantic meridional overturning circulation. This makes Agulhas monitoring of importance not just for Indian Ocean variability, but also for global climate. Despite its significance, the Agulhas Current system remains poorly measured, such that its annual, interannual and longer-term variability remain largely unknown. Upstream, in the Mozambique Channel, Dutch scientists are maintaining a long-term monitoring array, which is part of their Long-term Ocean Climate Observations (LOCO) program. It is proposed to extend the LOCO program with the addition of an array in the East Madagascar Current over the period 2009-2011. It is proposed to combine this with an Agulhas Current moored array over the same period. That would create a unique program covering the greater Agulhas system. The Agulhas array would be best positioned off East London, South Africa. This position coincides with both good satellite altimeter coverage and a still relatively stable current trajectory.

The value of simultaneously maintaining three moored arrays will be considerably increased by sequentially releasing acoustically tracked RAFOS floats at the upstream arrays and tracking them as they drift to and through the downstream array. Concurrent experiments would allow for significant sharing of resources, shiptime and expertise. Local South African oceanographers of international repute will also participate in this Agulhas monitoring/pilot program. Together, the moored and Lagrangian data would yield an unprecedented, synoptic view of the strength and variability of the major ocean currents in the southwest Indian Ocean and enable a direct evaluation of the teleconnections between the tropical and subtropical regions, the Agulhas and the global overturning circulation. An initial pilot study for two years is proposed, with continuation for long-term monitoring using an optimal array design based on the information and analysis from the pilot.

ACTION ITEM 6. Comment on the Agulhas monitoring proposal (all members) and assess the proposal based on comments (G. Meyers and Y. Masumoto)

13. Air-Sea heat, freshwater and momentum fluxes in the Indian Ocean (*L. Yu*)

SST in the Indian Ocean has been rising in recent decades as part of global ocean warming. The air-sea fluxes of momentum, heat, and freshwater, being intimately coupled to SST, have also shown long-term trends. A survey has been carried out of time series of net heat, evaporation-precipitation, and wind stress from NCEP and ECMWF reanalyses, satellite- and ship-based analyses, and blended analysis products for the period from early 1980s to present. It is found, however, a reliable quantification of the magnitude of the trends is difficult to obtain due to large uncertainties in climate flux datasets.

One common feature among all products except ERA40 is the increase in latent evaporation in concert with SST rising, with maximum amplitude occurring in the eastern and central equatorial Indian Ocean. This is consistent with the Clausius-Clapeyon relation, which states that warmer air holds more moisture and warmer sea surfaces cause more evaporation and so the evaporation rate increases under the warming. The trends in surface radiation budget vary with data products. Satellite products are plagued by the gap over the area centered on 70°E, where there is no coverage from geostationary satellites. Ship-based analysis at the National Oceanography Centre, Southampton, UK., indicated an overall decrease of about 3 Wm^{-2} in solar incoming radiation over the 20-year period starting from 1980; while the reduction in ERA and NCEP solar radiation was much larger, reaching at about 15 Wm^{-2} and 10 Wm^{-2} respectively. Despite the differences, none of the datasets showed an increase in net heating into the ocean – in stark contrast to the fact that the Indian Ocean has been steadily warming up.

The long-term change in precipitation in the Indian Ocean cannot be decided using available datasets. The two satellite-based datasets GPCP and CMAP, though constructed from similar satellite retrievals and similar approaches, produced trends with opposite directions. GPCP showed an enhanced precipitation, while CMAP projected a reduced precipitation. When combined with the upward trend in evaporation, the E-P flux based on CMAP suggested a large deficit in regional freshwater budget that should be accompanied by an increase of upper ocean salinity. How realistic this projection is, can only be determined by data-assimilated models and long-term sustained in situ observations.

Also shown in all products, including NWP reanalyses, satellite- and ship-based analyses, is an increase in wind speed over the Indian Ocean basin. Yet, there exist no reference time series that are sufficiently long to validate the climate trends in either wind stress, or heat, or freshwater fluxes. The flux buoy time series obtained from the integrated Indian Ocean Observing System (IndOOS), though available at limited locations and for limited periods, have already demonstrated their value in identifying biases in flux data products, analyzing upper ocean heat budgets from intraseasonal, seasonal, to interannual timescales, and improving the understanding of key air-sea coupling issues in the Indian Ocean. To track and understand the decade long changes that are occurring, observations from IndOOS should be sustained and long-term.

14. 2006 IOD Predictions (*Y. Masumoto*)

A comparison has been made of prediction experiments of the IOD in 2006 among three coupled forecast models, SINTEX-F, GFDL CM2.1, and POAMA. Forecast plumes of the IOD indices indicate significant differences among the models; e.g., SINTEX-F predicted the 2006 positive IOD consistently from Nov. 2005, while the positive IOD conditions were not captured by the other models. On the other hand, the 1997 event was consistently predicted by the GFDL model with a lead-time longer than six months, while SINTEX-F is unsuccessful in predicting the correct evolution of the event. It is also found that, even with the same model, the predicted evolution of the indices differs significantly among forecasts from different initial conditions.

To explore a possible cause of these differences in the forecasts plumes, the depth of 20ºC isotherm anomaly (D20a) field is compared between SINTEX-F and POAMA outputs. It turns out that the D20a in the SINTEX-F initial conditions for different starting months has some dissimilarities in the tropical region and that the D20a initial conditions of POAMA is of opposite sign in the western equatorial Indian Ocean. The subsurface conditions, apparent in D20a field, can be considered as an important factor for determining the subsequent evolution of the IOD in the coupled forecast models. Further studies are required to clarify the causes of the large differences in the IOD prediction plumes.

The panel recognized the importance of the intercomparison of the coupled forecast models available for the IOD predictions and encouraged conducting the studies in collaboration with AAMP.

15. NOAA's Objectives in Establishing Indian Ocean observing Partnerships *(S. Thurston)*

The United States contribution to the Global Earth Observation System of Systems (GEOSS) is the Integrated Earth Observation System (IEOS). IEOS is expected to satisfy US requirements for high-quality, global, sustained information on the state of the Earth for policy decision makers in many sectors of society. In many geographic regions observations are already being collected, while in some areas there remain gaps that need to be filled. NOAA has undertaken an initiative to implement increased global ocean observations for GEOSS and the UNFCCC via the GCOS Implementation Plan (GCOS-92), to include the Indian Ocean. NOAA's Office of Climate Observation (OCO) was established to manage the implementation of NOAA's in-situ, operational ocean observations for climate, however, they are also providing ocean data for many other uses. NOAA OCO manages the tropical array of moorings in the equatorial Pacific (TAO) and Atlantic (PIRATA), the global surface drifters array, Argo profiling floats, global sea level networks, polar observations, ships of opportunity XBT networks, global carbon and hydrographic surveys and ocean reference stations. The mission of OCO is to build and sustain a global climate observing system that responds to the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments. The OCO objectives are contributing to instrumentation of the global oceans and are consistent with the objectives of IndOOS as stated in the IOP implementation plan.

While the Indian Ocean is one of the most sparsely sampled basins in the world, as we begin to understand its effects around the globe, it is also becoming one of the most important basins for observations. With the Indian Ocean influencing the monsoons and climate variability in the region as well as potentially playing a role in the western United States precipitation patterns on decadal time scales and influencing El Nino through the Indonesian throughflow, NOAA has been deploying drifting buoys, XBTs, Argo floats and tide gauges into the region for years. NOAA expanded its tropical mooring array into the basin in October 2004 as part of the fruitful Partnership with India's National Institute of Oceanography (NIO) with ATLAS deployments from the Indian ORV *Sagar Kanya*.

The Ministry of Earth Sciences (MoES) of India and NOAA are currently establishing a Partnership program in climate research and measurements.

The purpose of the MoES-NOAA Partnership is to study the variability of weather and climate over the Indian subcontinent and its linkage to behavior elsewhere, with the aim of improving predictions. NOAA plans to continue Indian Ocean mooring and other instrument deployment. Ship-time, however, is the principal constraint to this expansion. To achieve NOAA's objectives in this basin, there is the need for long-term regional partnerships that include reliably scheduled ship-time. In addition to NOAA's long and fruitful relationship with the Japan Marine-Earth Science and Technology Center (JAMSTEC) in the western tropical Pacific and now close coordination in the Indian Ocean, and emerging Partnership with India's Ministry of Earth Sciences, NOAA is also developing partnerships with institutes of Nations located in the Indian Ocean region under the initiative known as *PArtnerships for New GEoss Applications*, *PANGEA.* This capacity building initiative provides in-country training to local decision-makers and scientists on the socio-economic applications of ocean data by US experts in exchange for shiptime to NOAA for instrumentation deployments. By including policy and budget officials at these meetings and demonstrating the economic benefits realized from ocean data, it is expected that new resources can be acquired for regional ocean observations and capacity building activities.

Since the last IOP-3 meeting, a promising NOAA partnership is emerging with Indonesia via InaGOOS with the Ministry of Marine Affairs and Fisheries (DKP). A NOAA-supported capacity building workshop was held in Bali in June 2006 to enhance in-situ ocean observations in the eastern Indian Ocean while also demonstrating the practical socio-economic applications of these ocean data for fisheries, agriculture, climate and marine hazards risk management. A second capacity building workshop tailored for fisheries applications of ocean data was supported by NOAA in Bandung Indonesia in September 2006 at the Bandung Institute for Technology ITB. In exchange for these two socio-economic in-country applications training workshops by US experts, Indonesia provided shiptime to NOAA for ATLAS climate mooring deployments aboard their Research Vessel Baruna Jaya-1 in November 2006. A Radio-Internet (RANET) and Education Capacity Building and Training workshop will be supported by NOAA in Bali this August 2007 in exchange for the deployments of NOAA ATLAS Climate moorings in conjunction with the deployment of one NOAA DART Tsunami mooring off Sumatra. Each of the twenty-one DKP major fishing ports of the Indonesian archipelago will be equipped with RANET receivers, antenna and computers to receive emergency marine hazards warnings, ocean content information such as SST as well as educational-related announcements.

The Indonesian Throughflow (ITF), is a significant part of the ocean system of interocean fluxes, ocean-scale heat and freshwater budgets and sea-air fluxes. The ITF was measured during the NSF funded INSTANT program from January 2004 to November 2006, and by the NSF funded Arlindo program from December 1996 to July 1998. Immediately after the INSTANT moorings were recovered in November 2006, with NOAA's Office of Climate Observation (OCO) support, a single mooring at the site of the INSTANT MAK-WEST (2°51.11'S; 118°27.33'E) was deployed. This was done to avoid a data gap between the INSTANT time series and the long-term NOAA OCO sponsored ITF measurement program, to begin in late 2008. A transfer function based on the Arlindo and INSTANT time series will allow the MAK-WEST data to be converted to a full Makassar ITF. It is important that a long-term time series be based at the MAK-WEST site where archived records can provide a reliable indicator of the Makassar and perhaps the entire ITF. The NOAA Makassar mooring will be recovered and redeployed in November 2008, officially beginning the NOAA long-term ITF measurement program.

Before scheduling the recovery of the MAK-WEST mooring in November 2008 an Implementation Agreement (IA) will be signed between Lamont-Doherty Earth Observatory of Columbia University and the Agency for Marine and Fisheries Research, Indonesia. The IA will define the program objectives, the responsibilities of each side, associated training for mooring maintenance and associated data processing and quality control activities. Training of Indonesian students and technical staffs in the ability to maintain deep-sea current meter moorings and processing and analysis of data obtained from the moorings will be provided.

Since the initial IOP Implementation Plan High-Level Review (HLR) two years ago in Bali there has been much progress in the implementation of IndOOS as well as the applications of these new ocean data for societal benefits. There has also been increased political interest in earth observations in general as a result of the Global Earth Observation System of Systems (GEOSS) initiative. With this recent activity and visibility, a second High-Level Review (HLR-II) is proposed to be held in conjunction with the next IOGOOS-V in Phuket Thailand. The Review Panel (RP) is expected to be broadly comprised of high level persons drawn from member countries of the IOGOOS Regional Alliance, and interested potential new members who are willing to advance GOOS in their Country and actively contribute to its extension in the Indian Ocean region and adjacent connecting regions. The RP will be requested to provide input and guidance in response to the IOP briefings as well as an update on their National contributions and implementation plans to IndOOS since the last High-Level Review at IOGOOS-III. A review of updated stakeholders' interests for IndOOS data and their social, economic and environmental outputs/outcomes and benefits as well as an assessment of available and future resources towards completing the IndOOS implementation milestones should also be discussed.

ACTION ITEM 7. Determine the feasibility and organize a 2nd IOP High Level Progress Review at IOGOOS-IV (~ November 2007), potentially including names for the Resources Board (S. Thurston and D'Adamo)

16. Preliminary results from process studies and plans for future process studies (convenor: G. Meyers)

16.1. The CIRENE Cruise: preliminary overview (J. Vialard)

The Seychelles-Chagos thermocline ridge of the Indian Ocean has recently attracted a lot of interest, with studies of its intraseasonal and interannual variability, and its potential impact on tropical cyclones. The Vasco-Cirene experiment, in early 2007, has been designed to provide oceanic, atmospheric and air-sea fluxes in this region in winter, and to contribute to the observing network in this region.

Due to an Indian Ocean Dipole (IOD) climate anomaly of late 2006, there were unusual conditions in the Indian Ocean during January and February 2007. The thermocline ridge between 5°S and 10°S, that is also a cyclone genesis region, had stronger than usual heat content. The Cirene oceanographic cruise and Vasco field experiment allowed us to collect oceanic, atmospheric and air-sea fluxes observations during this unusual period. Vasco-Cirene also contributed to the development of the Indian Ocean Observing System (deployment of an ATLAS mooring and 12 Argo profilers).

Cirene measurements show that the IOD was associated with deeper than usual thermocline, warmer and fresher surface ocean and eastward currents above 0.2 $m.s^{-1}$ down to 800m. At the synoptic scale, our dataset sampled the initiation and development of cyclone Dora. Before the cyclogenesis, we observed high surface temperature and strong diurnal warm layers. We also observed the upper ocean cooling and currents associated with various phases of the cyclone.

The Vasco (Validation of the Aeroclipper System under Convective Occurrences) component of the experiment allowed testing of a new observation platform. The Aeroclipper is a profiled balloon carrying an instrumented guide rope in contact with the ocean surface, that freely drifts with surface winds and maximises observations in low level convergence regions associated with convective systems. During Vasco, two of these Aeroclippers survived in the tropical cyclone Dora, enduring wind speeds larger than 40m/s and giving continuous estimates of the wind as a function of the eye distance. The two Aeroclippers then stayed confined into the eye of Dora for more than a week and remained captured in the low-pressure center when Dora became an extra-tropical depression.

We observed a whole range of fine scale atmospheric (e.g. dry intrusions) and oceanic (e.g. diurnal warm layers, fresh water lenses, double diffusive mixing, baroclinic tides) structures during Vasco-Cirene. The analysis of observational data and the accompanying modelling studies will now try to investigate the importance of these basic physical processes at synoptic to intraseasonal time scales. No strong intraseasonal response of the ocean to convection was however observed during Cirene. The idea of a coordinated international experiment to study both intraseasonal ocean response and cyclogenesis has emerged during this IOP meeting and will be explored in the near future.

16.2. Early Results from and Updates on MISMO (K. Yoneyama)

The field experiment MISMO (Mirai Indian Ocean cruise for the Study of the MJO-convection Onset) took place in the central - eastern equatorial Indian Ocean during October - December 2006. The aim of MISMO is to capture the atmospheric and oceanic features of the equatorial Indian Ocean when convection in the Madden-Julian Oscillation (MJO) is initiated. At this meeting, preliminary results as well as recent activities related to the MISMO were presented.

During the intensive observation period from October 24 through November 25, a buoy array with two m-TRITON buoys, three ATLAS buoys, and four sub-surface ADCP moorings at (1.5°N, 80.5°E), (0°, 82°E), (1.5°S, 80.5°E), and (0°, 79°E) was constructed and stationary observations by the R/V Mirai at (0°, 80.5°E) were conducted from October 28 to November 21. In addition, with the aid of the Maldives' Department of Meteorology, meteorological observations at three islands (Gan, Hulhule, and Kadhdhoo) in the Republic of Maldives were also carried out to construct the large-scale flux array with the R/V Mirai.

Intensive observations were carried out under the relatively strong positive Indian Ocean Dipole (IOD) event. Since in-situ observation during the IOD has not been done before, we believe we obtained very unique data during MISMO. From the satellite-based cloud data, it was confirmed that MJO-convection developed in mid- to late November, and large-scale cloud systems moved eastward in early December. Since the R/V Mirai stayed in a fixed position in November, and cruised eastward in early December, we could observe both phase shift from convectively inactive to active at the fixed site in November and inside of the active MJO-convection in December. Therefore, although the ADCP mooring data at (1.5°N, 80.5°E) were lost due to technical trouble, observations were generally well conducted to capture the atmospheric and oceanic features related to MJO-convection onset.

Preliminary results revealed that while local instability such as moist static energy in the lower troposphere and the moistening of mid-troposphere by congestus clouds played some roles for gradual change from inactive to active MJO phases, dramatic enhancement of cloud activity happened just after the upper tropospheric wind changed from westerly to easterly in one-day (November 16). From the analyses of satellite and reanalysis data, it was shown that this change of wind direction was induced by westward propagating Rossby wave. The relationship among these parameters will be further analyzed.

A diamond-shaped ocean observation network centered at 80.5ºE on the equator was developed, to understand ocean responses to the atmospheric intraseasonal variability through the calculation of the mass and heat budget in the upper-layer. Although the ADCP located at 1.5ºN did not work appropriately, other data from JAMSTEC buoys were successfully obtained. The data indicate rich ocean variations associated with the intraseasonal variability under the strong positive IOD event in 2006. The volume budget analysis in the southern triangle region shows an intense upwelling event around Nov 5, 2006, associated with the large amplitude intraseasonal variability in the meridional currents. This strong upwelling of the strength of more than 10 m/day is accompanied by the distinct upward movement of the isotherms at the depth of 270m and by a significant variation of chlorophyll-a concentration at the thermocline depth.

Quality checks for data have been mostly done and MISMO participant researchers are now extensively analyzing them. Data obtained during MISMO will be opened to the public through the MISMO web site at http://www.jamstec.go.jp/iorgc/mismo/ and it may start from the mid-December 2007.

ACTION ITEM 8. After confirmation with K. Yoneyama and J. Vialard, engage the interest of AAMP, VACS and GSOP in a multi-national experiment in 2012 following from MISMO/Cirene (G. Meyers and Y. Masumoto)

16.3. *On the use of Hydrometeorological ARray for Isv-Monsoon AUtomonitoring (HARIMAU) Radar network in the Indian Ocean monitoring system* (F. Syamsudin)

HARIMAU has been selected as a 5-year project (FY2005-2009) under the JEPP (Japan Earth observation system Promotion Program) as a contribution of Japan to GEOSS (Global Earth Observation System of Systems). The major objective of HARIMAU is to install a radar-profiler network over the Indonesian maritime continent (IMC), and to establish both scientific understanding and practical concepts of intraseasonal variations (ISVs) and their interactions with larger/smaller scale phenomena. The main objectives of HARIMAU are:

- Improve understanding of intraseasonal variability (ISV; period of 60-90 days) in terms of convective and rainfall events over the maritime continent. These phenomena might have a great effect on global climate modes, such El-Nino Southern Oscillation (ENSO) and theIndian Ocean Dipole mode (IOD), through tropical ocean-atmosphere interaction.
- Contribute to prediction of and preparation for natural disasters such as flush flood, landslip, drought, and air pollution, caused by extraordinary weather in relation to the ISVs, by monitoring the atmosphere continuously and distributing real time data to governmental institutions.
- To provide data for climate variability and change studies. Provide information to socio-economic sectors such as agriculture, water resources management, aviation, air pollution control. Improve capacity building for younger scientists.

After a Memorandum Of Understanding (MOU) stating collaborations for HARIMAU between JAMSTEC and BPPT (Indonesian Agency for Assessment and Application of Technology) had been signed in July 2006, the first HARIMAU observation station equipped with two meteorological Doppler radars were installed in Sumatera Island in October 2006. Observations showing where and how much rainfall occurs are freely available in real time on the internet (http://www.jamstec.go.jp/iorgc/harimau/) In March 2007 two wind profilers were installed in Kalimantan and Biak (near Papua), and in September 2007 another meteorological radar will be installed near Jakarta in Jawa. A central facility to collect and archive data of all the stations will be also established in Jakarta, which will be a regional center for multi-lateral scientific approaches such as MAHASRI and Asia Monsoon Year (AMY) intense observations in 2008/09. The data will be used also in Indonesian domestic operational agencies and sent to the world-wide operational meteorological network. In 2008 one more wind profiler station will be constructed in Sulawesi. Some preliminary results of HARIMAU Intensive Observation Period (IOP) in collaboration with the "MIRAI Indian Ocean cruise for the Study of the MJO-convection Onset (MISMO)" were shown. The IOP was conducted during 23 October – 26 November, 2006 on west Sumatera and Siberut island off west Sumatra water.

The eastern Indian ocean is a region subjected to interannual, seasonal, intraseasonal and smaller scale events that directly impact on the Indonesian environment. Future process studies should address:

- How much water contributes to the freshening of ITF? This will lead to understanding changes in the ITF intensity and how it influences the Eastern Indian Ocean dynamics that have direct impact to the climate in this region
- How does the diurnal signal of rainfall over the IMC modulate the intraseasonal variation?
- How to exploit the radar-wind profiler data for operational oceanography and validation of models for climate predictions

Indonesia marine research facilities that could be shared under the Indian Ocean Monitoring Program include: 6 modern research vessels of Baruna Jaya belonging to BPPT, the tide gauge network along the Indonesian seas belonging to Bakosurtanal and the NOAA receiving system belonging to LAPAN.

The Indonesian collaboration with NOAA-USA and Germany on the Tsunami buoy program were also presented as well as the 22 planned locations.

17. Making use of ocean analysis/reanalysis products for Indian-Ocean Research *(T. Lee)*

CLIVAR/GSOP & GODAE are coordinating an ongoing effort to inter-compare global ocean analysis/reanalysis products geared towards climate applications.

- Approximately a dozen groups/products participated in the 1st meeting for inter-comparison (Aug.31-Sep.1 2006 ECMWF).

- Highlights of some inter-compared quantities related to the Indian Ocean: (1) top-300 averaged T, (2) ITF transport, (3) DMI index.
- How can IOP take advantage of these products for IO research?

Examples of inter-comparison quantities:

(1) T300 estimates from various products for the Indian Ocean are not as consistent as those of the Pacific, reflecting the lack of observational constraints, but all products appear to show an overall warming since the 1970s.

(2) ITF transports (volume, heat, and salt) and DMI indices from various products are relatively consistent.

What can IOP use these products for?

- Validation of the reanalysis products using IO data (one such effort has been initiated by Arnold Gordon for INSTANT data).
- If consistency is found, use reanalysis fields to further interpret the data.
- For a variability of a quantity for which different products show consistency, one could examine the processes associated with such variability.
- Poorman's estimate of uncertainty.
- Changes in meridional and gyre circulations.
- Heat budget analysis: (more reliable for seasonal-interannual than decadal time scales).

18. SIBER: Sustained Indian Ocean Biogeochemical and Ecological Research *(R. Hood)*

SIBER was initiated in 2005 with funding from the U.S. NSF (Office of International Science and Engeering workshop grant to R. R. Hood). This support was augmented by a major contribution from the National Institute of Oceanography, Goa, India. Additional funding was provided by several other international agencies including SCOR (Scientific Committee on Ocean Research), IMBER (Integrated Marine Biogeochemical and Ecosystem Research), the WIOMSA (Western Indian Ocean Marine Science Association), the Indo-US Science and Technology Forum and IOC/IOGOOS (Intergovernmental Oceanographic Commission), along with contributions from individual countries such as Australia, Kuwait, Oman and Pakistan.

SIBER emerged as a result of the potential opportunity to leverage the planned CLIVAR/GOOS Indian Ocean mooring array and associated servicing and support cruises. The overarching goal is to develop a new, parallel program in the IO focused on sustained biogeochemical and ecological research, with the mooring array providing a physical observational foundation. SIBER also represents an opportunity to promote interdisciplinary, international collaboration and research in the Indian Ocean, which is long overdue - the last major program was JGOFS, over 20 years ago. Another important motivation is that the Indian Ocean is interesting and very different scientifically from the Atlantic and Pacific. It is one of the last great frontiers for ocean biogeochemical and ecological research.

The SIBER workshop was convened in Goa at NIO, October 3-6, 2006. There were 44 invited speakers, seven theme sessions, and more than 50 Poster Presentations. More than 200 registered participants attended from many nations. The topics were basin-wide in scope. The seven theme sessions included: 1) Atmosphere-ocean interactions and physical oceanography, 2) Nutrient cycling and limitation, 3) Biological production, export and remineralization, 4) Pelagic carbon cycling and air-sea exchange, 5) Anthropogenic impacts, 6) Benthic biogeochemistry and ecology, and 7) Future plans and technologies.

Some knowledge gaps and major questions that were identified at the workshop include the need to do 1st order basin-wide descriptive science, investigate zooplankton grazing impacts in the Arabian Sea, and determine the extent and impact of Fe limitation in the Arabian Sea and elsewhere in the IO. There is also a need to develop a better understanding of the biogeochemical differences between the Arabian Sea and the Bay of Bengal, and there is a lack of knowledge about shelf denitrification in the Bay of Bengal. Finally, there is a need to better quantify N_2-fixation rates and net nitrogen flux, understand anthropogenic impacts, especially in the Bay of Bengal, and better constrain the basin-wide carbon flux in the IO.

Progress to date from the workshop includes the submission of several research proposals to the U.S. NSF, and the R.V. Roger Revelle has been secured for AS biogeochemical research during summer/fall of 2007. Review Articles on the SIBER workshop have also been published in CLIVAR Exchanges, IMBER Newsletter, and

AGU/EOS. Workshop products still under development include the development of a SIBER Science Plan, and the compilation of an AGU Monograph and an IJMS Special Issue from the workshop presentations. A follow-up workshop is planned for the Fall of 2007 at NIO in Goa to develop the science plan, but additional funding still needs be secured.

IMBER and IOGOOS provide the logical international programmatic home for the SIBER effort.

19. Climate Change and Coral Reefs: improving climate and ocean information in coral bleaching studies *(D. Obura)*

In 1997-8 and 2006-7 positive phases of the ENSO and the Indian Ocean Dipole occurred. In 1997-8 sea surface temperatures exceeded long term maxima by >1°C for over 2 months, associated with unusually calm conditions. The result was a mass bleaching and mortality of corals throughout the region, except in Mauritius and Reunion where a cyclone shielded the islands and caused water mixing. Scientists recorded bleaching levels averaging 50-80%, and to near 100% in the worst impact reefs from February to May 1998, and similar levels of mortality within a few months. Overall coral cover decreased by about 66%, with progressive recovery being recorded each year since then. Coral species diversity decreased by approximately 30% on study reefs in Kenya. Differences in the resistance and resilience of corals to thermal stress – between sites and regions and at intra- and inter-specific levels is a major area of research to better understand past events and predict future vulnerability.

Without rapid adaptation, scientists predict that global warming trends will exceed the bleaching thresholds of corals with return times of 1-5 years within 20-50 years, in the major coral reef biomes. If this is the case, the prognosis for coral reefs is poor. However many factors may alter this prediction including adaptive capacity of corals and/or zooxanthellae, and whether physical or climate variability and trends may alter the expected rise in sea surface temperatures.

Increasing the use of climate and oceanographic information in coral reef studies will contribute significantly to improving science and management of coral reefs. Possible areas for future collaboration with the IOP, likely through the development of an IOGOOS programme on coral bleaching include the following:

1. Establishing a coral bleaching early warning system as part of the IUCN Climate Change and Coral Reefs working group, to best utilize available information and expertise on Indian Ocean climate and ocean variability.
2. Analysis of 1997-8 and 2006-7 ENSO/IOD and coral bleaching event, in comparison with other years in which mild or no bleaching were observed. Multiple scales could be considered:
   a. Ocean scale - East Africa, islands, South Asia, Andaman Sea.
   b. Meso scale - East Africa mainland coast - latitudinal sequences north and south.
3. Contributing climate and oceans information to climate vulnerability assessments of coral reefs and other systems in Indian Ocean countries (e.g. current projects in Madagascar, Tanzania, Kenya).
4. Generation of specific products needed to support components of a climate vulnerability analysis of coral reefs such as connectivity models at ocean-basin, meso-scale and with coastal/tide interactions to give information on forcing functions, recruitment/dispersal and sedimentation/pollution dispersal.

20. Western Australian Marine Science developments relevant to IOP *(N. D'Adamo)*

A number of recent Western Australian marine scientific initiatives potentially relevant to the Panel's overall objectives and scientific programs were reported. These programs cover Western Australia's marine ecosystems of the tropical north/northwest, the tropical/temperate transition zone of the west coast and the temperate south. The presence of the unique poleward flowing Leeuwin Current down the Western Australian coastline is principally responsible for this idiosyncratic latitudinal gradient in marine biodiversity, as described at the first Leeuwin Current Symposium of the Royal Society of Western Australia held in Perth, Western Australia during 1991 (eds A F Pearce and D I Walker (1991), *J. Roy Soc. of W. Aust. Vol 74*). The second such symposium is to be held in Perth on 22 September 2007.

Western Australian Marine Science Institution (WAMSI): 2007-2012.

WAMSI (www.wamsi.org) is a virtual research institute based in Perth, Western Australia that brings together industry, academia, government agencies (State and Federal), and Federal marine science research organisations in a collaborative partnership. WAMSI aims to support sustainable development of the State's marine resources and the conservation of its biodiversity, especially in marine protected areas such as the Ningaloo Marine Park (northwest Australia). Several key research areas have been identified, and these are mutually interlinked by three integrating science themes: *ocean systems forecasting*; *biodiversity conservation;* and *natural resources development and management*. These interlinked science themes underpin a cluster of output-focused 'Research Nodes' with each Node concentrating on a particular area of research covering these overarching themes. The work will be driven by key government policy issues to provide outcomes of benefit to Western Australia through economic, environmental and social dividends. The award of $AUS21 million of Western Australian State Government funding to WAMSI will leverage a further $AUS30 million of in-kind and cash support from the collaborating partners.

WAMSI's current marine scientific research emphasis is on the following six interlinked biophysical areas, with the key geographical focus being on Western Australia's nearshore/shelf zone, but with necessary attention to scales that couple the shelf with open ocean processes. The inherent science programs in these six themes cover disciplines that include biology, geochemistry and physical oceanography. See www.wamsi.org for further detail.

- Node 1: Strategic Research on Western Australian Marine Ecosystems;
- Node 2: Climate Processes, Predictability and Impacts in a Warming Indian Ocean;
- Node 3: Managing and Conserving the Marine State: Best Practice Management and Underpinning Science;
- Node 4: Sustainable Marine Ecosystems: Ecologically Sustainable Development for the Marine State's Fisheries;
- Node 5: Marine Biodiscovery, Biotechnology and Aquaculture: the Blue Farm;
- Node 6: Ocean Science for Offshore and Coastal Engineering.

In respect to the prospect introduced at this workshop for the formation of a bio-geochemical program/panel for the Indian Ocean (akin to the oceanographically based CLIVAR/GOOS Indian Ocean Panel), under the ambit of **SIBER** (***Sustained Indian Ocean Biogeochemical and Ecological Research***: see abstract by Dr Raleigh Hood, this meeting) and Coastal GOOS, WAMSI with the associated marine scientific community of Western Australia has the potential to form relevant and strong links, particularly through the bio-geochemical programs of Nodes 1 and 3. Node 1 will focus on cross shelf characterisation and modelling of the bio-geochemistry off central Western Australia, covering nearshore (lagoons/embayments), shelf and continental slope domains (including the influence of the Leeuwin Current and wind driven coastal counter currents). Node 3 will include detailed characterisations of oceanographic processes (including characterising and modelling of wave pumping over reefs), and research into life cycle processes (eg coral and fish recruitment, herbivory). Some work on the bio-geochemical processes at work within and between lagoons and adjacent oceanic waters will be undertaken. Node 4 of WAMSI will focus on understanding the marine processes that drive and maintain fisheries off Western Australia. Ecosystem based studies will feature in this respect and some of the key research areas will focus on community structure, biodiversity assessments, habitat mapping, trophic interactions and cascades, and ecosystem based modelling.

Oceanographic research in the Indian Ocean off Western Australia figures most prominently in Nodes 1, 2, 3 and 6 of WAMSI.

In Node 2, the region of interest is the Indian Ocean and the sub-Antarctic Southern Ocean, upwind from Western Australia in the westerly air-streams. The research will identify links between large-scale anomalies in oceanic structure and impacts on the marine environment off Western Australia. The research will address oceanographic research relevant to the climate of Western Australia. It will focus on identifying ocean-processes that feed back to the atmosphere and give persistence and predictability to climate anomalies. The three key projects of Node 2 (www.wamsi.org) will be:

- Predictability of the Indo-Pacific ocean regions as a global condition on marine and terrestrial climate impacts in Western Australia.

- Dynamics and impact of the Leeuwin Current on the marine environment off Western Australia.
- Oceanic conditions at Ningaloo Reef through an analysis of downscaling ocean climate in the Ningaloo Reef Tract (using nested models and downscaling from 1000s km to 10s km to $\leq$ 1km).

Node 2 will address the question of "… will the oceanographic processes that are intimately linked to the health and condition of Western Australia's marine and coastal ecosystems change as the global climate changes?".Node 2 will have strong connections to **Bluelink** (below).

Intensive research on the presence and effect of internal wave breaking on continental slope domains will figure prominently in Node 6, as relevant to establishing the true design forces on submerged structures. This is of high interest to the oil/gas industry in respect of its sub-sea infrastructure design and maintenance.

Key aspects of the Western Australian component of the Integrated Marine Observing System for Australia (**IMOS**, see abstract by Dr Gary Meyer's, this meeting) is embedded within Node 6 of WAMSI.

Research and Monitoring in Western Australia's high conservation areas

Western Australia is developing a system of multiple use Marine Protected Areas (MPAs) that will provide comprehensive, adequate and representative reserves to cover all of the State's marine biodiversity. There are currently about eight existing MPAs (and 3 more imminent) from the northwest to southwest of the State and about another 65 areas have been identified for MPA status in the future, some of which will be as large as 10,000 square kms. The existing MPAs also include some that are very large (eg Shark Bay Marine Park ~8700 square kms; Ningaloo Marine Park ~3000 square kms). The Western Australian Department of Environment and Conservation (www.dec.wa.gov.au) is primarily responsible for management of the MPAs. The Western Australian Department of Fisheries also has statutory responsibilities specific to fish in these marine reserves (www.fish.wa.gv.au). The Department of Environment and Conservation is also responsible for the conservation of indigenous marine flora and fauna throughout all of the State's waters and the Department of Fisheries also manages fisheries throughout all of the State's waters. The Western Australian Department of Transport is responsible for monitoring of marine properties such as tides and waves and for the production and supply of maritime charts (www.dpi.wa.gov.au).

The respective programs of these departments involve the statutory monitoring of many marine variables around Western Australia.

Indian Ocean Climate Initiative Stage 3 (IOCI3) and links to WAMSI Node 2

The Western Australian State Government recently announced that it would provide funds for fundamental research to support vulnerability assessments on the likely consequences of climate change on the marine ecosystems and human populations of the State. About $AUS5 million will support a 5 year program of research by CSIRO and BoM. The funds may lever a further $AUS5 million in collaborative contributions by the partners. The funds will support IOCI Stage 3, which will be a continuation of the CSIRO/BoM research that was undertaken during the past 7 years through IOCI Stages 1 and 2. The climate science focus will centre around three broad themes:

- Baselines, drivers, large-scale features and predictability of Western Australian climate.
- Current and future climate of Western Australia's north-west, including extremes.
- Scenarios of climate change for sector impact and vulnerability studies.

Both IOCI and WAMSI (Node 2) have research components that aim to better understand the factors affecting the variability and predictability of WA climate. The focus of WAMSI will be oceanic processes in the Indo-Pacific Ocean, the Leeuwin Current and the sub-Antarctic Southern Ocean. The research will be based on in situ observations (e.g. expendable bathythermographs and Argo floats), satellite measured sea level and surface temperature as well as model results, and will concentrate mainly on ocean prediction, improving ocean processes in models and identifying feedbacks between the ocean and atmosphere that give persistence and predictability to climate anomalies. WAMSI will also provide a scientific foundation for sustainable coastal management by identifying the impact of large-scale ocean modes on the regional marine environment. WAMSI will involve time scales covering intra-seasonal, inter-annual and climate change.

In IOCI, one focus will be on the inter-annual variability and predictability of observed Western Australian surface climate (that is, rainfall, and surface temperature from the BoM National Climate Centre (NCC) datasets), relationships with observed atmospheric circulations and sea surface temperature variability, and the potential skill of seasonal climate forecasts. Statistical techniques, recently developed by BoM scientists, allow upper limits of climate predictability to be estimated from observations over many decades. The techniques also provide a means of identifying important atmospheric circulations, or teleconnections, that are related to the sources of predictive skill and uncertainty in seasonal forecasts of WA surface climate. To a large extent seasonal predictability in the climate system comes from large scale, coupled interaction between the ocean and the atmosphere. Herein lies a key IOCI – WAMSI nexus.

IOCI also will aim to determine how much recent and emerging climate change can be attributed to natural variability and will identify indicators of a changing climate, and how they should be measured and monitored. The Indo-Pacific Ocean plays a critical role in shaping climate change in Australia, in particular oceanic and atmospheric teleconnections from both oceans have an impact on southwest Western Australia.

At the interannual and seasonal time scales, there are important possible synergies between the work proposed in WAMSI and IOCI. Thus, for example, WAMSI will identify dynamical mechanisms and processes that generate a response in the atmosphere over the ocean. IOCI will identify the atmospheric teleconnections that carry the response to Western Australia. How well the observed relationships between oceanic and atmospheric circulations and the predictable component of Western Australia surface climate variability are simulated in dynamical ocean-atmosphere models can be used to identify strengths and weaknesses in the atmosphere and ocean models and their coupling, and assess their capability in climate prediction. Together IOCI and WAMSI will provide a more complete understanding of Western Australia's climate.

IOCI is to be administered out of the Greenhouse Unit of the Western Australian Department of Environment and Conservation (www.dec.wa.gov.au).

Western Australian Global Ocean Observing System (WAGOOS): Proposal for WAGOOS review of Remote Offshore Warning System, Replacement Infrastructure and Future Developments off northwest Australia

WAGOOS is currently developing a proposal for a major review and assessment of the oil and gas industry's met-ocean observational network for the northwest shelf of Australia, with a view to including at a later stage the Arafura-Timor seas regions.

The concept is in the early stages of development and is being scoped through the efforts of the WAGOOS Chair, Dr Ray Steedman, with the assistance of the IOC Perth Office.

The intent is to seek funds to undertake a systematic review that will lead to recommendations to key oil/gas industry stakeholders in the region for an improved observational network, and also for an improved modelling capacity for the area, through the connecting synergies that can be formed with Bluelink (below).

An underpinning motivation for this study is the WAGOOS report: *The Economics of Australia's Sustained Ocean Observation System, Benefits and Rationale for Public Funding* (Western Australian Global Ocean Observing System (WAGOOS), and Academy of Technological Sciences and Engineering, Perth, Western Australia, 2005).

The WAGOOS report demonstrates that investing in the ocean observing system represents value for money in terms of the considerable and diverse benefits to communities and industries. Oceans are important to the government, industry, and people of Australia. Not only are they an efficient means of transport for exports and imports, they also impact on many industries through weather and climate effects. The economic study showed that expenditure on ocean observations generally gave a benefit cost ratio of **at least 20:1**. Some benefits could also accrue to elements of the Australian economy that are not measured in the market. For example, there are potential natural resource management and environmental gains associated with climate and ocean forecasting, as well as potential gains for recreation activities and marine safety and rescue. The report emphasises how measurements provide a greater understanding of the oceans, which benefit industry considerably, although the benefits may not be immediately realised because of the lead-time required to implement and apply the system. Hence, the WAGOOS proposal for a review and subsequent improvement of the current observational network has a sound foundation in the WAGOOS/ATSE report.

BLUElink**: Ocean forecasting Australia**

The Australian Government, through the Commonwealth Bureau of Meteorology, Royal Australian Navy and CSIRO has initiated **BLUElink: Ocean forecasting Australia**, a $AUS15 million project to deliver ocean forecasts for the Australian region. The forecasts will provide information on coastal and ocean currents and eddies, surface and subsurface ocean properties, that impact and are linked to maritime and commercial operations, defence applications, safety-at-sea, ecological sustainability, regional and global climate. Bluelink will be able to assist oceanographic studies such as those embedded in the WAMSI framework (above) through the provision of open ocean boundary conditions and forcing input to focussed nested models. The stated centrepiece of Bluelink will be the development of a prototype ocean simulation for the Australian region, underpinned by advanced data and product server system. The animation of circulation around Australia, shown at the IOP4 workshop, can be accessed via the Bluelink website. http://www.bom.gov.au/oceanography/projects/BLUElink/index.html.

21. Coordination with VACS and AAMP *(C. Reason and J. McCreary)*

The AAMP met in February 2007 (http://www.clivar.org/organization/aamp/8thmeeting.htm). At the meeting, the role of the Indian Ocean in the climate system was discussed. J. McCreary reported that the AAMP was asked to consider developing a process study in conjuction with the IOP to address outstanding issues of ocean-atmosphere coupling in the Indian Ocean. The AAMP's opinion was that any activity that leverages on the improved IO observing system would be appropriate.

They agreed to organize analysis of existing hindcasts of predictability of IOD. This would be a project in collaboration with WGSIP, the WCRP Task Force on Seasonal Prediction (TFSP) and IOP which aims at studying the ability of current models to predict the IOD. AAMP also discussed the possibility to make a joint process study on IOD predictability with IOP in order to assess the benefit of the IndOOS in term of societal impacts.

ACTION ITEM 9. Draft a brief paper on basin array and potential collaborations and submit it to all the groups interested in studying intraseasonal timescale, including AAMP, YOTC, MJO WG and THORPEX (Y.Masumoto, K. Yoneyama and G. Meyers)

The CLIVAR Variability of the African Climate System (VACS) panel met in Dar es Salaam in mid July 2006. In many respects, VACS has tended to follow a regional approach and AMMA is a good example of a multi-disciplinary, collaborative, international research programme for the West African region. It is clear that VACS now needs to give impetus to developing similar type programmes for the southern African and East African regions. Prototype plans exist for these regions but there is now an urgent need to refine these to meet the needs of the various stakeholders and to target funding.

The workshop that VACS organized on African Climate Prediction in July 2006 emphasized seasonal to decadal prediction over Africa and the influence of Indian Ocean via IODZM, subtropical dipole modes. C. Reason reported that a white paper on Decadal Prediction and Predictability of African climate and links with the Indian and Atlantic Oceans is in preparation.

22. Membership and next meeting

Gary Meyers expressed the will to step down as co-chair by the end of the year however he will remain a member of the panel for another one year or two. He will continue serving as the rep for IOGOOS and help for the assessment.

ACTION ITEM 10. Find a replacement for co-chair G. Meyers (G. Meyers and Y. Masumoto)

Will de Ruijter was proposed as new member of the IOP

ACTION ITEM 11. With the agreemend of the CLIVAR SSG, invite W. de Ruijter to become member of IOP (G. Meyers, Y. Masumoto and R. Boscolo)

The panel suggested holding the next meeting in Indonesia to foster collaborative projects with the local institutions.

ACTION ITEM 12. Investigate dates and venue for next IOP meeting in Bali, Indonesia (F. Syamsudin and R. Boscolo)

APPENDIX A. List of Participants

Panel Members

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APPENDIX B. Meeting Agenda

Day 1: Monday 23 April

9.00	Welcome by SAWS representative *(Mark Majodina)*
9:10	Introduction and Local arrangements *(G. Meyers and C. Reason)*
9:15	Variability of the Indian Ocean and Impacts on Southern African Climate *(C. Reason)*
10:00	Review of the agenda *(G. Meyers)*
10:10	Welcome by IOC-GOOS *(N. D'Adamo)*
10:20	Welcome by CLIVAR and WCRP/CLIVAR activities related to IOP *(R. Boscolo)*
10:20	Inter-sessional activities and confirmation of agenda *(G. Meyers)*
10:40	**Coffee/Tea Break** and Awards for naming IndOOS
11:00	Inter-sessional activities and review of the CLIVAR-14 SSG discussions *(G. Meyers and M. McPhaden)*
11:15	Tropical Moored Buoy Report *(M. McPhaden)*
12:20	Upper Ocean Variability of Measured Currents from ADCPs along the Equator in IO during Nov. 2004 – July 2006 (*VNS Murty)*
13:00	**Lunch**
14:00	Review of TRITON and JEPP-IOMICS Projects (*Y. Masumoto)*
14:40	Status of Floats in IO and Plan for next year *(M. Ravichndran)*
14:50	Introducing an Integrated Marine Observing System for Australia – IMOS *(G. Meyers)*
15:00	The IndOOS Data Portal (*M. Ravichandran)*
15:40	**Coffee/Tea Break**

Science talks by the new members: What future research-directions should IOP take? *(Convenor: Y. Masumoto)*

16:00	Mixed-layer temperature budget in IO as a future research direction of IndOOS *(T. Lee)*
16:55	Bay of Bengal Studies (*VSN Murty)*
17:15	IOP future directions: Dec-Cen to Climate Change? (*G. Vecchi*)
18:00	Discussion on future research directions
18:30	**Reception at SAWS**

Day 2: Tuesday 24 April

Indian Ocean impacts on Africa: science talks *(convenor: C. Reason)*

8:40	The 2006/07 summer season over South Africa, rainfall anomalies, regional SST anomalies, forecast and verification *(W. Landman)*
9:10	Indian Ocean variability and east African climate *(A. Kijazi and A. Mafimbo)*
9:40	Indian Ocean and Madagascar climate variability *(N. Raholijao)*
10:00	The Influence of the Agulhas Current on SA Weather *(S. Mkatshwa)*
10:20	Numerical Weather Prediction at the SAWS, short and medium range and THORPEX link *(W. Tennant)*
10:45	**Coffee/Tea Break**

11:10 Activities in Oceans surrounding South Africa *(J. R. van der Merwe)*

11:45 Circulation of the SW Indian Ocean and Rationale for Monitoring the Agulhas Current system (*W. de Ruijter)*

12:30 **Lunch**

13:40 Air-Sea heat, freshwater and momentum fluxes in the Indian Ocean (*L. Yu)*

14:20 2006 IOD Predictions (*Y. Masumoto*)

14:50 NOAA's Objectives in Establishing Indian Ocean observing Partnerships *(S. Thurston)*

15:30 **Coffee/Tea Break**

Preliminary results from process studies and plans for future process studies *(convenor: G. Meyers)*

16:00 The CIRENE Cruise: preliminary overview *(J. Vialard)*

16:45 Early Results from and Updates on MISMO *(K. Yoneyama)*

17:30 On the use of Hydrometeorological ARray for Isv-Monsoon AUtomonitoring (HARIMAU) Radar network in the Indian Ocean monitoring system *(F. Syamsudin)*

18:00 **Adjourn**

Day 3: Wednesday 25 April

8:40 Making use of ocean analysis/reanalysis products for Indian-Ocean Research *(T. Lee)*

9:20 Discussion on IO indices to report to OOPC *(G. Meyers)*

10:00 SIBER: Sustained Indian Ocean Biogeochemical and Ecological Research *(R. Hood)*

10:30 **Coffee/Tea Break**

11:00 Global Warming and Coral Bleaching – Western Indian Ocean Initiatives *(D. Obura)*

11:45 Western Australian Marine Science developments relevant to IOP *(N. D'Adamo)*

12:30 Coordination with VACS and AAMP *(C. Reason, Jay McCreary)*

13:00 **Lunch**

14:00 Panel Business:

- Future directions discussion
- Membership
- Next meeting

15:30 **Coffee/Tea Break and End of meeting**

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