Indian Ocean Observing System (IndOOS)

Decadal Review

Executive Summary

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Executive summary

J. Vialard[1], L. Beal[2]

1. Laboratory of Oceanography & Climate (IRD), France

2. University of Miami, USA

Sustained Indian Ocean observations for climate: IndOOS 2020-2030

IndOOS is the sustainable ocean observing system for the Indian Ocean. The goal of IndOOS is to provide sustained high-quality oceanographic and marine meteorological measurements to support knowledge-based decision-making through improved scientific understanding, weather and climate forecasts, and environmental assessments. The current IndOOS design was established on the basis of the Implementation Plan drafted by the CLIVAR/GOOS Indian Ocean Panel (IORP) in 2006. Since then, societal and science priorities and measurement technologies have evolved and many of the practicalities of implementation have been learned. In this summary we incorporate these needs, tools, and experiences into actionable recommendations for priority observing system components moving forward, including pilot studies with new technologies. Justification for these recommendations is grounded in the chapters of this white paper, where we review the current status of IndOOS and its past successes and failures; articulate scientific and operational drivers and their societal impacts; and identify the essential ocean variables (EOVs) that address these drivers, their geographical coverage and spatio-temporal resolution.

1. Societal motivations

The Indian Ocean may be the smallest of the four major oceanic basins, but the 22 countries that border its rim gather one third of mankind. Many of these countries have developing or emergent economies, which are vulnerable to extreme weather events and climate change.

Many Indian Ocean rim countries depend on rain-fed agriculture. In India, for instance, 60% of jobs are in agriculture, which accounts for 20% of GDP, and there is a tight link between grain production and monsoon rainfall (Gadgil and Gadgil, 2006). Indian Ocean sea surface temperatures have been shown to influence these monsoon rains, as well as flooding in east African countries (Webster et al. 1999), droughts and wildfires in Indonesia (Abram et al. 2003, D'Arrigo and Wilson 2008) and Australia (Ashok et al. 2003, Ummenhofer et al. 2009a), and the strength of the Southeast Asian monsoon (Ashok et al. 2001, Hanamalai et al. 2005; Chapters 1 and 13). Recently, the Indian Ocean has been warming faster than any other basin in response to climate change (Chapter 11, Roxy et al. 2015) and as a result decreasing rainfall over eastern Africa is predicted to increase the number of undernourished people in this region by 50% by 2030 (Funk et al. 2008).

In a region where many populations are dependent on fisheries for their livelihood (Barange et al. 2014), the intense marine productivity of the northern Indian Ocean is under threat (Chapter 12, Allison et al. 2009, Roxy et al. 2015). Here, productivity is highly vulnerable to projected climate change (Allison et al. 2009), because the monsoon winds that drive upwelling and support high productivity are changing and because underneath the surface, one of the largest regions of oxygen-depleted waters in the world ocean is expanding (chapter 2). These oxygen-depleted waters are predicted to expand towards the ocean surface and cause an increasing number of large mortality events, as has been seen in the past (e.g. Naqvi et al. 2009).

The Indian Ocean coastal population density is projected to become the largest in the world by 2030, with 340 million people exposed to coastal hazards (Neumann et al. 2015). This rapid population growth will conflate with climate-change induced sea level rise (e.g. Han et al. 2010) and increasing tropical cyclone intensity to increase vulnerability (e.g. Elsner et al. 2008; Rajeevan et al., 2013). Already, the Bay of Bengal region witnesses more than 80% of the total fatalities due to tropical cyclones (chapter 4), while only accounting for 5% of these storms globally (Paul, 2009).

Beyond its direct impact on rim countries, the Indian Ocean influences climate globally. As a whole, the basin accounts for about one fifth of the global oceanic uptake of anthropogenic CO_2 (Chapter 8; Takahashi et al., 2002), helping to buffer the effects of global warming. It is the breeding ground for the Madden Julian Oscillation (chapter 5), an atmospheric phenomenon that modulates rainfall and tropical cyclone activity across most of the tropics (MJO; Zhang, 2005). Year to year temperature variations associated with the Indian Ocean tropical dipole influence the evolution of the El Niño Southern Oscillation (ENSO) in the neighbouring Pacific Ocean (e.g. Clarke and Van Gorder 2003; Luo et al. 2010; Izumo et al. 2010), a leading climate mode with global-scale impacts. The Indian Ocean is also a tropical-subtropical gateway from the Pacific to the Atlantic Ocean, as part of the global “conveyor belt” (Chapter 7; Broecker, 1991) that drives climate variability at multidecadal and longer timescales. For instance, a redistribution of heat from the Pacific to the Indian Ocean is thought to have played a key-role in regulating global mean surface temperatures over the last decade (Tokinaga and Xie 2012; Liu et al. 2016), with rapid warming of the Indian Ocean representing about two thirds of global ocean heat gain (Chapters 10, 11 and 14; Lee et al., 2015; Nieves et al. 2015). The Indian Ocean surface warming trend has had far reaching impacts, modulating Pacific (e.g., Luo et al. 2012, Han et al. 2014, Hamlingon et al. 2014) and North Atlantic climate (e.g., Hoerling et al. 2004) and causing droughts in the West Sahel and Mediterranean (e.g., Giannini et al. 2003; Hoerling et al. 2012).

The role of the Indian Ocean in regional and global climate variability and change, and the heightened vulnerability of its rim populations, are strong incentives to better observe, understand and model this ocean, with the ultimate goal of being able to make quantitative predictions of future climate.

2. Established scientific drivers and new frontiers

Scientific interest in the Indian Ocean is not new and was initially fostered by its unique features. One of these is its geometry. A low latitude throughflow from the Pacific via the Indonesian Seas (e.g. Gordon et al. 2010) and the Asian landmass to the north (Figure 1) bring about unusual features in the Indian Ocean, such as the reversing monsoon currents and western boundary upwelling in the north, a shallow overturning circulation and semi-annual jets along the equator, and in the southern subtropics a unique poleward eastern boundary current and the strongest western boundary current of the world ocean.

Cut off to high latitudes, the Indian Ocean receives excess heat from the atmosphere and via the Indonesian Throughflow that must be evacuated towards the Atlantic and Southern Oceans. This heat export is achieved through an upper-ocean gyre circulation and a deep overturning cell (chapter 9; Ganachaud and Wunsch, 2000; Lumpkin and Speer, 2007; Hernandez-Guerra and Talley, 2016). The properties and heat content of the outflowing waters depend strongly on mixing in the Indian Ocean, which has been estimated to be several times stronger than in the Pacific or Atlantic, with unknown causes (Lumpkin and Speer, 2007). The variability of Indian Ocean overturning and heat export and its relationship with sea surface temperatures across the basin remains unknown at any time scale, but is thought to be strongly constrained by the Agulhas Current at the western boundary (Bryden and Beal, 2001) and by the Indonesian Throughflow (Sprintall et al., 2014).

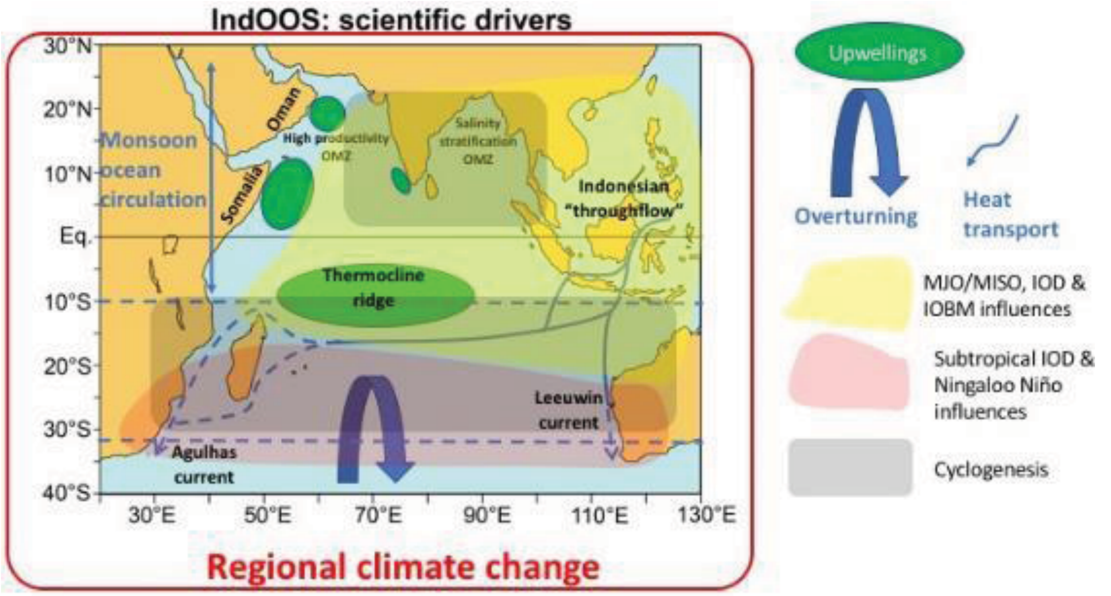

Figure 1. The region north of 10°S is strongly influenced by monsoons. The shaded regions indicate the rough area of influence of important phenomena. The green ovals indicate the main coastal or open-ocean upwellings. The thin blue arrow indicates the Indian Ocean part of the global oceanic "conveyor belt". Key regions are also named.

The presence of the Asian landmass induces a complete reversal of the winds across the northern Indian Ocean; the northeast and southwest monsoons (e.g. Schott et al. 2001). These winds drive a complex reversal of the currents north of 10°S (Figure 1), including the Somali Current at the western boundary and semi-annual eastward jets (the Wyrtki jets) along the equator that redistribute heat zonally during the inter-monsoon periods and help to establish the mean state. Many of these oceanic processes are not well reproduced by state-of-the-art climate models, with adverse impacts on predictability of the monsoons (e.g. Annamalai et al. 2016). The strong southwest monsoon winds also yield intense upwelling along the western boundary in the Arabian Sea (figure 1, chapter 3). This unique upwelling system modulates evaporation and moisture transport towards India (Chapter 1, Izumo et al. 2008), provides a globally significant source of atmospheric CO_2 (chapter SD08), and fosters intense oceanic productivity (chapter 12). This high productivity, together with low ventilation, leads to a subsurface depletion of oxygen (oxygen minimum zone, chapter 2) that is now expanding and has already led to a dramatic shift in the Arabian Sea ecosystem (Gomes et al., 2014). In the Bay of Bengal, saline stratification creates a very different habitat. Excess freshwater input from monsoon rain and river runoff strongly inhibits the vertical mixing of both heat and nutrients. This barrier layer is thought to regulate regional climate (Shenoi et al. 2002), oceanic productivity (Prasanna Kumar et al. 2002), wet/dry spells of the monsoon (chapter 5), and cyclogenesis (Sengupta et al. 2008).

While the powerful ENSO climate mode focussed the attention of the international climate community during the 1980s, the last two decades have witnessed rising awareness of the importance of coupled climate variations in the Indian Ocean (Schott et al. 2009). The tropical Indian ocean has a large warm pool (surface temperature >27.5°C), common to the neighbouring Pacific, that maintains atmospheric convection (e.g. Graham and Barnett, 1987) and energizes the largest global atmospheric circulation cell, the Walker circulation. This Indian Ocean warm pool is modulated at the 30-90 day timescale by the Madden-Julian Oscillation (MJO) in boreal winter and by the Monsoon intraseasonal oscillation (MISO) in summer (chapters OD01 and SD05, figure 1), oscillations that are strongly coupled with Indian Ocean processes. These modes influence rainfall and cyclogenesis and, if simulated correctly, could yield enhanced predictability throughout the tropics (chapter 15). The western tropical Indian Ocean, around 5-10°S, is another important region for air-sea coupling. The thermocline dome of the tropical gyre is very shallow, making sea surface temperatures highly sensitive to atmospheric anomalies, with impacts on cyclogenesis and MJO development (e.g. Vialard et al. 2009).

At interannual time scales the tropical Indian ocean is strongly influenced by ENSO, warming uniformly during El Niño events (chapter 6) and remaining warm (e.g. Xie et al. 2009), a response known as the Indian Ocean Basin Mode (IOBM). But the Indian Ocean also has important interannual climate modes of its own, such as the Indian Ocean Dipole (IOD, Saji et al. 1999; Webster et al. 1999, chapter 6). In its positive phase, cold surface temperatures near Java-Sumatra, warm temperatures in the western tropical Indian Ocean thermocline dome, and anomalous easterly winds near the equator induce various impacts like droughts in Indonesia and Australia and floods over eastern Africa (e.g. Yamagata et al. 2004). The IOD develops through the Bjerknes feedback, similar to ENSO (Saji et al. 1999; Webster et al. 1999), with equatorial wave processes playing a central role in its evolution (Nagura and McPhaden 2010; McPhaden et al. 2015), and often co-occurs with ENSO (Yamagata et al. 2004). The Indian Ocean is also home to two subtropical climate modes. Subtropical Indian Ocean Dipole events manifest as large-scale SST anomalies spanning 15-45°S, with strong influence on South African rainfall (Reason 2001). Ningaloo Niño events are marine heatwaves off western Australia which can affect fisheries and lead to increased Australian rainfall. In 2011 a strong event caused the first recorded bleaching of the pristine Ningaloo reef (Feng et al. 2013). Some Ningaloo Niño events have predictability due to their association with ENSO (e.g. Doi et al. 2016).

The relative paucity of observations prior to the advent of IndOOS ten years ago has largely precluded studies of decadal and multi-decadal variability of the Indian Ocean (chapter 10), except through sparse repeat hydrography lines (now GO-SHIP). Hence, little is known in comparison with our understanding of the Pacific Decadal Oscillation and North Atlantic Oscillation (Han et al. 2014) and this is a serious problem when it comes to distinguishing climate change trends from patterns of natural variability (e.g. Carson et al. 2015). Even less is known about the changing biogeochemistry of the Indian Ocean at these time scales. There is, however, no doubt that the Indian Ocean, as other basins, is responding to anthropogenic climate change, with evidence of increasing surface temperatures and heat content, rising sea level, increased carbon uptake, and an intensified water cycle (IPCC 2013). The biogeochemical consequences of these changes are serious, with warming, acidification, and an expansion of oxygen minimum zones all putting serious stress on ecosystems (Bopp et al. 2013). Understanding regional patterns of change within the Indian Ocean (e.g. Han et al. 2010), the coupling and time scales of those changes, and predicting future change to the benefit of marine management and coastal resilience for Indian Ocean rim countries is our future challenge. Only a well-planned and internationally-supported IndOOS can provide the needed data.

The outsized increase in Indian Ocean heat content over the last decade, representing 60% of the global increase (Lee et al. 2015; Vialard 2015; Nieves et al. 2015; Liu et al. 2016), is a potent illustration of the need for sustained observations: Will the Indian Ocean continue to warm more rapidly than the rest of the world ocean? What effects will this have on the Walker circulation? On upwelling, ecosystems, and fisheries? On the monsoon wet/dry spells (MISOs)? On carbon uptake and vertical mixing? On cyclone activity and storm surges? Where and how will the excess heat received by the Indian Ocean be distributed? To answer these questions and others of societal importance requires sustained measurements of essential ocean variables (EOVs): upper-ocean temperature, salinity, air-sea fluxes, and currents at hourly-to-daily time scales across the tropics, augmented with chlorophyl, nutrients, oxygen, pCO2, and pH within the Arabian Sea, Bay of Bengal, and off western Australia; weekly-to-monthly measurements of full-depth temperature, salinity, nutrients, and pCO2 throughout the subtropics; and full-depth, high spatial resolution, daily-weekly measurements of these same EOVS plus velocity within boundary fluxes, such as in the Agulhas Current and Indonesian Throughflow.

3. IndOOS components and its achievements

IndOOS (Figure 2) has been comprised of five *in situ* observing networks: profiling floats (Argo), surface drifters (GDP), a moored tropical array (RAMA), seasonal repeat temperature/salinity lines (XBT/XCTD network), and tide gauges. Augmenting these networks are remotely-sensed observations of surface winds, sea level, sea surface temperature and salinity, rainfall, and ocean colour (chapter 18).

The Research Moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA, chapter 20, McPhaden et al. 2009) was arguably the observing network that launched IndOOS. It followed from tropical arrays in the Pacific and Atlantic Oceans, which together comprise the Global Tropical Moored Buoy Array (McPhaden et al, 2010). These arrays provide sub-daily time series of key oceanographic and surface meteorological variables in real-time (https://www.pmel.noaa.gov/gtmba/) in a region where the oceanic response to atmospheric forcing is rapid and coupled feedbacks are critical. All RAMA moorings measure meteorological surface parameters and oceanic temperature and salinity down to 500m. Some also make direct measurements of velocity, including three sites measuring deep currents along the equator, while others are “flux reference sites” with additional measurements for computation of momentum, heat, and freshwater fluxes across the air-sea interface (chapter 16), and a few sites have biogeochemical sensors (chapter 8). RAMA data have enabled the study of tropical modes of variability in the Indian Ocean, such as the MJO, MISO, and IOD, as well as the equatorial circulation and biophysical interactions. RAMA data also feed important operational applications, such as numerical weather and seasonal forecasts, gridded continuous estimates of air-sea fluxes, ocean re-analyses, and inter-calibration of successive satellite missions (chapters 15, 16, 17, 18). As one measure of its outstanding success, the original RAMA publication (McPhaden et al, 2009) has been cited 232 times as of December 2017.

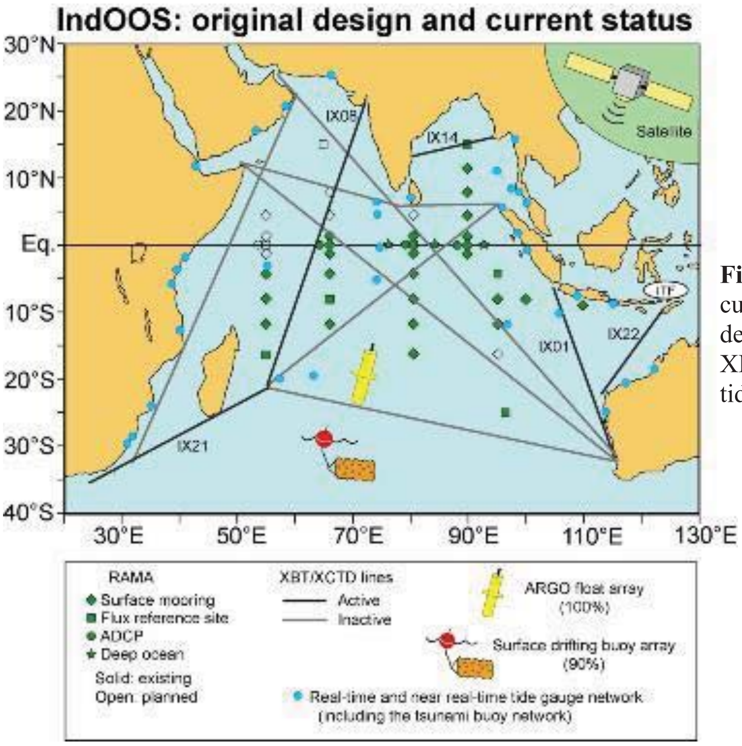

Figure 2. IndOOS original design and current state. The original IndOOS design comprises the RAMA, Argo , XBT/XCTD, surface drifting buoys and tide gauges components.

The Argo network is global (Chapter 19, Gould et al. 2004), consisting of one autonomous profiler per 3° x 3° region, each profiling the ocean (temperature, salinity, and pressure) down to 2000 m every 10 days for at least 3 years. Full coverage requires about 450 floats in the Indian Ocean north of 40°S and was first achieved in 2008. There are currently 576 active floats providing over 20,000 profiles per year. Argo data have captured the seasonal-to-interannual variability of the subtropical circulation and thermohaline structure in the Indian Ocean for the first time and were instrumental in tracking the enormous oceanic heat uptake during the “hiatus” decade (chapter 2). Argo has become a primary data source for operational oceanography (chapter 17) and for validating and initialising numerical models of the ocean and climate. A growing number of profilers (currently 48) are equipped with biogeochemical sensors to measure key processes related to plankton blooms, OMZs, and fisheries, to name a few, particularly in the Arabian Sea, Bay of Bengal, and thermocline dome region.

The voluntary observing ship eXpendable BathyThermograph (XBT) network collects temperature observations over the upper ~800 m of the ocean along regular commercial shipping routes. Prior to the advent of Argo, XBTs provided more than 50 % of all subsurface temperature observations (chapter 22). The XBT network is transitioning to monitoring phenomena poorly sampled by Argo, such as boundary currents and oceanic fronts, mesoscale variability, and volume and heat transports. For instance, the IX01 and IX22 XBT lines between Indonesia and Australia are critical for quantifying the interannual-to-decadal variability of the Indonesian throughflow (Meyer et al., 1995; Sprintall et al., 2002; Wijffels et al., 2008) and were able to capture its strengthening trend during 1984-2013 (Liu et al., 2015), which has played an important role in the redistribution of heat between the Pacific and Indian ocean over the last decade (Lee et al. 2015, Nieves et al. 2016; Vialard, 2015).

The Global Drifter program (GDP, chapter IR04) consists of surface drifters drogued to follow ocean currents at a density of one drifter per 5° x 5° region. All drifters also measure temperature and about half now measure sea level pressure, which has significantly improved numerical weather prediction (Centurioni et al. 2016). Coverage in the Indian Ocean has been about 70% since 1996 and about 90% since 2014. Surface drifters have allowed the seasonal mapping of the reversing monsoon circulation in the Arabian Sea (Beal et al., 2013). The tide-gauge network around the Indian Ocean rim provides measurements of sea-level (chapter 23) which are needed for Tsunami warnings, the monitoring and prediction of tides, the study of cyclone-induced storm surges (chapter 4), and for the understanding of basin-scale variations and trends in sea level rise (chapter 14). Tide gauges can also provide proxies for dynamical changes, such as coastally-trapped waves and the Pacific inflow along the west coast of Australia (chapter 9). Only a subset of tide gauges also monitor the level of the land, a necessary condition for a precise quantification of long term trends in sea level.

The observing networks that make up IndOOS are most effective when combined together and used with other vital observing programs, such as global satellite missions and the decadal, multi-disciplinary, hydrographic surveys of GO-SHIP. For example, Vialard et al. (2008) used a combination of RAMA, Argo, and satellite data to discover links between the thermocline dome region of the southwestern tropical Indian Ocean and the Madden-Julian Oscillation.

4. IndOOS 2020-2030: the way forward

The first decade of IndOOS has held its promise for unprecedented measurements of phenomena such as cyclones, the MJO and IOD, the equatorial circulation, and the Indonesian throughflow. **These are important measures that must be preserved in the future design.** However, IndOOS has so far fallen short of providing some critical data for the investigation of Indian Ocean biogeochemistry and fisheries, and for decadal variability and climate change.

In the Arabian Sea, where piracy and vandalism has long been a stumbling block for the completion of RAMA, **lack of measurements of the uniquely seasonal western boundary current, upwelling system, and oxygen minimum zone has stunted our understanding of biological productivity as well as monsoon variability and predictability**. With piracy receded, deployments are planned in the Arabian Sea in 2018. There have been few biogeochemical measurements as part of IndOOS (chapters 8, 19, and 2) and **hence biophysical processes and the carbon cycle remain poorly understood even in critical regions like the northern Indian Ocean oxygen minimum zones and eastern boundary upwelling cells. The subtropical Indian Ocean has also been relatively neglected** while it harbours climate modes, such as Ningaloo Niño and subtropical IOD (chapter 6), and is one of the fastest warming regions of the world ocean (chapter 11). Recent widespread interest in the “hiatus” in climate change and the associated storage of heat in the Indian Ocean has put strong emphasis on the need to be able to estimate basin-scale budgets over long time scales (chapter 7). This requires **monitoring the fluxes across the open southern boundary of the Indian Ocean, including the mighty Agulhas Current**, capturing changes in subtropical stratification, including Antarctic bottom water, and **improving surface flux estimates, particularly in the cloud-rich regions of the tropical Indian Ocean** (chapter 16).

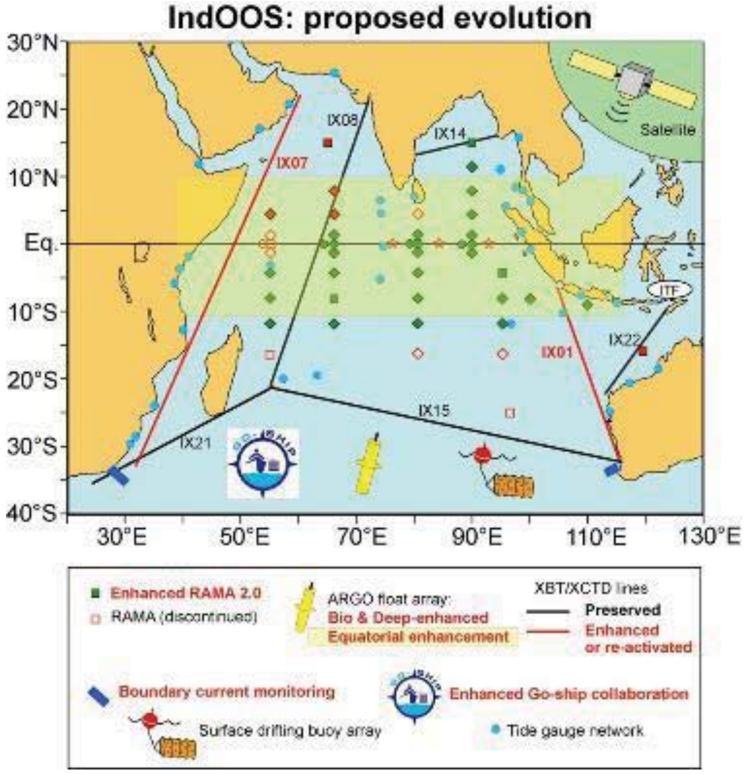

Figure 3. IndOOS original design and current state. The original IndOOS design comprises the RAMA, Argo , XBT/XCTD, surface drifting buoys and tide gauges components.

Increasing societal demand for seasonal-to-decadal climate predictability in the face of global warming makes the need for strategic, sustained observations of the Indian Ocean more urgent. At these time scales understanding the role of the ocean and its feedbacks are paramount. Here, we distill the collective wisdom from the chapters of this decadal review into a list of recommendations that can provide an Indian Ocean Observing System more capable of meeting these societal demands in the future.

Actionable recommendations:

A. **Maintain core components of IndOOS. A1:** RAMA, Argo, and surface drifter networks are the mainstays of IndOOS and must be completed and sustained. Multi-decadal records are critical, since so few long-term measurements exist, therefore **A2:** Prioritise XBT lines which have been active for 30 years or more, and **A3:** Prioritise established, long-term tide gauge measurements and add ground elevation monitoring.

B. **Expand observing system into the Arabian Sea.** The Arabian Sea is a critical region for understanding monsoon processes and predictability, and biogeochemical processes and marine productivity, yet piracy has precluded observations for almost two decades. **B1:** Deploy RAMA sites in the Arabian Sea with biogeochemical sensors. **B2:** Re-activate a portion of the IX07 XBT line with enhanced sampling in boundary current and upwelling regions. **B3:** Prioritise bio-Argo deployments in the Arabian Sea (Chlorophyll, oxygen, nutrients, pH).

C. **Eliminate redundancy and consider logistical constraints. C1: Re-e**valuate the need for XBT lines IX22, IX08, and IX14 and prioritise a sustained Argo network in their place. **C2:** Streamline RAMA by elimination of thirteen moorings from the original design. This will ease current implementation challenges and the upcoming transition to more capable T-FLEX moorings (Figure 2 and chapter IR03).

D. **Improve Indonesian Throughflow monitoring. D1:** Maintain and enhance measurements of volume, heat, and freshwater transports along XBT line IX01 by including XCTDs for salinity measurements, a thermosalinograph to capture surface properties, automated XBT launchers, and a hull-mounted ADCP (chapter IR07). **D2:** A pilot project for glider deployments along IX01.

E. **Measure the overturning and heat budget of the Indian Ocean.** Three elements are needed, **E1**: Sustain an Agulhas Current volume, heat, and freshwater transport array (such as ASCA, chapter 24) and consider a pilot glider project. **E2:** Deploy a hydrographic end-point mooring (or CPIES) in deep water near the end of the Leeuwin current array off Australia, and **E3:** Launch a deep-Argo program in the subtropical Indian Ocean to capture the deep overturning cell (chapter 24). Finally, **E4:** Evaluate IX15 and IX21 XBT lines as possible additional constraints on transport.

F. **Implement joint biophysical measurements**, including chlorophyll, CO_2, oxygen, pH, and essential nutrients, beginning in key regions. **F1:** Deploy bio-Argo floats in Somali and Omani upwelling cells, Arabian Sea and Bay of Bengal OMZs, thermocline dome upwelling region, and south of Madagascar (chapter 12). **F2:** Enhance RAMA moorings with biogeochemical sensors in the Arabian Sea, Bay of Bengal, and Java upwelling regions.

G. **Establish and enhance air-sea flux reference sites. G1:** Implement unoccupied RAMA flux reference sites in western tropical Indian Ocean. **G2:** Establish new flux reference sites at the mouth of the Indonesian Throughflow, in the eastern equatorial Indian Ocean where various flux products strongly disagree (chapter 16), and within the Agulhas Return Current. **G3:** Enhance a subset of flux reference sites for direct flux measurements. **G4:** Improve vertical sampling to capture the diurnal cycle at selected flux reference sites in convective regimes, such as the Bay of Bengal, eastern equatorial Indian Ocean, and the thermocline dome.

H. **Constrain the deep circulation and capture multidecadal timescales.** Improve mapping of the deep Indian Ocean thermohaline structure and circulation. **H1:** Deploy deep-Argo in the most under-sampled regions of the deep Indian Ocean and to capture the deep overturning at ~32°S. **H2:** Increase collaboration with GO-SHIP decadal hydrographic surveys to optimize the use of ship-time and promote international participation for targeted Indian Ocean surveys.

I. **Pilot project for high-resolution thermohaline monitoring in the tropics.** Iridium Argo floats spend only minutes at the surface, compared to hours for the original Argos floats, allowing for improved sampling of strong and divergent currents along the equator that could complement RAMA. J1: Pilot project to double the number of Argo floats with enhanced 5-day temporal resolution within 10° of the equator.

J. **Complementary satellite observations.** Planned satellite missions will ensure a good continuity for EOVs such as SST, sea level, ocean winds and colour, and outgoing long-wave radiation. However, the following missions are also essential

I1: Passive microwave SST measurements to track SST signals under atmospheric convection (chapter IR01, Sengupta and Ravichandran 2001, Duvel and Vialard 2007). **I2.** Sea Surface Salinity, due to the strong role of the halocline in regulating air-sea interactions in the Bay of Bengal and equatorial Indian Ocean. **I3.** Increase the number of scatterometers (currently 2) to minimize aliasing of winds by the diurnal cycle in the equatorial Indian Ocean.