IMPLEMENTATION OF MULTI-DISCIPLINARY SUSTAINED OCEAN OBSERVATIONS (IMSOO)

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1 - Executive Summary

To date, largely independent observing systems have evolved to meet the needs of particular disciplines and end users – many of these still measure only ocean physical variables routinely. The Implementation of Multidisciplinary Sustained Ocean Observations (IMSOO) workshop was held to identify priority steps to further multi-disciplinary collaborations in coordinating continuous and long-term ocean observations for the benefit of better understanding of the ocean and its ecosystems, as well as human impacts and vulnerabilities. The workshop was designed to follow the approach of the Framework for Ocean Observing (FOO), within which societal and scientific requirements for measurements as well as the feasibility of making such measurements combine to prioritize Essential Ocean Variables (EOVs). With the goal of supporting the global implementation of the FOO, an international and multi-disciplinary group of experts in ocean observations and modelling successfully addressed the three major aims of the workshop which were:

- To build on the established societal and scientific requirements expressed in EOVs and identify the key applications and phenomena that will benefit from co-located multi-disciplinary sustained observations;
- To identify near-term innovation priorities for observing platforms and sensors to enable multi-disciplinary observations; and
- To identify programmatic and professional connections between existing and emerging observing networks and modelling efforts that will increase multi-disciplinary observations and analyses.

To provide an innovative mechanism fostering convergence across the ocean disciplines, the workshop focused on three "demonstration themes", chosen because they represent global and challenging problems that are best addressed through collaboration of physical, biogeochemical and biological observations and analyses.

Demonstration Theme 1: Plankton Community Changes (including ocean colour)

In order to address the overarching topic set for this Demonstration Theme: 'Measuring ocean health through plankton: how and why is plankton changing at regional and global scales due to anthropogenic drivers and climate variability?', the participants recognized the need to distinguish between the requirements and priorities for observing system development in the coastal zone versus the open ocean. Discussions held on a number of topics led to a consensus on the challenges in plankton monitoring and recommendations for further work in the demonstration theme area. The following key points were considered:

- Most biological measurements are currently not automated.
- The challenge of data sharing is a key issue and a recommendation is to conform to existing standards and best practices.
- The use of common approaches facilitates capacity building with special benefits for developing countries. Capacity building should not be limited to the biological planktonic community but also include associated biogeochemistry and physics measurements needed for biology/ecosystem research.
- For the coastal science community: work across gradients of anthropogenic impact, with an emphasis on eutrophication, and other pressures; develop a review or meta-analysis of existing data and gaps.

- For the open ocean community: increase synergies with existing autonomous networks and the remote sensing community; initiate dialogues with global observing platforms/networks (e.g. GO-SHIP) to integrate measurements of biological EOVs, incentivize more routine collection of environmental data from continuous plankton recorders with oxygen being the first priority.

A detailed list of actions planned on a 2 and 5-year time scale was created for both the coastal zone and the open ocean observing systems (Table 6).

Demonstration Theme 2: Oxygen Minimum Zones

The participants agreed that the proposed demonstration project would focus on a specific feature of the OMZ – the upper oxycline. A potential 5-year implementation plan for a recommended project on the "Variability in the Oxycline and its ImpaCts on the Ecosystem (VOICE)" was presented.

Potential sites for the project were considered and the following were identified: Benguela Current System, Canary Current System, California Current System, Humboldt Current System and the Northern Indian Ocean (Bay of Bengal). The primary requirement in each location is the existence/potential for concurrent physical and biological measurements to complement the biogeochemical measurements.

The project would be carried out in several phases, and would include an analysis of historical data from the selected sites, and the development of a conceptual model of oxycline dynamics among other things. The major anticipated outcome of the VOICE project would be a blueprint of a multi-disciplinary sustained OMZ observing system, outlining a minimum and optimized set of observational and modelling requirements for a fit-for-purpose system that is capable of informing the society about the variability of the oxycline and its impacts on the ecosystem, and which is applicable within the global ocean observing system.

A successfully completed 5-year VOICE project would be a critical element in designing and implementing as well as securing funding for an observing system that is, within ten years, capable of addressing the overarching question of "How do changing Oxygen Minimum Zones (OMZs) affect the spatio-temporal distribution, productivity and trophic structure of the benthic and pelagic communities?"

Demonstration Theme 3: Open Ocean, Shelf and Coastal Ocean Interactions

The participants identified the following three main issues to address in this demonstration theme:

1. Inter-annual variability of currents and water properties has fundamental effects on ecosystem structure/dynamics in all boundary current systems;
2. Cross-shore overturning is a key exchange between shelf and deep ocean;
3. Episodic events (e.g. upwelling) are key in the translation of physics to biology, as are sub-mesoscale processes, and ecological hotspots.

They recognized that relevant processes, such as those listed above, vary in significance in different locations and that different societal requirements drive the need for observations in each boundary or coastal system. Also the technical needs and capacities vary by system, posing unique implementation challenges. The majority of the discussions in this demonstration theme focused on the first issue above. The demonstration theme participants formulated a methodology for defining requirements/capabilities, and agreed that the first step would be to test this methodology in eastern and western boundary current systems that are already well observed: the California Current and the East Australian Current.

The recommendations therefore were to build on existing experience in the California Current and the East Australia Current (1-2 year timeline), to develop concept/blueprint for a Multi-disciplinary Backbone observing System (2-3 years); and to develop a concept for a multi-disciplinary relocatable observing system pilot for finer scale (3-5 years) observations.

Moreover, the group recommended developing observation requirements for finer scales (mesoscale, hot spots) through the development of pilot flexible/relocatable observing systems.

The long-term vision would be to have a continuously deployed nested observation system where the fixed assets would focus on the interannual and climate scale variability and high resolution/fast assets would adapt to the problem *du jour*.

Integrated Perspective

The near term outcomes of the workshop are a series of suggested actions and recommended directions for the three demonstration themes including efforts of collaborations across disciplines, observation platforms and networks. The first steps are a series of planning and implementation meetings and workshops planned for 2017 and 2018. Only a few of the planned actions fall within currently funded activities; therefore the groups have started to seek out required resources through funding avenues identified at the workshop.

There was a recognition that new capabilities and new observation systems must be built on existing capabilities and this should be done with minimal impact on the current operations. Examples include the introduction of Biogeochemical Argo to the Argo network and the recommended addition of water sampling for biological measurements to repeat hydrography surveys.

The recommendations called for expanding the range of platforms available for observation including expanded use of autonomous sampling and fixed-point observatories for biogeochemical measurements.

Due to the complexity and widely varying scales of ocean dynamics, modelling plays a key role in addressing the three demonstration themes. Further expansion of models and closer coupling of models with observations was noted as a priority.

Capacity building was another common thread. This includes the use of existing standards and best practices for data management and could include the creation of best practices manuals and similar documentation.

The challenges discussed by the participants for each demonstration theme are not new, however, the emphasis on multi-disciplinary information and collaboration was a step forward in expanding traditional dialogues. The planning with a multi-year perspective offers the opportunity for advances that otherwise could take a decade of evolution.

2 - Introduction to Multi-Disciplinary Sustained Ocean Observations and Desired Outcomes

Motivation for the IMSOO workshop

The ocean covers over 70% of the Earth's surface and more and more people are depending on the ocean for food, transport, recreation, renewable energy, waste disposal and other aspects of their livelihoods. A better understanding of ocean climate and ecosystems, as well as human impacts and vulnerabilities, requires the coordination of a continuous and long-term system of ocean observations.

Despite projects such was the World Ocean Circulation Experiment and the Joint Global Ocean Flux Study, the ocean observation community lacked a common framework for developing, building and implementing a continuous long-term system of ocean observations across disciplines. However, a framework was introduced following the OceanObs'09 Conference held in Venice in September 2009 (www.oceanobs09.net) through the drafting of the Framework for Ocean Observing (FOO) [UNESCO, 2012].

Following the FOO and using societal and scientific requirements to drive the identification of what is essential to measure as well as assessing the feasibility of making such measurements, an assessment was (and is) done which combines both feasibility and impact of the variables to create a priority for observations. Global Ocean Observing System (GOOS)[1] along with the Global Climate Observing System (GCOS)[2] have identified the key scientific and societal requirements for sustained observations and captured these in the Essential Ocean Variables (EOVs) (www.goosocean.org/eov), many of which are also Essential Climate Variables (ECVs) (http://www.wmo.int/pages/prog/gcos/).

Delivering observations of the EOVs will help inform societal challenges as expressed in international agreements for Sustainable Development Goals (SDGs) (UN, 2015), Biodiversity (The Convention on Biological Diversity; [UN, 1992]), Climate change (Paris Agreement; [UNFCCC, 2015]), Disaster Risk Reduction (Sendai Framework for Disaster Risk Reduction 2015 – 2030; [UNISDR, 2015]) among others. The social challenges represented by these international agreements are complex and while the natural tendency for ocean science may be to focus on SDG 14, "Life below water" [UN, 2016] there is a clear connectivity among several goals [ICSU, 2016]. The oceans play a role in other SDGs from zero hunger (SDG2) to affordable and clean energy (SDG7) to climate action (SDG 13) to life on land (SDG 15) (Fig. 1), reinforcing the critical role the oceans, and essential observations thereof, play in sustainability of human livelihoods.

GOOS has identified three application areas for which ocean observations are essential: climate, real-time services and ocean health. Increasingly, to deliver the needed climate

[1] GOOS is part of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

[2] GCOS is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU).

information for adaptation and mitigation, a broad perspective integrating across disciplines is essential. Real-time services depend in great part on the real-time availability of sustained physical observations, but society also needs information on biogeochemical and biological data streams, of which few are available from many parts of the ocean and much less in real time. The G7 noted that "The seas and oceans are changing rapidly, with overuse and destruction of marine habitats, warming, increased ocean acidity and depleted oxygen. The health of the oceans has rightly been recognized as a crucial economic development issue and was included as the United Nations sustainable developments goal 14 (SDG 14)" [G7, 2016]. Questions about ocean health and the sustainability of ocean ecosystems are also deeply rooted in biological variables, but require underpinning biogeochemical and physical information to interpret.

Figure 1. Oceans play a direct (blue) and indirect (green) role in supporting SDGs.

To date, largely independent observing systems have evolved to meet the needs of particular disciplines and end users – the majority of these measure ocean physical variables. It is now critical to extend the scope of observing networks to include broader capabilities in ocean geochemistry and biology, and to integrate efforts across these scientific disciplines. A key recommendation from the OceanObs'09 Conference held in Venice in September 2009 was for international integration and coordination of interdisciplinary ocean observations [UNESCO, 2012]. Yet the interdisciplinary collaboration at the necessary scale is only beginning. The evolution of Argo to include biogeochemical observations is an example and is a step forward in fostering simultaneous multidisciplinary observations. The advancement of cabled observatories provides a platform for diverse measurements. The advancements of sensors in, for example, the Oceans of Tomorrow projects [EC, 2014; Pearlman & Zielinski, 2017] support expansion of chemistry and biology observations. The rapid evolution of 'omics in ocean science is creating powerful tools and new ways to look at spatial and temporal processes [Karl & Church, 2014]. The movement toward integrated observation systems for the Atlantic [AtlantOS, 2017], the Arctic (e.g. INTAROS) and the Southern Ocean (SOOS; [Schofield et al., 2016] is creating new opportunities for coordinated observations.

Under the FOO three GOOS Expert Panels have identified EOVs for their respective disciplines (Table 1). Given the key recommendation from OceanObs'09 and all the other interdisciplinary activities currently ongoing, the timing was right for a workshop focused on Implementation of Multi-disciplinary Sustained Ocean Observations (IMSOO).

Table 1. Essential Ocean Variables guide observation priorities (colours indicate observations that are in concept (red), pilot (blue) or mature (green) readiness level, as defined in the FOO).

PHYSICS & CLIMATE	BIOGEOCHEMISTRY	BIOLOGY & ECOSYSTEMS
Sea State	Oxygen	Plankton biomass and diversity
Ocean surface stress	Nutrients	Zooplankton biomass and diversity
Sea Ice	Inorganic carbon	Fish abundance and distribution
Sea surface height	Transient tracers	Marine turtles, birds, mammals abundance and distribution
Sea surface temperature	Suspended particulates	Live coral
Subsurface temperature	Nitrous oxide	Seagrass cover
Surface currents	Stable carbon isotopes	Macroalgal canopy
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity	Ocean colour	
Subsurface salinity		
Ocean surface heat flux		

Objectives

The IMSOO workshop was held to identify priority steps moving forward to further multi-disciplinary collaborations in ocean observations and ocean science. The three major aims of the workshop were:

- To build on the established societal and scientific requirements expressed in EOVs and identify the key applications and phenomena that will benefit from co-located multi-disciplinary sustained observations;
- To identify near-term innovation priorities for observing platforms and sensors to enable multi-disciplinary observations; and
- To identify programmatic and professional connections between existing and emerging observing networks and modeling efforts that will increase multi-disciplinary observations and analyses.

This workshop is not the first time that such aims have been voiced and pursued. To provide an innovative mechanism fostering convergence across the oceans disciplines, the workshop focused on three "demonstration themes" that should be addressed from a multidisciplinary perspective:

- Demonstration Theme 1: Plankton Community Changes (including ocean colour)
- Demonstration Theme 2: Oxygen Minimum Zones
- Demonstration Theme 3: Open Ocean, Shelf and Coastal Ocean Interactions

Thus they are appropriate to use as foci for implementation of multidisciplinary observing systems and effective to examine the benefits and impacts of collaboration. The three themes are described in the following section.

3 – Overview of demonstration themes, discussions and context for the breakout sessions

Demonstration Theme 1: Plankton Community Changes (including ocean colour)

Background/Motivation

Plankton communities constitute the base of the marine food web and comprise viruses, bacteria, phytoplankton, and zooplankton. Zooplankton includes single-celled (protozoans), multi-cellular (metazoans), and the larval stages of many benthic organisms and fish (ichthyoplankton). Ocean physical, biogeochemical, and biological processes all affect the abundance, composition, patchiness, and distribution of plankton assemblages. Plankton plays a key role in the global chemical cycles, and also provides essential ecosystem services such as carbon fixation, oxygen production, nutrient cycling, and food provisioning to higher trophic levels, many of which are important commercial species for humans. The abundance and distribution of many fish species, sea birds, and marine mammals are tied to fluctuations in the abundance of planktonic organisms. These are driven by and in turn affect physical and biogeochemical processes. Bottom-up changes such as grazing pressure and other biological interactions also have a marked influence on the diversity, abundance, and productivity of the phytoplankton. Thus the plankton community interacts with its physical, chemical, biological, and geological environment across a range of temporal and spatial scales. These changes have direct impacts on ecosystem function.

Indirect and direct human pressures also have significant impacts on plankton communities. These pressures can affect fishery catch potential, patterns of harmful algal and bacterial bloom occurrence, the dispersal of invasive or introduced species, and cause further shifts in marine habitats around the world. Changes in the plankton community provide valuable insights on the effects of both bottom-up pressures like climate-induced and other changes on the rest of the marine ecosystem, including the carbon cycle and all other marine organisms up to the top of the food chain, and top-down pressures that cascade through the food web (e.g. increasing pressure on certain types such as large copepods and krill, for omega-3s and aquaculture).

Combinations of in-situ and remotely sensed observations are vital to understanding changes in planktonic communities and assessing the impacts of those changes. At present, it is still impractical to sustain the collection of such observations over large areas. Much of our understanding of global plankton distribution, composition and biological rates comes from conceptual models and newer coupled biological–physical oceanographic and earth system simulations.

One of the challenges addressed at the workshop is to design a multi-disciplinary observing system that will enable us to monitor plankton community and change, and improve our understanding of the drivers of this change.

Aims

1. Identify opportunities for collaboration that will facilitate in-situ and satellite observations (physical, biogeochemical and biological) required to understand the drivers of plankton community change. This should include consideration of innovative observation networks and novel sensors.
2. Identify opportunities and mechanisms to integrate the disparate data types and resolutions related to understanding plankton community changes. This should include consideration of the requirements of modelers (from Regional Oceanographic Models to global scale Earth Systems Models).

Anticipated Outcomes

It was anticipated that the workshop would result in recommendations for a multi-disciplinary demonstration project(s) based on the focal discussion areas described above that would:

1. Articulate requirements for plankton community observations within an integrated, multi-disciplinary approach (i.e. including necessary physical, biogeochemical and biological observations).
2. Articulate the role and synergies of the range of networks and technologies in plankton community observations, including (but not limited to), Satellite observations, CPR surveys, Imaging FlowCytoBots, Deep and Shelf Moorings, Gliders, HF Radar.
3. Envision technological developments to facilitate and automate multi-disciplinary observations of plankton communities.

Highlights from the demonstration theme overview talk by Frank Muller-Karger

The overview talk given by Frank Muller-Karger on the “Plankton Community Changes” Demonstration Theme focused on the challenges and benefits of transitioning regional plankton diversity, abundance, and productivity observations into the global ocean observing system. On top of the demonstration theme rationale described above, Frank’s talk highlighted several points to consider when observing and modeling plankton community changes in the ocean, also in relation to the other two demonstration themes:

- Areas with the richest fisheries yields are those with the highest biological productivity of the plankton. This realization led to the conceptualization and implementation of the Large Marine Ecosystem (LME) concepts (Fig. 2). These biological ‘hotspots’ are also areas where there are strong ocean-shelf interactions – an observation that reveals a strong link with the “Open Ocean, Shelf and Coastal Ocean Interactions“ Demonstration Theme.

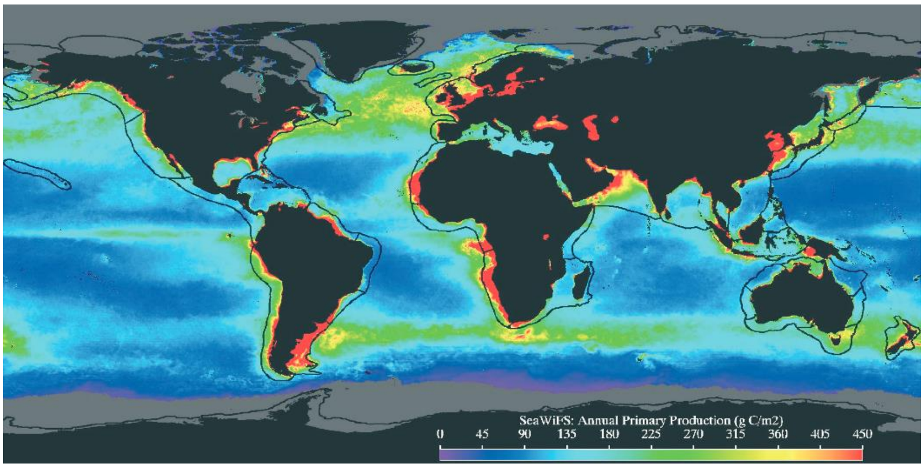

Figure 2. Map of Large Marine Ecosystems derived from satellite images over a decade ago. From: Sherman et al. (2004).

- The high productivity in the surface ocean also leads to export of organic matter to the deeper ocean as plankton and associated particles sink, leading to the expansive ocean minimum zones found at shallow depths near the coast and at intermediate depths in the deep ocean. This observation highlights the strong link with the "Oxygen Minimum Zones" Demonstration Theme.
- The current challenges for understanding plankton processes are that there are few measurements, multiple "standards" for measurements, and the high cost of in-situ monitoring. Expanded observations and related modeling are needed for: (i) species (diversity), (ii) biomass, (iii) productivity, (iv) traits, including responses to environment (response traits) and biogeochemical function (effects traits), (v) species interactions, and (vi) trophic interactions.
- At present, only a few plankton EOV time series exist, and most are coastal. There is a need to have a broad and sustained observation capability.
- Satellite observations are only able to provide estimates of ocean chlorophyll concentration, which is a crude index of phytoplankton biomass. These indices often fail near coastal zones with the present satellite technology, although advances are expected if higher spectral resolution ocean color sensors were to become available. While there have been advances in extracting phytoplankton functional group information from satellite ocean color data, these efforts need dedicated research efforts in coastal zones, in high latitudes, and in different regions around the world.
- New partnerships, such as that which is developing between GOOS, the Marine Biodiversity Observation Network (MBON) of the Group on Earth Observations Biodiversity Observation Network (GEO BON) and the Ocean Biogeographic Information Service (OBIS), are important in developing and disseminating the standards and protocols required to measure life in the ocean.

Plenary discussion in response to the overview talk

The overview presentation stimulated a plenary discussion that centered around four issues.

First, the discussion concerned the challenge for the community and GOOS to ensure an integrated biological-environmental meta database exists. Current capabilities and gaps in existing databases, such as OBIS, were pointed out. The participants identified some issues related to apparent recent decline in biological data submissions to shared databases, limited inclusion of commercial data (e.g. fisheries and plankton surveys), and the need for integrating the wealth of “omics”-type data with other types of measurements.

Second, the importance of microbial activity and the potential need for developing a dedicated EOV for microbes was brought up and briefly discussed. Microbes are currently considered an emerging EOV.

Third, the issue of whether standards for plankton measurements were of sufficient quality was discussed. It was noted that large uncertainties do not necessarily mean poor standards, as biological measurements are used to detect changes in orders of magnitudes. It was agreed that more investment is needed to ensure higher and more widely used standards.

Fourth, an apparent disconnect between the process of developing EOVs and Essential Biodiversity Variables (EBVs) was pointed out. The two efforts focus on communicating observing requirements on various levels, hence do not necessarily need to be overseen in parallel under the umbrella of GOOS.

Demonstration Theme 2: Oxygen Minimum Zones

Background/Motivation

Ocean ecosystems are increasingly stressed by human-induced changes of their physical, chemical and biological environment. Among these changes, a trend toward deoxygenation in particular coastal and mid-depth open ocean systems has been reported. Concentration or lack of uniformity in distribution of dissolved oxygen (O_2) is has a major impact on the distribution and abundance of marine species globally, and therefore deoxygenation is considered as one of the three major human-induced stressors on ocean ecosystems[3]. These trends emerge from physical, chemical and biological changes that the ocean is undergoing in response to increased concentrations of anthropogenic carbon dioxide (CO_2) in the atmosphere and subsequent changes to the Earth’s energy budget.

Open ocean deoxygenation has been recorded in parts of nearly all ocean basins during the second half of the 20th century. However, the scarcity of data does not allow us to fully comprehend the magnitude, dynamics and extend of this process. The O_2 minimum is typically found at depths between 400 m and 1200 m, near the base of the permanent thermocline, however they are found at depths as shallow as 100 m in the eastern tropical Atlantic and tropical Pacific oceans. Still relatively sparse and localized observational studies indicate a mostly negative trend in the O_2 content over recent decades in several basins of the world’s ocean including Black and Baltic Seas, the Arabian Sea, and the California, Humboldt, and Benguela Current systems. The reduction in O_2 concentration is consistent with that expected from higher ocean temperatures and a reduction in mixing (increased stratification). The most intense (O_2 <20 μmol kg^{-1}) and largest O_2 minimum zones (OMZs), known as suboxic layers, are mainly localized in subsurface of the tropical regions in the Eastern Pacific (both north and south of the Equator) and Northern Indian open oceans (Arabian Sea and Bay of Bengal). In the Atlantic, a slightly lesser degree of O_2 depletion is reported in shadow zones that exist north and south of the Equator in the east of the basin.

[3] The other two are warming and ocean acidification.

In addition to open ocean OMZs, several coastal regions are experiencing oxygen depleted waters, often with a seasonal signal, but also, in many cases, dependent on variability large scale circulation and upwelling. The extents of coastal OMZs are generally increasing with increasing nutrient load from the coast.

In most marine systems, hypoxia alters physiological and metabolic rate processes, organism abundance, lifestyles, composition, complexity, diversity, and size structure resulting in mortality of benthic fauna, fish kills, habitat loss, and overall physiological stress. The biggest threat related to open ocean deoxygenation is that of decline in biodiversity through attrition of intolerant species and elevated dominance, as well as reductions in body size, with impacts on organisms within the affected areas as well as in their vertical and horizontal proximities. Shoaling of the tropical OMZs restricts the depth distribution of tropical pelagic fishes such as marlins, sailfish, and tuna by compressing their habitat into a narrow surface layer. Restriction of these fishes toward the surface could make them more vulnerable to over-exploitation by surface fishing gear, and to air-breathing predators such as marine mammals in other cases. For many fish and crustacean species, larvae are less tolerant to hypoxia than adults, and thus expansion of hypoxic waters may create or enlarge dispersal barriers. Among adults, reproducing females might also be more likely to experience O_2 limitations, as gonads have elevated O_2 demand.

Hypoxia also influences biogeochemical cycles of elements, with perturbations to the global nitrogen cycle being one of the greatest concerns (see Fig. 3). Expansion of OMZ's is expected to lead to increased production of nitrous oxide (N_2O), an ozone-destroying greenhouse gas with global warming potential significantly higher than that of CO_2. Because of the paucity of direct measurements of N_2O production and consumption in the ocean, current rate estimates and predictions of how the N_2O budget will respond to future changes in oceanic O_2 concentration remain uncertain. However, the strongest oceanic sources of N_2O to the atmosphere are the suboxic waters overlying the OMZs, based on measurements and models of supersaturated N_2O concentrations. Changing oxygen concentration has profound impact on a range of chemical redox reactions in the ocean, prominently the reduction of NO_3^{2-}. Also several biological relevant trace metals exhibit redox sensitive behaviour that is oxygen dependent, for instance Fe, Mn and Co. Similarly, anoxic sediments below OMZs are strong sources of reduced iron, phosphorus and ammonia to the benthic boundary layer. When (if) these nutrients reach the photic layer, they fuel primary production that has the potential to further expand the OMZ. Expansion / contraction of anoxic sediments in OMZs has potentially large impact on the long-term trend in OMZs volume/area.

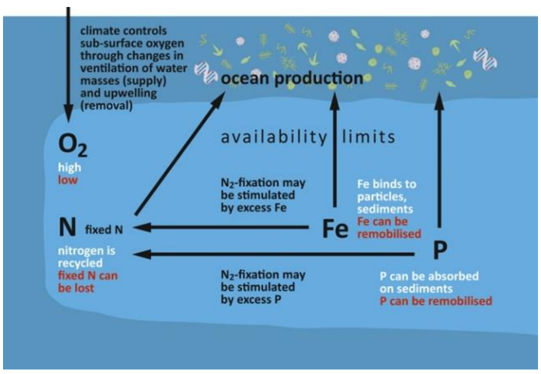

Figure 3. Selected Ocean elemental cycles.

These global changes are influenced by regional differences such as wind stress, coastal processes, and the supply of nutrients and organic matter. Global trend quantification remains a very challenging task. In particular, low resolution CMIP-class coupled models still have severe SST biases, particularly in Eastern Boundary Current systems, which have eluded the interpretation of long-term trends in OMZs. Two sources cause these biases: the absence of regional processes, in particular the meso and submesoscale activity, and the consideration of ocean-atmosphere interactions at very fine scale. For the latter, the wind drop-off close to the OMZ coast and the mechanical coupling transferring energy from the ocean to the atmosphere modulate the level of mesoscale activity impacting consequently on primary and export production and on oxygen distribution. The role of eddy activity is also being investigated and mesoscale eddies might be found to shape the OMZs by controlling the diffusion of oxygen into the OMZ at its meridional boundaries. Still, a proper representation of the particle export and remineralization processes along the water column and within the sediments of the shelves, together with adequate representation of nitrogen cycling components (denitrification, DNRA, anammox, nitrification, N_2 fixation, etc.) with realistic stoichiometries, need to be formulated for mimicking (and thus understanding) the past OMZ trends and predicting the future ones.

Aims

- Mounting evidence suggests that expanding OMZs are a strong threat to ocean health and to marine ecosystems. Therefore, it is essential to enhance the current observing system to adequately monitor OMZs to improve our physical and biogeochemical process understanding and enable us to predict the impacts on ecosystems. Such observations combined with projections of deoxygenation state in the future ocean, based on the observed and projected rate of deoxygenation change (trend quantification) will allow realistic considerations of mitigation and adaptation interventions.
- Significant reduction in the uncertainty of model projections is needed for informed regional management interventions and policy implementation. Strengthening of our observational capacity by designing a multi-disciplinary, sustainable observing system/study focused on understanding the OMZ (and its attributes such as oxyclines) will improve understanding of very dynamic relationships between the ocean circulation, biogeochemical and biological processes. These observations, will allow assessment of the reliability of model forecasts and predictions.
- Decline in O_2 solubility with increased temperature and reduced O_2 supply due to increased ocean stratification and reduced ventilation and increased deep-sea microbial respiration are the most (if not only) cited factors influencing ocean deoxygenation. Exact quantification of these processes and understanding of underlying mechanisms will allow us to better connect the climate-ocean interactions and their impact on future changes in the strength and distribution of oxygen minimum zones.

Anticipated Outcomes

The following is the list of very broad, potential OMZ Demonstration Theme outcomes anticipated prior to the workshop that were provided to the breakout group for consideration:

- Develop/fine-tune observing system design in order to
    - establish a baseline number/volume of ocean minimum zones (with 3D distribution of oxygen levels within them)
    - monitor the fronts and eddies region(s) that are known to "produce" suboxic eddies,
    - most efficiently describe the vertical movement of major OMZs
- Develop a scheme for implementation of a demonstration project linking the above observations with impacts on ecosystems adjacent to major OMZs
- Recommend improvements in modelling approaches: projections, reanalysis, data assimilation, observations-model comparisons, allowing more efficient planning of observations and improved model parameterisations.
- Articulate the roles and synergies of the range of observing networks and technologies in deoxygenation observations.

Highlights from the demonstration theme overview talk by Lisa Levin

In an overview talk on the "Oxygen minimum zones" Demonstration Theme, Lisa Levin not only defined hypoxia (or limited oxygen environment) and the concept of oxygen minimum zones (Fig. 4), but also discussed the different mechanisms responsible for the onset of this phenomenon. Internal drivers were distinguished from expanding oxygen depletion caused by increases in atmospheric carbon dioxide and resultant warming. She also gave an overview of the most recent analyses on regional and global trends in oxygen concentration in the ocean.

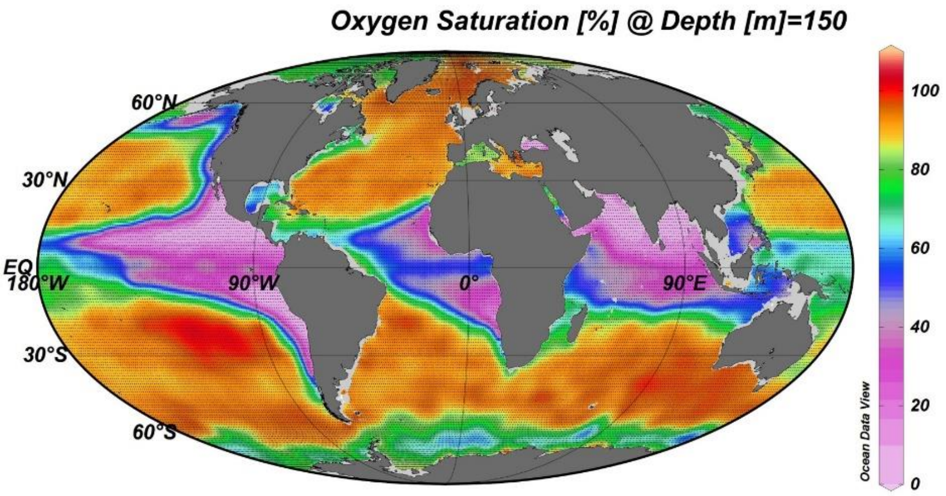

Figure 4. Global view of the oxygen saturation state at the 150 m depth. Pink areas point at locations of most pronounced OMZs. OMZs (here defined as waters < 22µM O2) constitute 8% of surface area. Courtesy of Lisa Levin.

The presentation highlighted the many impacts of changes in oxygen concentration on ecosystems, which as described above, motivate the need for implementing multidisciplinary sustained ocean observations under this Demonstration Theme. Additionally, several challenges in better understanding of the OMZ, relating to the temporal and spatial scales of available observations, were presented. These included:

- Limited sustained oxygen measurement
- Unexpected spatial variability

- Temporal variability (seasonal, event driven, diurnal/internal tides)
- Natural variability - time of anthropogenic signal emergence
- Multiple mechanistic drivers (Physics vs. Biogeochemistry)
- Feedbacks (nutrient cycling, productivity, warming)
- Bentho-pelagic coupling
- Interacting (multiple) stressors (temperature, ocean acidification, food, light)
- Links to coastal waters/land
- Measurement at low O_2
- Observing innovations

Plenary discussion

The discussion sparked by the overview presentation centred on the issue of choosing the right scales for a given problem. Modelling capabilities differ depending on whether regional or global estimates are considered, and this has consequences for how well the direction and magnitude of change in both ocean productivity and ocean oxygen content can be constrained.

Demonstration Theme 3: Open Ocean, Shelf and Coastal Ocean Interactions

Background/Motivation

Circulation in the coastal ocean and near shore zone influences a diverse range of human activities including maritime industry, recreation, and defence, and plays a vital role in environmental health and productivity that deliver important ecosystem services. The coastal circulation is driven by local terrestrial influences at the land-shore boundary, coastal zone meteorology, tides, and, equally important, by forcing at the shelf/open-ocean boundary.

In many coastal circulation regimes, the proximity of energetic boundary currents in deep water at the shelf edge is a key dynamic in mediating shelf/open-ocean exchange. On coasts for which estimates exist, fluxes of nutrients and carbon across this boundary are leading order terms in the nitrogen and carbon budgets of shelf ecosystems. In addition, mass, heat and salt exchange across the open ocean-shelf are also of significant importance in the coastal and basin-scale ocean budgets. The exchange at the ocean boundary, and shelf edge dynamics have immediate impacts on ecosystem function and productivity on weekly to seasonal time scales, but can also drive multi-decadal changes in ecosystem structure through effects on habitat ranges and biodiversity.

Direct observations of biogeochemical and physical exchanges across the shelf-open ocean boundary have not been sustained to the extent required to fully complement observations within the ocean interior. In large part, this is due to the particular challenges of maintaining observing networks within energetic regimes, and capturing the significantly shorter time and space scales of variability there. While there is an appreciation of the importance and impact of these exchanges between the shelf and open ocean, the effect on the coastal ocean biodiversity and ecosystem is poorly understood.

The long-term monitoring of physics, biogeochemistry and biology across the open ocean-shelf boundary, at key locations (i.e. western and eastern boundaries, and upwelling region), can provide a comprehensive reference data set that will measure exchanges across the open ocean-shelf boundary, improve our understanding of the relationship of boundary currents and the basin-scale gyre forcing, and determine the impact of boundary current variability on coastal marine ecosystems. The observations will also be used to generate initialized boundary conditions for high-resolution coupled reanalysis and forecast model of the coastal seas, and assess the simulation of various regional and coastal models. The continued monitoring of the open ocean-shelf boundary and coastal oceans, combined with a suite of dynamical models, is central to improving our understanding of how climate signals are communicated through the ocean.

Addressing these issues by downscaling coarse resolution climate model predictions through the application of higher resolution regional and coastal models has shown promise, but still faces research challenges. Furthermore, a significant amount of physical, biogeochemical and biological response on the continental shelf is due to episodic oceanic and atmospheric events at timescales of variability that are absent from coarse models and cannot be recovered locally. To be valid globally, the veracity of downscaled models needs to be appraised by supporting observations of shelf edge fluxes in a diversity of circulation regimes.

Coastal observing systems have now become sufficiently comprehensive that it is feasible to broadly measure these shelf-sea/deep-ocean exchange processes in conjunction with deep-ocean observing networks that capture variability within boundary current regimes, and the ocean interior, at increasingly fine scales.

Aims

Specific issues that a comprehensive (observations, and dynamical models) Open Ocean, Shelf and Coastal Ocean Interactions study should address are:

- Understanding the impacts and influences of large-scale remotely driven variability on boundary currents and how this affects the shelf and coastal ocean;
- Understanding how variability of the strength and dynamics of the dominant boundary processes drive shelf-sea/deep-ocean exchange, including nutrient forcing, carbon export, and other aspects of productivity of shelf and coastal waters; and
- Understanding the response of boundary and shelf dynamics and exchange to local and regional wind and buoyancy forcing fields, and the impact of these on biogeochemical fluxes and ecosystem properties at the shelf and in the coastal ocean.

The provision of robust three-dimensional and time-varying ocean circulation estimates in boundary current regimes, resolving scales of a few kilometres, is seemingly within reach through advances in data-assimilative ocean models. However, development of integrated systems that could deliver the scope of observations required, and the models capable of fully utilizing them, are not yet available. To succeed, this will require a coordinated international effort that brings together the expertise of the ocean modelling and observational communities in the multiple ocean science disciplines.

Anticipated Outcomes

The following outcomes were anticipated by the workshop Organizing Committee and were provided to the breakout group for consideration:

- Articulate requirements for open ocean, shelf and coastal ocean monitoring including:
    - Scientific applications,
    - Questions to be addressed,
    - Phenomena/processes to capture,
    - Variables to be measured, at what spatial and temporal scales
    - Modelling approaches (reanalysis, data assimilation, observations-model comparisons for observation planning and improved model parameterizations).
- Articulate the role and synergies of the range of networks and technologies in boundary current observations, including (but not limited to), Satellite Observations, Deep and Shelf Moorings, XBT Lines, Gliders, HF Radar, net tows, CPR, line-transect sampling, animal telemetry, active and passive acoustic monitoring.

Highlights from the demonstration theme overview talk by John Wilkin

In an overview talk on the "Open Ocean, Shelf and Coastal Ocean Interactions" Demonstration Theme, John Wilkin referred in detail to the different aspects motivating the need for implementing multidisciplinary sustained observations of the boundary currents and continental shelf dynamics as described above. Among other things, he emphasized that studies of shelf/deep-ocean interaction processes that fuel coastal productivity should be considered in context with boundary current dynamics that vary on larger space and longer time scales. Sustained deep ocean observing would provide the deep ocean context to complement coastal process studies; each with appropriate technology. The importance of deep ocean mesoscale interactions with slope and shelf waters is well known, but only recently have comprehensive in-situ observing systems and high resolution data assimilative models been able to reach below the sea surface and propose robust dynamical mechanisms by which these circulations are driven (e.g. see Fig. 5). For example, repeated deep glider observations in boundary currents show ocean state characteristics that potentially pre-condition shelf edge exchanges, and also reveal ecosystem/sediment processes (including sediment and particulate export from the shelf).

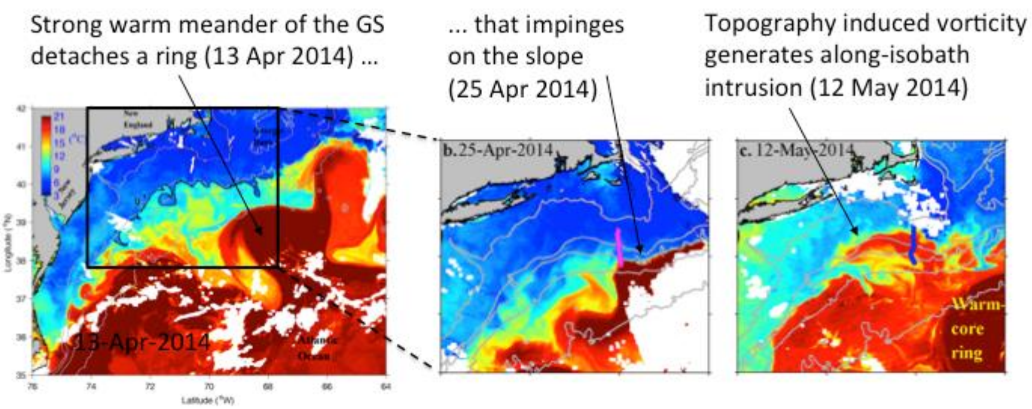

Figure 5. SST snapshots from Gulfstream rings in April 2014, illustrating the direct intrusion of Gulf Stream ring water on the Mid-Atlantic Bight Continental Shelf. From: Zhang & Gawarkiewicz (2015).

Additionally, the talk highlighted specific issues that a comprehensive, combined observational and modelling study could address with respect to this Demonstration Theme:

- impacts and influences of large-scale remotely driven variability on boundary currents;
- impacts of variability in strength and dynamics of the boundary currents on shelf-sea/open-ocean exchange, including nutrient forcing, carbon export, and other aspects of productivity of shelf waters;
- response of coastal and boundary current dynamics to local and regional wind and buoyancy forcing; impact these have on dynamics at larger scales through teleconnections;
- quantifying resolution required to represent coastal and boundary current dynamics in global climate models; and
- obtaining basin-wide estimates of meridional transports through a synthesis of coastal, boundary and open ocean observations.

Ocean Models related to the three Demonstration Themes - overview by Marion Gehlen

Models are essential to integrate diverse data sets, particularly in multi-disciplinary applications of ecosystem and biogeochemical analyses. Yet there is no optimal model; models are tools developed for specific applications to address specific questions. Data needs vary with the model type (global, regional, resolution) and the application. For boundary current and coastal applications (models with increasing resolution), there is a need for multi-variate data sets and for trends over time (such as climate impacts), there is a need for sustained observations. Multi-variate, multi-annual data sets provide statistical relations between observed variables such as chlorophyll anomaly and stratification index.

In this context, model studies and results illustrating challenges specific with relevance to the three demonstrations themes were presented, addressing the specific perspectives of each demonstration theme.

Plankton Community Changes

Biogeochemical components of OBGCMs have become increasingly complex over the past decade and start to be used to evaluate changes in first levels of marine ecosystems. The comparison between model output and remote sensing derived data products allows the linking of observed variability in phytoplankton and underlying major physical drivers [Alvain et al., 2013]. While time series start to be of sufficient duration to allow for the analysis of decadal trends in community composition [Rousseau & Gregg, 2015], a model study highlights the need for sustained observations to detect climate change induced trends against the background of natural variability [Henson et al., 2016].

To conclude, it is emphasized that while precise data needs vary with model type and application, the increase in model resolution calls for multi-variable data sets for model evaluation. The robust detection of climate change trends calls for multi-decadal sustained time series.

Oxygen Minimum Zones (OMZs)

Fully coupled Earth system models (IPCC class models) consistently project a decrease in dissolved oxygen by a few percent over the 21st century in response to warming, reduced ventilation and enhanced stratification. The decrease is dominantly driving by the sub-surface mid-latitude oceans. However, these models diverge in their projections of the future evolution of the volume of hypoxic and suboxic waters [IPCC, 2013].

The lack in skill of IPCC class models to represent observed oxygen minimum zones is in part due to the coarse spatial resolution of both the oceanic and atmospheric components. Increasing the resolution from 2° to ¼° in a global OBGCM resulted in the improved representation of main thermocline (200-600 m depth range) of mean dissolved oxygen levels (unpublished data). Similar to what has been discussed above, regional model systems provide an increasingly realistic representation at the scale of a particular OMZ. Gutknecht et al. [2013] present a model developed for the Benguela upwelling and its evaluation against a particular rich data set is an example of such improvements. However, the scaling from a focused regional model to a global capability remains a challenge.

Open Ocean, Shelf and Coastal Ocean Interactions

The accurate representation of continental shelves and boundary current systems challenges present-day global coupled ocean biogeochemical general circulation models (OBGCMs). These mostly coarse resolution models (nominal resolution between 1° and 2°) fail to adequately resolve the coastal bathymetry, which substantially alters coastal - ocean circulation [Fiechter et al., 2014] as well as mesoscale dynamics, upwelling, and coastal currents. Thus, some differences in the residence or flushing times are to be expected.

Recent progress in computing power now enables global hindcast simulations at ½° or ¼°. An example targeting the contribution of the global coastal to the global marine carbon cycle is given by Bourgeois et al. (2016). The diversity of regimes is grouped into representative systems (see Fig. 6) following the MARgins and CATchments Segmentation (MARCATS) of Laruelle et al. (2013). Model output is computed for individual MARCATS and compared to an evaluation dataset. The residence time of water masses on the continental shelf emerges as a key control of anthropogenic carbon uptake by coastal waters. The strategy followed by Bourgeois et al. (2016) allows for centennial model integration and the coherent representation of margins, boundary currents and open ocean systems.

Regional models are developed at much higher spatial resolution ensuring an increasingly realistic representation of physical processes [Fennel et al., 2016, AGU]. These models cover, however, only parts of the global system and open boundary conditions will have to be specified from global models using downscaling techniques. While it would be valuable to join together regional models to better address the biogeochemistry and ecosystem conditions, efficient simulations at very high spatial resolution that cover significant segments of the global coastal ocean remains a technical challenge [Holt et al., 2009].

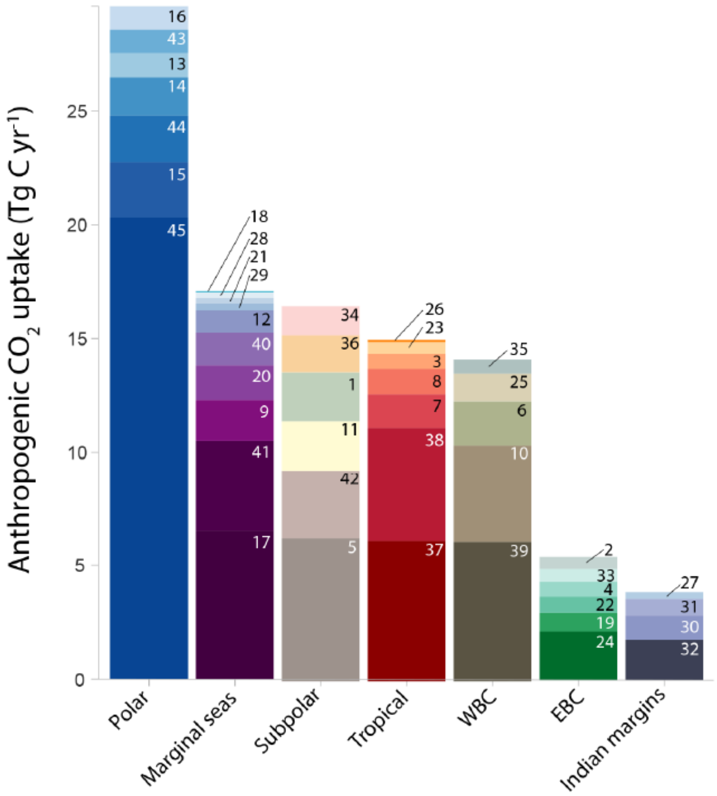

Figure 6. MARCATS regions: Anthropogenic carbon uptake: WBC, Western Boundary Currents; EBC, Eastern Boundary Currents (see Bourgeois et al. (2016) for details.

Breakout Session Instructions

The goal of the four breakout sessions was to consider the issues raised for each demonstration theme, as presented earlier in this section, and to provide a cross-disciplinary forum to identify a pilot project(s) or activities for each demonstration theme that will facilitate improved, integrated, multi-disciplinary observations and analyses around that theme. The activities/project(s) were envisioned as realistically having a 2 to 5-year time line.

The breakout discussions were divided into four sessions, each followed by a "report out" session in plenary. Some experts were deliberately asked to work on themes outside of their area of expertise to encourage the multi-disciplinary discussions that were the main focus of the workshop. The "report out" discussion session in plenary provided an opportunity to hear discussions from the other themes and allow experts an opportunity to contribute to each of the demonstration themes. Thus, the participants were not only asked to contribute to their 'assigned theme' but also to the discussions of other themes in these plenary sessions. Any overarching themes or challenges across demonstration themes and disciplines were discussed during the plenaries.

Each of the four breakout sessions were intended to build on the previous session(s) to identify and develop ideas for activities/projects that could be put forth for funding proposals or implementation with existing resources/project(s) in the near future to improve integrated, multi-disciplinary observations around each theme.

The first breakout session of each demonstration theme discussion focused on scoping potential integrated, multidisciplinary projects, activities or focal regions/topics for each demonstration theme. This included identifying societal impacts or significance of the proposed activities/project(s) as well as setting requirements. The second breakout session focused on what is needed for technical implementation of the identified activities, while the third breakout session asked the participants to step back and think about programmatic implementation and what is needed to make these projects happen in a practical sense. The fourth and final breakout session was aimed at synthesizing the emerging project/activity implementation plans across the demonstration themes and identify priorities and a path forward for development ahead of the Ocean Obs'19 Conference.

4 – Outcomes and recommendations from demonstration theme breakouts

Demonstration Theme 1: Plankton Community Changes (including ocean colour)

Chairs: Samantha Simmons, Bernadette Sloyan

Note-taker: Patricia Miloslavich

Participants: Sonia Batten, Emmanuel Boss, Fei Chai, Hervé Claustre, Albert Fischer, Marion Gehlen, Takafumi Hirata, David Legler, Anthony Richardson, LuAnne Thompson, Peter Thompson, Rik Wanninkof.

Rapporteurs: Sonia Batten, Anthony Richardson, Peter Thompson

Facilitators: Nic Bax, John Gunn

Breakout Session 1. Framing demonstration themes and associated requirements

The goal of this session was to focus on scoping potential integrated, multidisciplinary projects, activities or focal regions/topics to improve our understanding of plankton community changes. This included identifying impacts or significance of the proposed activities/project as well as setting requirements. For this demonstration theme the focus was on the phytoplankton diversity and biomass and zooplankton diversity and biomass essential ocean variables.

Discussion topics to refine the list of projects/activities included: Societal impact(s) of the project(s), gap assessments, technology requirements, financial feasibility, any new observations, data and modelling requirements, and implementation challenges.

The breakout session began with introductions of the attendees who were mostly experienced in open ocean communities and processes. Following introductions, much of the first breakout session was spent on identifying current gaps in plankton observations; focused on the gaps in terms of the scientific questions to answer, rather than what measurements are not being made by current platforms.

Photo 1. Bernadette Sloyan leading the discussion to identify gaps.

The major gaps identified in our understanding of plankton communities were:

- Species diversity and vertical structure (including microplankton)
- Temporal and spatial variability at different scales
- Ecosystem structure, function, and connection to the physical and biogeochemical environment (at a global scale)
- The link through the entire system: from ocean color to fisheries, which is needed to truly address societal

impact. This includes the energy flow from plankton to fish to apex predators and the importance of export (Particulate Organic Matter - POM)

- The Deep Scattering Layer (DSL) and mesopelagic populations: function and productivity needed to build models linking surface and subsurface biomass
- Autotrophy in the dark ocean. Non-sunlight fueled production
- Changes in rates (stocks and production) and ecological relationships, structure and function

Based on the gaps identified above and always keeping in mind societal needs as a priority, the following topics were suggested to be developed through a project(s) and activities:

1. Drivers of biological productivity change at regional/global scales and future projections.
2. Energy transfer (includes energy flow and trophic efficiency) from phytoplankton to fisheries in the shelf zone, in the DSL (structure, function, impact on fisheries) and its relationship to fluxes.
3. Improved understanding of ecosystem structure and function, ultimately this would support ecosystem assessments (e.g. biodiversity for the Convention on Biological Diversity (CBD), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), World Ocean Assessment (WOA))

For each of these topics, a summary of the societal impact(s), gap assessments, technology requirements, financial feasibility, any new observations, data and modelling requirements, and implementation challenges is provided below.

Table 2. Drivers of biological productivity change at regional/ global scales and how this can be projected into the future (Summarized by Peter Thompson)

Discussion Topic	Key points from Breakout discussions
Societal impact(s) of the project(s)	There is no doubt the ocean is changing and these changes will impact on global issues such as biological production including food security. A predictive capability (model) will enable us to quantify the impacts and focus mitigation in the most appropriate regions.
Gap assessment(s)	The majority of methods are operational today. There is a need to collect and analyze samples for genomics (microbial processes and players) although this technology is not yet fully mature.
Technology requirements	Most of the technologies exist although there may be some advantages of newer technologies when the regions are selected.
Financial feasibility	Expensive, bring as many of the groups together as possible.
Any new observations, data and modeling requirements	The proposal is to sustain a time series of observations across several regions of rapidly rising Primary production (PP), some control regions and several regions of declining PP. These might span from shore, across the shelf, through a boundary current to the edge of the open ocean. If possible some of these would extend into a region of declining dissolved oxygen (DO).
Identifying possible implementation challenges	It would best if all appropriate observations were made. This may require working cooperatively & collaboratively with our physical and chemical colleagues. Other challenges include funding.

Table 3. Energy transfer (flow---trophic efficiency) from phytoplankton to fisheries in the shelf zone, in the DSL (structure, function, impact on fisheries) and relationship to fluxes (Summarized by Anthony Richardson)

Discussion Topic	Key points from Breakout discussions
Societal impact(s) of the project(s)	Food security; Supporting Marine Management - Ecosystem Approach to Fisheries; Global carbon cycle
Gap assessment(s)	Although more productive areas generally have more fish, the relationship is relatively weak. We currently do not have a good idea of how biological productivity feeds into fish biomass and how this varies in different systems. We suggest a comparative meta-analysis of biological productivity and fish biomass around the world. How many fish are there in the world? Research suggests that there might be 10x as much fish in the world because of recent bioacoustic estimates of mesopleagic fish. This is an outstanding questions. If this is true, oceanic systems could be much more productive than we currently think. New fishery resource?
Technology requirements	Biogeochemical data, Satellite information, Nets, Continuous Plankton Recorders (CPR), Laser Optical Particle Counter (LOPC), microbial data, bio-acoustics, fish tagging?, Underwater Vision Profiler (UVP)?
Financial feasibility	Mainly existing data. Cost effective methods. Need more information on microbes, phyto and zooplankton functional groups in some regions, mesopelagic fish
Any new observations, data and modeling requirements	Compare shelf systems and oceanic areas with existing fishery and plankton data and supplement these data with new data
Identifying possible implementation challenges	Availability of fish biomass data Less data in tropical systems

Table 4. Ecosystem structure and function --- support ecosystem assessments (Summarized by Sonia Batten)

Discussion Topic	Key points from Breakout discussions
Societal impact(s) of the project(s)	Incidence of Harmful Algal Blooms(HABs) / Global carbon cycle / Global biodiversity/ Food Security. Address needs of Convention on Biological Diversity (CBD) / Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) / World Ocean Assessment (WOA) ecosystem assessments
Gap assessment(s)	Baseline of phyto and zooplankton diversity (including microzooplankton) Key important regions are not sampled, or undersampled (to be defined: e.g. Tropical and subtropical/Ecologically or Biologically Significant Marine Areas (EBSAs)) Need to understand both standing stock and rates, rates are more difficult, but could be related to stocks using information gained from process-oriented “calibration” cruises.
Technology requirements	Some phytoplankton data can be got by satellites, some zooplankton information from active acoustics but both still require ground-truthing e.g. by CPR, or cruises (operational, at least at regional scales) or genomics (pilot) and potentially autonomous vehicles (concept). Space Agencies (e.g. NASA, JAXA) are interested in developing phytoplankton community structure from space. International Ocean Colour Coordination Group (IOCCG) also interested in bringing it to the operational level, especially for HABs. Also depend on scale of project: vary from local to regional to global (from shelf to open ocean, ships to satellites). Regional studies need to be scaled up to global level.
Financial feasibility	The more we have, the more we can do!
Any new observations, data and modeling requirements	Zooplankton community structure, including microzooplankton, not well considered in models.
Identifying possible implementation challenges	Level of maturity: still in concept and pilot stages globally. Mostly just a financial challenge.

The group continued discussions on these topics and which could be further developed into a project or series of activities. During the discussions it was acknowledged that the connection from plankton to fish remains somewhat tenuous despite nearly 70 years of research focused on it. Because of this, any aim to inform food security from plankton observations might be difficult. Instead there are many societal benefits that could more directly be informed by observations of plankton communities. The participants agreed not to consider food security but instead focus on ocean health and understanding climate change as the societal impacts of interest.

After more discussion about overlaps and synergies between the three topics listed above the group agreed to focus on a single merged topic: **Measuring ocean health through plankton: how and why is plankton changing at regional and global scales due to anthropogenic drivers and climate variability?**

For this merged topic a synthesis of the requirements can be derived.

Table 5. Synthesis of the requirements derived from breakout discussions.

Discussion Topic	Key points from Breakout discussions
Societal impact(s) of the project(s)	A predictive capability (model) on primary and secondary plankton production will enable us to quantify the impacts and focus mitigation in the most appropriate regions. Incidence of HABs / Global carbon cycle / Global biodiversity Address needs of CBD / IPBES / WOA ecosystem assessments.
Gap assessment(s)	Baseline of phyto and zooplankton diversity (including microzooplankton) and zooplankton biomass. Key important regions are not sampled, or undersampled (to be defined: e.g. Tropical and subtropical / EBSAS) There is a need to collect and analyze samples for genomics (microbial processes and players) although this technology is not yet fully mature.
Technology requirements	Majority of methods are operational today. Most of the technologies exist although there may be some advantages of newer technologies when the regions are selected. Biogeochemical data, Satellite information, Nets, CPR, LOPC, microbial data, bio-acoustics, fluorocytometer, echosounders, UVP. All remote sensing techniques still require ground-truthing e.g. by CPR, or cruises (operational, at least at regional scales) or genomics (pilot) and potentially autonomous vehicles (concept). Space Agencies (e.g. NASA, JAXA) are interested in developing phytoplankton community structure from space. IOCCG also interested in bringing it to the operational level, especially for HABs. Also depend on scale of project: vary from local to regional to global (from shelf to open ocean, ships to satellites). Regional studies need to be up-scaled to global level.
Financial feasibility	Mainly existing data. Most are cost effective methods, but expensive platforms.
Any new observations, data and modeling requirements	Zooplankton community structure, including microzooplankton, not well considered in models. Compare shelf systems and oceanic areas with existing plankton data and supplement these data with new data.
Identifying possible implementation challenges	Unsampled areas (e.g. tropical). Achieving all appropriate observations for which collaborative work is required with physical and chemical colleagues. Funding (and funding capacity development).

Breakout Session 2. Technical implementation planning

The goal of this breakout session was to focus on what is needed for technical implementation of the identified activities, regarding the project/activities' current feasibility and any developments that will be needed to realize them. Major discussion points focused on how to identify near-term innovation priorities for observing platforms and sensors, data and modelling to enable multi-disciplinary observations. To begin tackling these challenges for our overarching topic (Measuring ocean health through plankton: how and why is plankton changing at regional and global scales due to anthropogenic drivers and climate variability?) the participants split into two groups. One group focused on the open ocean and the other on the coastal zone.

Photo 2. The open ocean sub group begins its discussions. From left to right: Taka Hirata, LuAnne Thompson, Hervé Claustre, Marion Gehlen, Sonia Batten, Emmanuel Boss.

Despite this separation into two groups there was considerable overlap in the possible approaches and tools identified so a single list of proposed implementation approaches/activities and tools is presented here and, where possible, includes which of the plankton EOVs specifically would be measured by each:

Data:

- Meta-analysis of existing data to learn about and highlight gaps
- Help to fill gaps: Instrumentation of hydrographic surveys – Underwater Vision Profiler (UVP; Fig. 7), discrete water samples for additional biological measurements or proxies (genomics, cytometry, pigments, ...) (upper ocean)

Figure 7. An Underwater Vision Profiler.

- Select representative regions for higher intensity observations – for example open ocean, shelf, eastern boundary currents, western boundary currents, tropical regions.

Modelling:

- Regional models could be used to provide an adaptive sampling strategy – where and how often to deploy assets
- Model assimilation of plankton data for forecasting in ecosystem models

Tools:

- Databases: must be easy to upload data to and perform QC, meta data to include uncertainties, must be as interoperable as possible and accessible to modelers
- Sampling protocols: must be well defined and variables quantified with known uncertainties and internationally agreed upon, documented and implemented
- Satellites: Physics Essential Ocean Variables (EOVs) (SSH, SST), Biogeochemistry EOV ocean colour and use of LIDAR to deliver phytoplankton biomass & diversity
- From genomic data information on viruses, bacteria and other heterotrophs, plankton functional groups, ecological diversity (parasites, mixotrophs, symbionts, autotrophs) phytoplankton and zooplankton diversity can be obtained
- From imaging data information on plankton functional groups, ecological diversity (parasites, mixotrophs, symbionts, autotrophs) phytoplankton and zooplankton diversity can be obtained (Fig. 8).

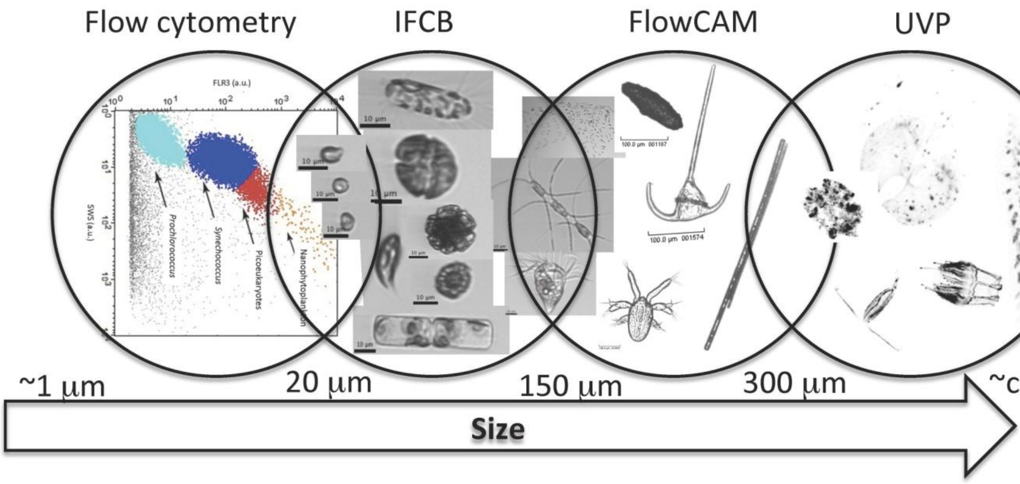

Figure 8. Imaging techniques and the range of plankton they can be used to identify. Figure courtesy of Lee Karp-Boss. IFCB – Imaging Flow CytoBot. UVP – Underwater Vision Profiler.

- Biogeochemical (BGC) Argo and gliders: BGC sensors, in the future to be able to measure zooplankton, which requires miniaturization and reduction in energy. Could add to BGC-Argo floats: UVP, Laser Optical Particle Counter (LOPC)[4], active acoustics to obtain zooplankton biomass and passive acoustics to resolve mammals.
- Bio-acoustics: use of echosounders and calibrated Acoustic Doppler Current Profilers (ADCPs) on research vessels and volunteer merchant ships as part of the Ship of Opportunity Programme (SOOPs) for acoustic backscatter, to obtain zooplankton biomass

[4] It was noted that there is uncertainty about the current and future availability of the LOPC instrument. However, it was included in the discussions and summary as it seemed it is an important component of sampling approaches and hopefully it, or a similar instrument, will be available moving forward.

- In-line instrumentation (clean lines): use of optical sensors, spectral absorption, automated microscopy (Imaging Flow CytoBot (IFCB), FlowCAM) to obtain phytoplankton and small zooplankton biomass and diversity
- Hydrographic surveys (GO-SHIP): use of bottles to obtain water for phytoplankton biomass and diversity, microscopy and High Performance Liquid Chromatography (HPLC), flow cytometers, UVP on CTD rosettes to obtain zooplankton biomass and diversity
- Towed instruments on SOOPs and remote vehicles: Continuous Plankton Recorder (CPR) to obtain larger phytoplankton biomass and diversity, and zooplankton biomass and diversity
- Moorings (e.g. OceanSITES): Use of automated water samplers (weekly to monthly with adaptive sampling), LOPCs to obtain zooplankton biomass, bio-optics, IFCB (on cabled observatories).

Breakout Session 3. Programmatic implementation considerations

The goal of this session was to think about programmatic implementation and what is needed to make these projects happen in a practical sense with regard to: (1) Project/Activity milestones for both a 2 year and a 5 year project, (2) Schedules and detailed needs for implementation (including project management), and (3) Funding requirements.

Discussions of these issues continued from both an open ocean and a coastal perspective and are summarized in Table 5.

Photo 3. The coastal ocean sub group continues their discussions. From left to right: Sam Simmons, Fei Chai, Peter Thompson, Bernadette Sloyan, Anthony Richardson.

In addition to the summary of discussions for open ocean and coastal systems (Table 6) a few points are worthy of further attention here: First was the discussion around ways to fill gaps in coastal observing programs, with a particular focus on Small Island Developing States. Instruments and observational approaches are available that could easily be used, following dedicated capacity building actions, by local community members (e.g. secchi disks, thermometers) and still expand and sustain observation in the coastal zone. Building long term relationships between individual scientists, scientific organizations and communities is essential for sustaining an observational system that relies on local citizen input. Motivation for community participation must come from community interests and needs, whether it is fisheries monitoring or supporting engaging young people in education or internship settings. Additionally, strategies must keep in mind best practices for obtaining both high quality observations and for building effective relationships with communities affected by ocean change.

Second was the discussion about developing a definition of Ocean Health as relevant to this theme of plankton community changes. There is an existing "Ocean Health Index" but the participants felt that the term "Ocean Health" remains poorly defined and there is a need for this community to come together to better define this term as relevant to plankton community changes and develop metrics for that definition based on the multidisciplinary observations being discussed at this workshop. The goal was within 2 years to have developed a definition and metrics (to be able to conduct a global 'health check' as an interim term as OHI is already being used) and within 5 years to have started implementation of sustained observations to inform both, including in developing nations (i.e. create a definition and metrics that will truly be global). It was agreed that one way to start this activity was through a dedicated workshop or working group (e.g. SCOR) to work on the definition and metrics.

Third was the importance of consultation with modellers was highlighted throughout the discussions. For any of the activities described in the table it is critical to ensure the observation outputs are optimized to meet the requirements of modellers. Along a similar vein the importance of QA/QC procedures, data being freely shared, and high quality data products being delivered was highlighted for both open ocean and coastal systems.

Table 6. Summary of activities and projects discussed over 2 and 5 year timescales to address our overarching topic in coastal waters and the open ocean.

	COASTAL/SHELF OCEAN	OPEN OCEAN
Short term goals (2-5 years)	**Within 2 years:** Integration of existing observations to deliver on phytoplankton diversity and biomass, and zooplankton diversity and biomass EOVs. Meta-analysis of existing data and encouraging the community to move towards free and open data access. E.g. identify gaps - overlay existing 300+ time series stations (including CPR), GO SHIP and distribution of BGC Argo to show the global coverage.	**Within 2 years:** Actively engage with the GO-SHIP steering committee to pursue augmenting the cruises with: Add a UVP to the rosette for zooplankton/particles (~$135k per ship) Additional water samples taken for flow cytometry, phyto pigments (HPLC), Particulate Organic Carbon (POC), genomics for micro-organisms (~$30k per voyage, $250k per voyage for additional on-shore analysis and data delivery). Optical sensors (transmissometer, fluorometer, back scatter) attached to the rosette. Possibly in-line imaging cytometry (~$135k per ship). This would provide a spatially intensive snapshot, i.e. a biodiversity census every 7-8 years. Great vertical resolution. Costs for augmenting are relatively small (~270k for instrumentation, <300k per voyage for additional sampling and data delivery.) Produce an internationally agreed to: 'A guide to best practices for relevant plankton measurements' and this to be added to GO-SHIP hydrography manual.
	Within 5 years: Filling gaps in coastal observing, with an emphasis on developing nations, especially Small Island Developing States (SIDS). Potentially each region would require $3-5,000,000 per year to implement a fully operational observing system for the EOVs discussed here.	**Within 5 years:** Move towards sustainable funding for the BGC-Argo network and ensure the database, quality control, and dissemination infrastructure are in place. Long term wishes may include passive acoustics (for marine mammals), active acoustics (zooplankton biomass), and/or zooplankton imaging (UVP).
Activities	Improved coastal (type 2) algorithms for algae (HPLC). Harmful algal blooms in particular. Toxin detection. Report into the assessment of biomass related to eutrophication (Sustainable Development Goal 14.1)	Advocate that BGC-Argo floats incorporate biological sensors. GO-SHIP measurements are very accurate but sections repeated at 7-8 year interval, corresponding BGC-Argo measurements have less accuracy but every 10 days – need to synergistically connect these approaches and optimize the BGC Argo data.
Sampling	Transect from shore to open ocean or stations. Sample at least monthly. More frequent inshore (ultimately move to	Continue existing CPR to provide large scale context for zooplankton (adding additional transects would be ~$250k for between 10,000 and 20,000 miles of transect plus additional capacity building costs of ~$50k per new

	adaptive sampling) Spatial by depth: 25m, 50, 100, 200, deep (TBD) Vertical: from surface to bottom of the euphotic zone. To fill gaps in under-sampled locations but those that have high human population pressure.	region). Eventually possible to compare and integrate CPR and UVP (each tells you something different about the plankton). Include use of satellites to provide large scale context for phytoplankton functional group information is in development. Satellite data essential for defining seasonality.
Tools	Optical technologies, CPR, net tows, bioacoustics, LOPC, UVP. Cell counts, flow cytometer, 'omics, fluorescence (or % transmission) profile or high frequency (gliders or other) – gliders programed to explore "under" blooms seen from satellites.	To be incorporated into BGC-Argo: UVP. Community has already agreed the 6 core BGC-Argo measurements– O_2, Nitrate, Chl-a, pH, backscatter and down-welling irradiance. (Goal is for 1,000 floats with 4-yr life span, and so 250 floats per year. Estimated cost is $25,000,000 per year including database and data distribution).
Essential Ocean Variables	**Biological:** Zooplankton biomass and diversity Phytoplankton biomass and diversity **Biogeochemical:** Dissolved oxygen, inorganic carbon, nutrients, ocean colour (includes light), suspended particles, particulate organic carbon **Physical:** Wind, ice, temperature, salinity, currents, continental /riverine input (an ECV)	**Biological:** Zooplankton biomass and diversity Phytoplankton biomass and diversity **Biogeochemical:** Dissolved oxygen, nutrients (nitrate, phosphate, silicon), pH, particulate organic carbon, and if possible iron. **Physical:** Temperature, salinity
Other issues / activities	Need for capacity building, especially to address harmful algal blooms. IOC WESTPAC might be a good vehicle for this for example Add biogeochemistry to modelling, data assimilating circulation model and validate some of the rates. Calibration and data management (QA/QC) all the way!	Data products and data access are important, not to be diminished. Needs to be some discussion with modellers to optimize model requirements in term of initialization and validation. Underway ADCP from ships also provides high resolution biomass data, but needs to be calibrated so data can be compared and integrated. A challenge is to produce a uniform and interoperable dataset or product from the different data types this approach would generate, but it would be of great value to for this community to define what "Ocean Health" means with respect to plankton. Need to consider how this would influence policy. Within 2 years: Define Ocean Health Indicators for plankton (through a convened workshop). Make emphasis on where the data will be going when collected – add value to BGC-Argo and GO-SHIP. Calibration and data management (QA/QC). Plans support GCOS IP (extending CPR observations, new sensors in BGC-Argo and GO-SHIP).

Breakout Session 4. Reviewing Implementation strategy and developing recommendations for pilot projects.

The goal of this session was to bring consistency to the emerging project/activity plans across the demonstration themes and ultimately perhaps identify 1 or 2 projects from the workshop overall as a priority of development ahead of Ocean Obs'19. Major discussion points to address: (1) the creation of a consolidated project/activity plan, (2) identifying opportunities for ongoing collaborations and communication, and (3) identifying potential opportunities for funding support for integrated multi-disciplinary projects/activities. However, by this point in the workshop each demonstration theme was at a very different stage of their discussions and not ready for this synthesis activity. Therefore, the participants further developed specific actions related to the projects and activities identified so far.

Coastal/shelf and the open ocean were continued to be discussed separately in this session. Participants focused on ways in which sustained plankton observations may feed into policy, how an observing system may contribute to move such policies forward, and what needs to be done to achieve this by building on the current momentum and taking advantage of multidisciplinary expertise.

Common key points to consider for both coastal and open ocean:

- technology limitations: most biological measurements are currently not automated and require in-situ observations. Some have been the focus of research cruises but have not underpinned ocean observation.
- the need to be more effective in multidisciplinary data collection: e.g. how to manage to have the technology in place to measure new variables without "slowing down" the physical cruise? For example, using pump systems to collect water without affecting/disturbing the campaign. Or to implement optical sensor on CTD rosette. In this way the physical observers may be more willing to include the biological measurements into their trips.
- selection of the project locations: at present, there are sensitive issues at the government/convention levels on eutrophication as it affects public health. Through satellite observations, coastal areas that would be the most sensitive to future, short term changes could be identified. Other considerations to select the project area would include latitude (temperature related) and mixing within the water column, as both affect primary production, as well as anthropogenic impacts already suffered.
- to increase chances of support, the project needs to be compelling both for the scientific community, providing data to answer questions, but also of use to society by addressing health issues for example. More likely, the project will be supported by individual governments who will provide funds (limited) to support the network at the national level, and this will contribute to the global system.
- opportunities for engaging with the community: reach out to the World Association of Marine Stations (WAMS). WAMS are already getting together to try and standardize their sampling. Compile manuals and best practices from current observing programs or groups, and try to reach agreements on standardization, or at least on how to convert the collected data into a standard metric that can be compared.
- the challenge of data sharing: this was recognized as a key issue. There are already many agreements between international groups to use the same methods/software within international standards and data sharing, so this should ideally be reinforced/supported.

- capacity development: One of the major advantages of having common approaches is the benefit for developing countries, as it helps build capacity on specific agreed-on packages. Capacity should not be limited to the biological planktonic community but also to be expanded to associated biogeochemistry and physics measurements. The Intergovernmental Oceanographic Commission (IOC) provides a capacity-building framework on technical aspects of ocean observing, but it is also needed to deliver useful products from the data, i.e. the importance of training users how to access and use the data from observations cannot be overlooked. The SIDS have a 20-year capacity building program which could serve as a good model. “Independent” observations made through technologies such as cell phone apps, etc., could be of great value for capacity-building, and be loaded in real-time. For these data to be useful, the metadata explaining the detailed protocol, standardization, calibration, etc., must be clearly documented, so that the user may decide to take the data or not. A data management platform would be needed to implement this.
- the need for a review paper(s) on what data are available and from where. This review would likely include an evaluation of existing time series data sets compiled as part of the IGMETS (International Group for Marine Ecological Time Series) project (Fig. 9), and other global datasets coordinated by GOA-ON, Argo and BGC-Argo, OceanSITES, etc. The review is envisioned as an international effort (to be led by Peter Thompson and Anthony Richardson) involving IMSOO participants and open to the broader community who is supportive of moving forward observations of EOVs across disciplines. The community would be the main driver of this initiative, and the products could be used to provide an incentive for broader data sharing. For example, highlighting where data are collected but not shared or more powerfully products that can be derived when data are shared as has proved so successful with carbon data products through the Global Ocean Data Analysis Project (GLODAP).

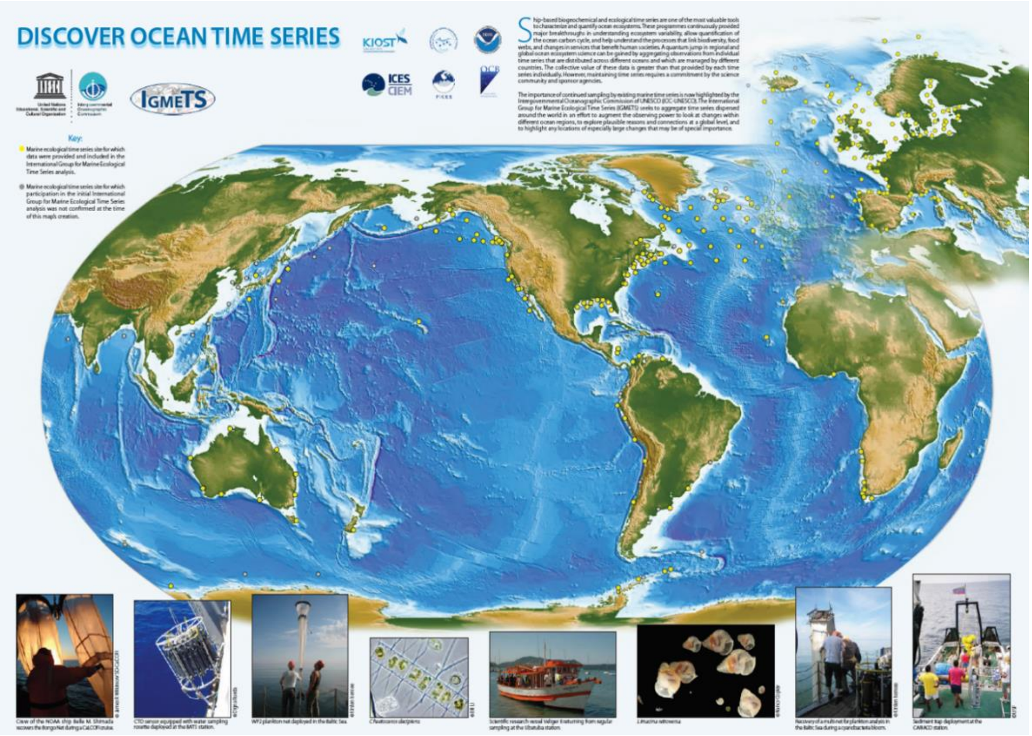

Figure 9. The Discover Ocean Time Series map (http://unesdoc.unesco.org/images/0023/002346/234627e.pdf)

COASTAL ZONE: agreed actions

- Work across gradients of anthropogenic impact, with an emphasis on eutrophication, and other pressures. Review the data that are available from current stations against information on anthropogenic pressures. Consider using different biogeographic provinces as a basis for comparison of pilot projects.
- Work towards a publication of a review or meta-analysis of existing data and gaps (ideally to include an implementation plan for a global observing system to address our agreed to topic)

2 year plan: *(Focus on coordination, engagement and outreach activities around the review publication and improving data standardization, access, and sharing in coastal regions)*

- Identify opportunities to co-locate observations with or collaborate with the activities and projects identified by the other two demonstration theme breakout groups at this workshop: oxygen minimum zones and open ocean/shelf interactions (boundary currents).
- Reach out to the Marine Stations of the world, bringing them together may help with access to data and implementation of standard methods and best practices (where appropriate).
- Conduct a meta-analysis of existing sources of observations on the EOVs identified during this breakout (Table 6). Develop a product, for example a map, that locates data sources globally and highlights the status of data availability and integration into global data products/indices and assessments.
- Anthony Richardson and Peter Thompson agreed to take the global data sharing initiative idea to the IOC's International Group for Marine Ecological Time Series (IGMETS) working group. Wherein they could review the availability of data and which data series are freely available. A joint international effort to improve data sharing such as through IGMETS would be powerful.
- Engage with the Partnership of Observation of the Global Oceans (POGO) to help promote data sharing, encourage the publication of data through data portals (with a DOI for the database), and also possibly as a partner for the development and promotion of best practices manuals and standards.
- Target for OceanObs19, be able to present progress on implementation of a global, sustained coastal observing system for plankton community changes, including how multidisciplinary observations are being used in evaluations of ocean health, and global assessments (e.g. CBD, IPBES, WOA, and Sustainable Development Goals). This would be a major breakthrough/contribution.
- Write or compile best practices manuals to present at OceanObs19, create low cost methods to be used as part of capacity building where possible.
- Encourage relationships between appropriate stakeholders (including, policy, education).
- Engage with other IOC groups and activities: Henrik Enevoldsen Global HABS, TrendsPO, IGMETS. Revisit the ideas of the Panel for Integrated Coastal Observations (PICO) plan and how it could be moved forward.
- Engage with other groups such as the Global Ocean Data Assimilation Experiment (GODAE offered by Marion), Global Ocean Acidification Observing Network (GOA-ON), and others (e.g. presentations to Institutional faculties of our participants) to invigorate the community and highlight links and opportunities for further engagement (GOOS panels and secretariat will provide some standard slides for this).

5 year plan:

- Design, propose, (implement?) a coastal observing program within GOOS
- Develop and produce an initial 'health check' report for coastal ecosystems
- Identify opportunities to build out the observing system and address the idea of an adaptive sampling strategy using platforms such as gliders (e.g. mapping the subsurface characteristics of a bloom in concert with the satellite observations and other in-situ observations)
- Promote the use of biological sensors on alternative platforms such as gliders, floats and moorings.

OPEN OCEAN: agreed actions

- increase synergies with existing autonomous networks (Argo, BGC-Argo, BGC-gliders, OceanSITES). This also includes strengthening the connection to the remote sensing community (ocean color, temperature, etc.), and satellite technologies as this will open a door to funding from space agencies.
- incentivize the more routine collection of environmental data (temperature and salinity) from the CPRs in addition to development/addition of new sensors with oxygen being the first priority.
- to initiate dialogues with global observing platforms/networks, e.g. GO-SHIP, OceanSITES, TPOS2020, ichthyoplankton networks, and collectors of long-term time series to identify specific opportunities to integrate measurements of the biological and other EOVs identified during the workshop (see Table 6 and details below) into these networks.

2 year plan:

- link to satellite community: working through the International Ocean Color Coordination Group identify opportunities to increase in-situ observations used for calibration and validation of satellite measurements. For example, the proposed HPLC and other measurements on water samples from GO SHIP or the plankton functional type information that would come from the UVPs or LOPCs if integrated into GO SHIP (Figs. 10-11)
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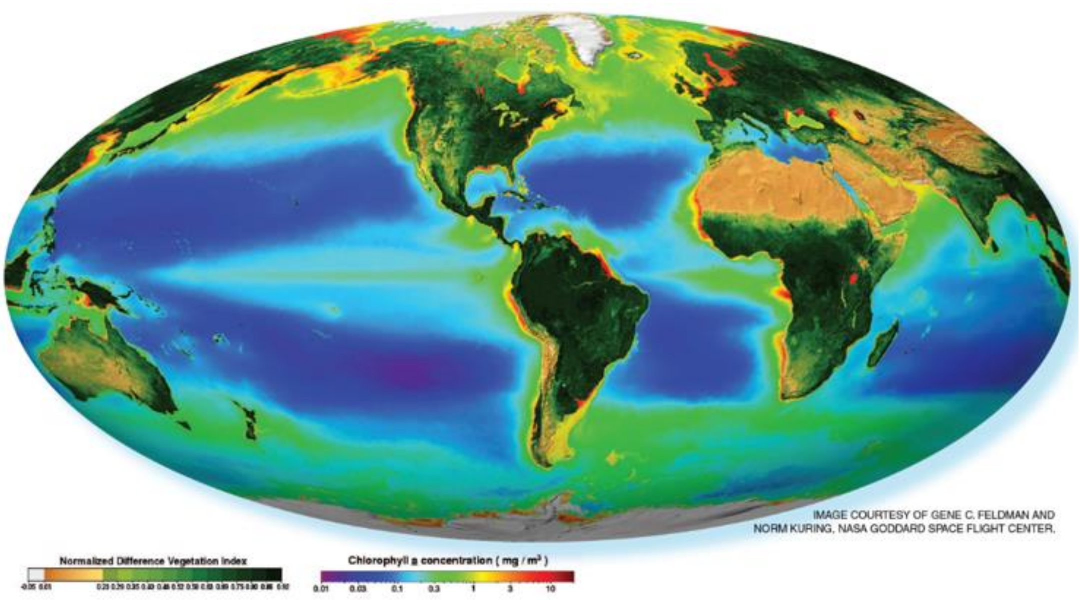

Figure 10. Phytoplankton as inferred from ocean colour satellite data on chlorophyll a concentration.

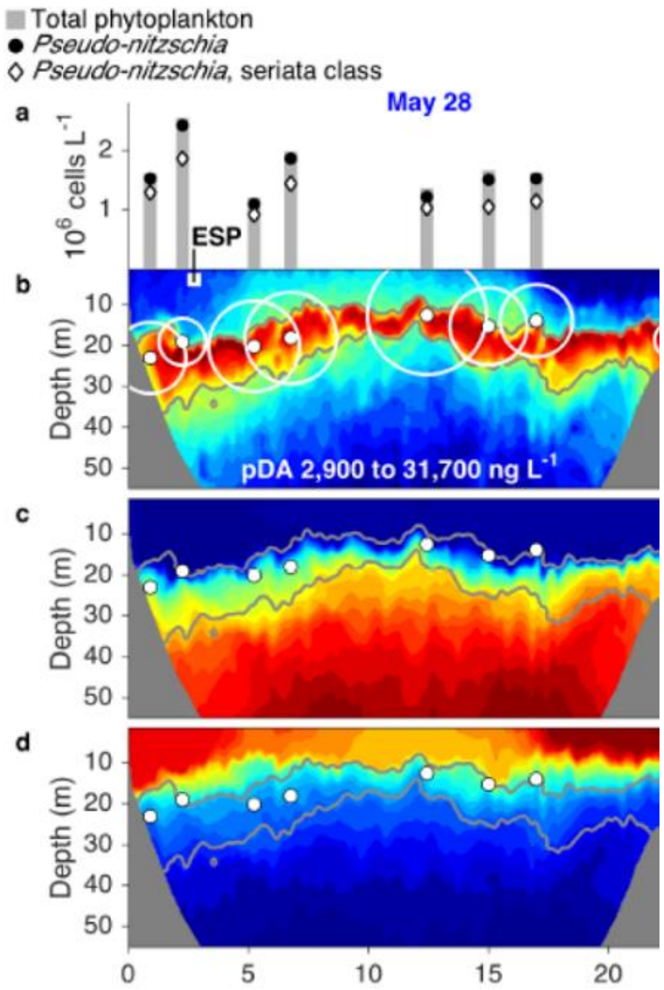

Figure 11. Sub surface changes in concentration of phytoplankton.

- CPR surveys: This group to draft a letter to the Global Alliance of CPR Surveys (GACS) including recommendations to make observations of temperature and salinity from CPRs more routine, promote the inclusion of oxygen sensors on the CPR or the ship itself where feasible, and to seek to extend surveys to other regions. Sonia agreed to raise these issues at the next annual meeting.
- link to GO SHIP: within 2 years have representatives for biological observations on the GO SHIP Steering Committee, begin collection or development of necessary best practice protocols and manuals for the proposed augmentation with UVP and bottle samples (See Table 5). Starting point might be to draft a letter of intent (to be drafted by Emmanuel Boss and Hervé Claustre and sent to Bernadette Sloyan) explaining what could be implemented, what it will require, levels of complexity for implementation (e.g. does it need special training of a technician). The letter should also have clear instructions on the protocols necessary to deploy the instruments and collect the proposed observations. If these standardized documents already exist, they should be sent to GO SHIP with the letter. If they do not already exist this group agreed to work on development of some of these required documents in the next two years.

- link to BGC-Argo: GOOS (Sam Simmons and Bernadette Sloyan initially) to draft a letter of support for BGC-Argo based on discussions at this workshop. Help move towards sustainable funding for the BGC-Argo network and ensure the database, quality control, and dissemination infrastructure are in place.
- link to OceanSITES: Huge potential to expand observations on moorings but what specifically depends on where the mooring is, its servicing frequency, power requirements for the sensors, etc. In the near term work on drafting a letter of support and recommendation for OceanSITES to collect observations of plankton EOVs[5]. Letter to include the addition of optical instruments, collection of bottle samples and calibration[6] and preservation of existing ADCP data to be used for biomass measurements on moorings. In the next two years use the letter and work to identify opportunities to engage OceanSITES (e.g. Marion to request at the European OceanSITES meeting later this year) to identify opportunities to add the highest priority and feasibility of these sensors/measurements to moorings in a few regions and then work to build out from there.

5 year plan:

- CPR surveys: Support the development/inclusion of addition sensors on the CPRs e.g. for nitrate and pH.
- Advocate that BGC-Argo floats incorporate a UVP. The community has already agreed the 6 important measurements to be added – O2, Nitrate, Chl-a, pH, backscatter and down-welling irradiance. Goal is for 1000 floats with 4 yr life span, and so 250 floats per year. $25,000,000 per year including database and data distribution. Long term wishes may include passive acoustics (for marine mammals) and active acoustics (zooplankton biomass).
- GO SHIP measurements are very accurate but sections repeated at 7-8 year interval, corresponding BGC-Argo measurements have less accuracy but every 10 days – need to synergistically connect these approaches and optimize the BGC Argo data.
- Open Ocean time series stations: find out what they are already measuring and what the specific requirements would be to expand their observations within the scope of addressing our topic (e.g. Hawaii Ocean Time Series (HOTS), Bermuda Atlantic Time-series Study (BATS)) could be augmented to have a UVP on every CTD cast. Tropical arrays could also be augmented.
- Need for an ongoing review of emerging technologies and their integration into the systems described above as appropriate. For example, the Environmental Sample Processor currently being developed at MBARI, or the idea of towing a pump from a ship to bring water on board for biological sampling while underway so as to not impact the other sampling or progress of the voyage.

Following each breakout session there was a report back to all the workshop participants in plenary and some important additional ideas that were generated there for further consideration include:

[5] Frank Muller-Karger, Raphael Kudela, Peter Thompson, Rudi Kloser and Emmanuel Boss identified as a sub group to work on drafting this letter.

[6] Calibration of ADCPs for acoustic return, e.g. https://academic.oup.com/icesjms/article/61/2/184/620162/The-biological-validation-of-ADCP-acoustic

https://www.researchgate.net/publication/272258768_Calibration_and_use_of_a_broadband_ADCP_to_measure_zooplankton_volume_scattering_strengths

- Fisheries agencies as a potential source of zooplankton data to be incorporated into all of these activities.
- The importance of gliders as a sampling platform particularly when it comes to connecting the open ocean and coastal systems as discussed here.
- Identify opportunities to use animals as ocean sensors to measure physical, biogeochemical, and biological EOVs. Current sensors on animal-borne instruments include temperature, salinity, fluorometers, light level, and oxygen sensors.
- There is a GODAE ocean observations task team potentially to connect with to help facilitate some of the activities identified.

In the final discussion session each group was asked about potential funding opportunities they may have discussed. There were no specific funders identified to approach. Rather in sessions 2 and 3 some specific asks were identified, some medium sized (e.g. additions to Go SHIP) and some big (e.g. BGC-Argo) but acknowledged that the addition of any of these would be a global ask that would go back to individual nations to decide if they wanted to contribute to by supporting the networks like GO SHIP and BGC Argo, etc.

In the coastal zone it gets a little more complicated as this groups does not have an international mandate but targeting observations to meet local/regional needs. While some rough estimates of what the ideal system might cost to implement were made, e.g. in the US $3-5 million per year, the importance of building community in certain parts of the world was also discussed, and that a different approach to implementing a coastal observing system might be warranted. For example, developing capacity with low cost options to stimulate engagement and buy-in to ultimately create a sustained system.

Demonstration Theme 2: Oxygen Minimum Zones

Co-Chairs: Véronique Garçon, Johannes Karstensen

Note-taker: Artur Palacz

Attendees: Arne Körtzinger, Bob Houtman, Lisa Levin, Francis Marsac, Kenneth Rose, Kevin Weng, Kyla Drushka, Mark Bourassa, Pierre Testor, Raphael Kudela, Tony Koslow

Rapporteurs: Kyla Drushka, Arne Körtzinger, Kevin Weng, Johannes Karstensen

Facilitator: Maciej Telszewski

Breakout Session 1. Framing demonstration themes and associated requirements

Objectives

The goal of the first breakout session was to identify one or several, focused, integrated and multi-disciplinary project/activity ideas for the theme (focused either geographically, temporally or by topic/question). The list of projects/activities was to be refined based on several discussion topics related to: societal impacts of the project(s), gap assessments, technology requirements, financial feasibility, needs for new observations, data and modelling requirements, and implementation challenges.

Proceedings

The breakout session began with introductions of the attendees who brought in expertise and interests from a wide range of disciplines and topics such as atmospheric science and physical oceanography, marine biogeochemical cycles, population dynamics, benthic ecology, fisheries and ecosystem modelling.

The session co-Chairs briefly introduced the objectives for all breakout sessions, explaining that the approach to follow was based on the Framework for Ocean Observing, i.e. a systems engineering approach "for identifying the requirements and their priorities, testing new technologies, endorsing implementation plans, and setting data sharing standards" for multi-disciplinary, multi-platform observations in response to both scientific and societal needs related to the OMZ theme.

Consequently, the first step was to identify the key societal and scientific questions that should drive the framing and implementation of the OMZ-related projects/activities. Questions posed by Lisa Levin during her overview talk were chosen as basis for further discussions.

The following overarching question was agreed upon for the proposed IMSOO-OMZ activities. This question is directly linked to multiple societal drivers for OMZ observing (e.g. fisheries, OMZ expansion, biodiversity changes, greenhouse gas emissions, carbon sequestration):

How do changing Oxygen Minimum Zones (OMZs) affect the spatio-temporal distribution, productivity and trophic structure of the benthic and pelagic communities?

In addition, the group identified several scientific questions that are linked to the overarching questions. The more specific, but still broad, supporting scientific questions should help to narrow down the phenomena and EOV space and thus the individual components for planning multi-disciplinary observing strategies for OMZs:

- What are the physical mechanisms controlling/influencing oxygen supply to OMZs?
- What are the biological components controlling/influencing oxygen consumption?
- How does benthic-pelagic coupling affect biogeochemical and ecological feedbacks?
- What is the role of microbial community metabolism on the development of OMZs?
- What is the bottom-up effect of changing OMZs on the trophic structure?
- How does the fish biomass and community structure change in relation to a changing OMZ?

For this breakout session, the co-Chairs and the facilitator strongly emphasized that the intention of the breakout group was not to design a substantial science campaign aimed at addressing all these questions, but rather, to narrow down the set of scientific questions that are related to the overarching question in order to propose/design a fit for the purpose multi-disciplinary observing system for an OMZ demonstration theme.

The group then proceeded to discuss the anticipated societal impacts as well as benefits of the proposed project, considering the three broad GOOS application areas: (i) climate, (ii) real-time services and (iii) ocean health. Changes in OMZs affect the distribution of greenhouse gases (GHG) in the coupled ocean-atmosphere system, and are a factor in regulating ocean carbon sequestration. As far as ocean health is considered, changing OMZs affect fish production, with consequences for both fisheries and aquaculture. OMZs are also linked to eutrophication, and can negatively impact species diversity, imposing additional requirements for ecosystem conservation. Multi-disciplinary observations related to OMZ dynamics are expected to bring benefits to society, for example through harvesting of new genetic resources having potential for wide-ranging industrial applications.

Photo 4. Discussions during one of the OMZ demo theme breakouts. From left to right: Johannes Karstensen, Francisco Chavez, Artur Palacz, Véronique Garçon, Wajih Naqvi, Raphael Kudela, Lisa Levin.

When brainstorming about gaps in the current observing system, the attendees pointed at certain phenomena and variables needed to (i) better constrain biogeochemical fluxes (including respiration), (ii) obtain high resolution estimates of physical supply of oxygen, (iii) improve the model constraints on atmospheric/wind forcing, and (iv) increase understanding of the impacts of OMZs on changes in biological community structure. Furthermore, it was noted that observations of the entire water column and the water sediment interface should be added as a mandatory critical element of OMZ observing systems.

Technology requirements were only briefly considered at this point, with conclusion that a complementary approach of ship-based, fixed-point, autonomous and satellite remote sensing observations is needed to survey the relevant time and space scales that will allow to describe the phenomena associated with the OMZ relevant processes.

The issue of scale, regional vs global, was raised in the context of phenomena and observations and modelling feasibility. It was concluded that the focus of a demonstration activity should be on the regional scale, considering the financial feasibility aspect of the demonstration activity but also increasing complexity by integrating a wider range of contributing processes. Building on existing and/or forthcoming initiatives, a multi-disciplinary OMZ project would be implementable in a number of key geographic regions, such as the Benguela and the Canary Current System (W. Africa), the California Current, the Humboldt Current System and the Northern Indian Ocean (Bay of Bengal).

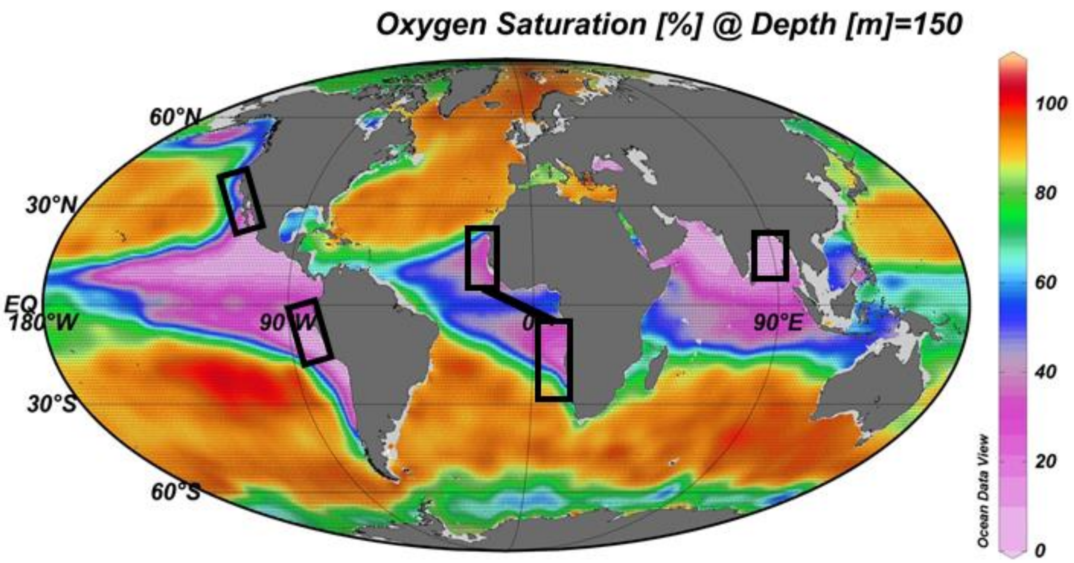

Figure 12. Locations of OMZ sites (black boxes) selected for consideration in this proposed project, overlaid on top of the global map of oxygen saturation at 150-m depth horizon.

While specific observational data sampling requirements were not discussed at this stage, much attention was paid to specific modelling requirements. It was concluded that high-resolution, regional, coupled atmosphere-ocean models were critical. Also, as the impacts of changes in OMZs propagate across the entire food web and ecosystem, from physics to apex predators, end-to-end models are also desirable.

Among the possible implementation challenges for the recommended OMZ projects the following were pointed out: (i) securing financial resources for a sustainable observation program, (ii) legal issues of working in the Exclusive Economic Zones (EEZs), (iii) accessing historical and current data, and (iv) technological limitations in instrument and sensor development.

Report-out

Arne Körtzinger was the rapporteur for this session. In plenary, he briefly summarized the breakout group discussions and presented the overarching question for the OMZ demonstration theme, as well as the list of supporting scientific questions. A summary of the discussion themes reported can be found in Table 7 below.

Table 7. Themes considered when framing the requirements for the proposed IMSOO OMZ project/activity.

Discussion Topic	Key points from Breakout discussions
Societal impact(s) and Benefits of the project(s)	<u>Impacts:</u> Fish production (fisheries + aquaculture), GHG emissions, carbon sequestration, conservation, eutrophication <u>Benefits:</u> genetic resources (potential industrial applications)
Gap assessment(s)	Biogeochemical fluxes, high resolution ocean physical supply, mesoscale atmospheric/wind forcing, impacts on biological community structure changes, etc.
Technology requirements	A nested approach of ship-based, fixed-point, autonomous and satellite remote sensing observations.
Financial feasibility	Feasible on a regional scale, not global. *[Implementable e.g. in the Benguela Current System, Canary Current System, California Current System, Humboldt Current System, Northern Indian Ocean (Bay of Bengal)– building on existing and/or forthcoming initiatives.]*
Any new observations, data and modeling requirements	High resolution regional, coupled atmosphere-ocean model (coupled physical, biogeochemical and ecosystem – End2end model).
Identifying possible implementation challenges	Financial resources for sustainable observation program. Legal issues of working in the EEZs. Access to historical and current data. Technological limitations.

Following the presentation, there was a short discussion in plenary in response to several questions and comments made:

1) *What is the societal impact that would drive this investment?*

   OMZs are expanding in areas where fisheries are of key importance to the relevant nations. Quantifying the effects of different drivers, no matter how small or large they might be, would be very helpful to resource managers.

Carbon sequestration was given as a second relevant societal driver. As biological particles falling from surface waters do not get digested as much in the OMZ areas, the sequestration rates might be altered significantly.

2) *Choice of regions of interest*

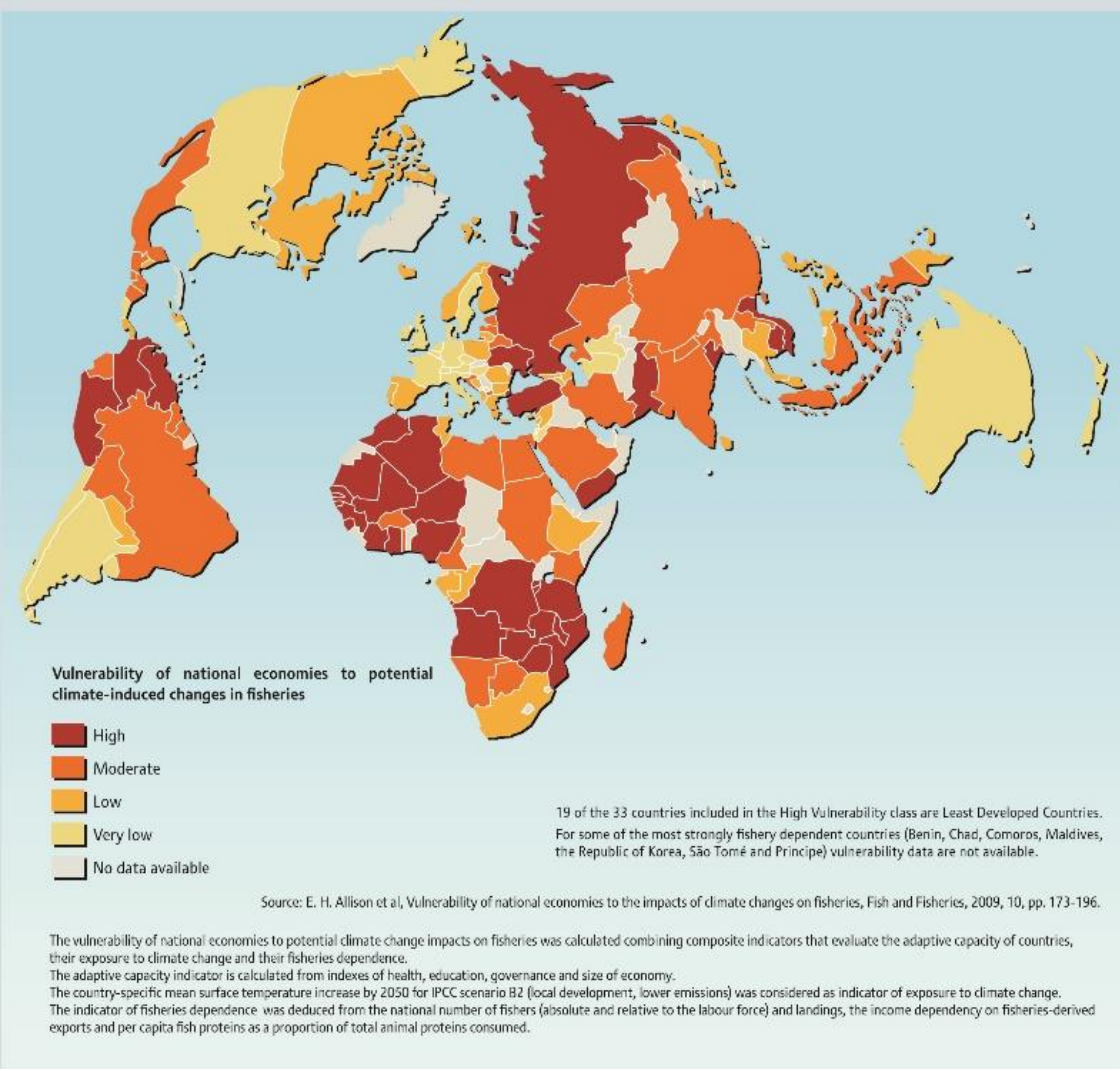

Figure 13. Vulnerability of national economies to potential climate-induced changes in fisheries. Adapted from: Allison et al. (2009).

The list of regions initially suggested in Table 6 was by no means exclusive. Focus on West African coast regions was based on published maps of highest economic vulnerability depending on the success in fisheries in a given country (Allison et al., 2009; Fig. 13). During the discussion it was suggested that Bay of Bengal be listed among the top areas subject to impacts of changing OMZs.

On top of the above arguments, the design of an IMSOO on OMZ should take into account the availability of historical and current data, and prospects for sharing data in the future. It has been made clear by the organizers that all data resulting from any activities stemming from IMSOO workshop will have to be made publicly available.

3) Continuity of changing OMZ impacts into the shoreline

When an OMZ comes right up to the coast, there is a continuity of impacts into the continental shelf, and thus a strong connection between inshore oxygen concentration levels with marine living resources and the landward watershed. In very shallow waters, these linkages would be considered to some extent by including benthic-pelagic coupling and a suite of feedbacks.

Breakout Session 2. Technical Implementation Planning

Objectives

In this breakout session, the participants were asked to focus on technical challenges of realizing actions/projects identified during the previous session, and to identify pathways to resolving them. Proposed discussion topics included: (i) identify near-term innovation priorities for observing platforms and sensors, data and modelling to enable multi-disciplinary observations; (ii) identify programmatic and professional expertise necessary to support specific project/activity (organizations, projects); (iii) scope an implementation plan for the project(s).

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During the initial discussion it became apparent that it is necessary to step back from the more technical implementation planning envisaged for this session, and focus more on the issues that were raised in plenary the previous breakout session, in particular on the choice of geographical regions which would fall under the scope of this project. This decision was additionally motivated by the fact that it became apparent that there will be overlaps in regional focus between two if not all demonstration themes, and these should be exploited to the benefit of the enhanced multi-disciplinary ocean observing system.

It was agreed that the aim of this OMZ-related project, short-term or long-term, would need to be applicable globally, i.e. its geographic scope would go beyond the observing efforts of developed countries. Moreover, the demonstration project would build upon existing capacities with minor modifications as required to answer the scientific questions posed. Such a process would for example involve recommendations to extend and potentially re-purpose elements of the existing well-established observing programs, such as CalCOFI and the Long Term Ecological Research (LTER) site in the California Current System OMZ, to establish the minimum set of infrastructure necessary to address IMSOO related OMZ questions, and thus generate a prototype for an interdisciplinary, integrated OMZ observing system – to be applied to and compared with other OMZ regions.

During the second part of the break-out, the group tried to summarize the current potential of selected geographical sites to meet the requirements of the observing system to answer scientific questions related to the OMZ theme (see above). Four locations were considered at this stage (Table 8): the California Current System, Northern Indian Ocean (Bay of Bengal), West Africa (Canary and Benguela Current Systems), and the Humboldt Current System (Peru).

It should be noted that Table 7 is incomplete and thus should be looked at with caution. Whenever there was insufficient expertize in the room, contact persons for obtaining more information were identified.

In accord with the Framework for Ocean Observing, the table includes a list of phenomena identified as needing to be observed and modelled in order to answer one or more of the relevant scientific questions which in turn help to provide the critical information for the societal driver of the sustained observing. In the next step (part of the IMSOO OMZ demonstration mission), the table would be refined and expanded upon to include all relevant phenomena and the EOVs of interest. Such a list would distinguish between:

- Describing relevant phenomena in disciplinary subspaces (physics, geochemistry, biology/ecosystem), including time and space scales of relevance for the selected OMZ demonstration mission scientific objectives
- Describing relevant EOVs in disciplinary subspaces (physics, geochemistry, biology/ecosystem) distinguishing between:
  - EOV for which measurements are already performed and available as needed,
  - EOVs for which there are requirements for new measurements, and
  - EOVs measured but not meeting any requirements, thus pointing at redundancies in the system.

Finally, it is critical that convergence with the other two demonstration themes is sought whenever possible, in order to address the requirements with respect to overlapping phenomena in an integrated and efficient manner, e.g. with respect to energy transfer commonly identified in the Plankton Community Changes and the OMZ themes.

Table 8. Current capacity vs phenomena requirements in selected geographical regions relevant to the OMZ-related scientific questions posed. Key: Y – 'yes' meaning present, N – 'no' meaning absent, NA – not applicable.

Location	**California Current System (CalCOFI + LTER)**	**Canary & Benguela Current Systems (W Africa)**	**Northern Indian Ocean (Bay of Bengal)**	**Humboldt Current System (Peru)**
Selected phenomena	**Selected observing approaches**			
Meso and sub-mesoscale features	O_2 on gliders: Y Models: Y Moorings: Y	O_2 on gliders: Y Models: ? Moorings: Y	O_2 on gliders: N BGC-Argo with O_2: Y (focus on upper ocean)	O_2 on gliders: Y Models: Y Moorings: starting (Korean partnership)
Riverine inputs	SCCWRP	*NA*	Very relevant: data classified	Relevant during El Nino; from Colombia and Ecuador
Upwelling dynamics	Satellite remote sensing + modeling, in-situ for vertical structure			
Wind and waves, buoyancy forcing				
Benthic-pelagic coupling				

Trophic connections	Fisher Observer Program - stomach content/diet analysis: Y Stable isotopes: Y Size-spectrum: Y Food-web modelling: Y	Fisher Observer Program - stomach content/diet analysis: Y Stable isotopes: Y Size-spectrum: Y	Fisher Observer Program - stomach content/diet analysis: N Stable isotopes: ?	Fisher Observer Program - stomach content/diet analysis: IMARPE regular coast-wide surveys Stable isotopes: N Paleo-records: Y
Redox dependent fluxes	N	Lander measurements: Y	Shallow landers over the shelf: Y Deep landers: N	Lander measurements: ad hoc
Microbial ecology + metabolism				
Microbial community structure	Genomics: starting LTER: ?	Genomics: ad hoc	Genomics: started to be routine	Genomics: ad hoc
Anammox/ denitrification rates	?	?	?	?
Functionality *[physiological response to oxygen stress]*				
Fish biomass and community structure	Catch and effort statistics: commercial + fishery independent surveys Ichtyoplankton surveys: Y Fish acoustics: regular	Catch and effort statistics: Fishery independent surveys on selected commercial species. Fish acoustics: regular *[availability TBD]*	Catch and effort statistics: Commercial vs independent surveys: probably yes Fish acoustics: regular *[availability TBD]*	Catch and effort statistics. Ichtyoplankton surveys. Fish acoustics: regular *[availability TBD]*
3D dynamic habitat mapping (#fish vs O_2 conc.)	Habitat maps constrained by e.g. Chl-a and zooplankton obs. Co-located O_2 measurements (discrete or continuous): ?	Habitat maps: ? Co-located O_2 measurements (discrete or continuous): ?	Habitat maps: N Co-located O_2 measurements (discrete or continuous): ?	Habitat maps: ? Co-located O_2 measurements (discrete or continuous): Y – acoustics on top of O_2 levels
Bottom-up effects				
Energy transfer *[also applicable in Plankton Changes Demo Theme]*	LTER: prim. Prod, grazing, sediment fallout rates vs indirectly O_2 conc.	?	?	?

Nutrient stoichiometry changes	Y	Y	Y	Y
General notes				
Vertical coverage	CalCOFI: only down to 500m. Of the 10s of CALCOFI stations on the grid, only a few are anywhere close to the sea floor			only down to 500m – needs to go deeper
Instruments and sensors			STOX (Switchable trace amount Oxygen) sensors (Revsbech et al., 2009) are preferred over Winkler to determine oxygen at very low (nM) concentrations.	

Report-out

Kyla Drushka was the rapporteur for this session. Upon the presentation of outcomes from this breakout session, it was suggested that more emphasis be put on biogeochemistry of OMZs. Currently, there appeared to be a bias towards looking at their ecology.

Furthermore, it was noted that there is a general need across the demonstration themes to explicitly include EOVs in the recommendations for implementation. This suggestion was adopted as the necessary next step in refining the summary table presented.

The presentation also sparked a general debate on the scope of activities and projects to be proposed under each demonstration theme. The emphasis was placed on the notion that in order to effectively meet the scientific and societal requirements, the goal should be to design an implementation plan which would focus on augmentation of existing observing systems through co-located measurements from three scientific disciplines, as opposed to building a new sustained observing system in locations with no existing infrastructure.

In terms of demonstrating that the requirements for observation data also meet the modelling requirements, it was noted that it is critical to clearly distinguish between the data-needs of operational vs ecosystem and climate models, used for tactical vs strategic decision-making.

Breakout Sessions 3 & 4. Program Implementation Considerations, Reviewing Implementation Strategy and Developing Recommendations for Pilot Projects

Objectives

Building on the detailed discussions of technical challenges and issues, the goal of these two sessions was to develop a consolidated implementation plan for the selected project/activity, including all the necessary steps from setting the goals of the project, through consideration of technical details and all the way to drafting a timeline with milestones, and identifying collaborators/partners and funding requirements and sources.

Proceedings

The set of OMZ-related but still very general scientific objectives (see page 1) that connect to the overarching/societal requirement linked IMSOO OMZ question ("How do changing Oxygen Minimum Zones (OMZs) affect the spatio-temporal distribution, productivity and trophic structure of the benthic and pelagic communities?") is to too broad to be approached with a dedicated demonstration project. Consequently, it was decided to focus the demonstration project to a specific key feature of the OMZ that is of high relevance in the context of many of the scientific objectives – the upper oxycline (see examples in Fig. 14). The oxycline is defined as a sharp vertical gradient in dissolved oxygen concentration. Because of the fundamental impact of oxygen on almost all marine life as well as biogeochemical cycling processes the oxycline sharpness and its location has an impact on both biotic and abiotic processes, and its changes have significant potential impacts on entire ecosystems. Both models and observations reveal that oxycline variability is driven by a balance of biogeochemical and physical processes. Therefore, an IMSOO demonstration project focusing on the oxycline features of all OMZ systems of interest is suitable to demonstrate the value of having co-located, multidisciplinary sustained ocean observations for the benefit of the society.

It was acknowledged that oxycline dynamics do not encompass all processes controlling OMZ formation and change. Nonetheless, such a focused study on "Variability in the oxycline and its impacts on the ecosystem" has a tractable scope, for which a tangible implementation plan could be developed. In order to answer other questions relevant to OMZs, it would be critical to establish linkages with organizations such as US Ocean Carbon & Biogeochemistry (OCB) and others with an interest in taking advantage of a multidisciplinary sustained observing system for OMZs.

Providing a critical review of the observing system with respect to the oxycline issue would involve a comprehensive analysis of the current capacities set against the phenomena and EOVs associated with oxycline time and space variability, the spatio-temporal sampling design requirements, as well as platform, instrument and sensor requirements. During the IMSOO workshop, a preliminary list of such requirements was produced and is included below.

The primary observing target is for concurrent physical and biological measurements. Optimizing the sampling pattern would be driven by the need to capture the spatially patchy and time-variable ecosystem components.

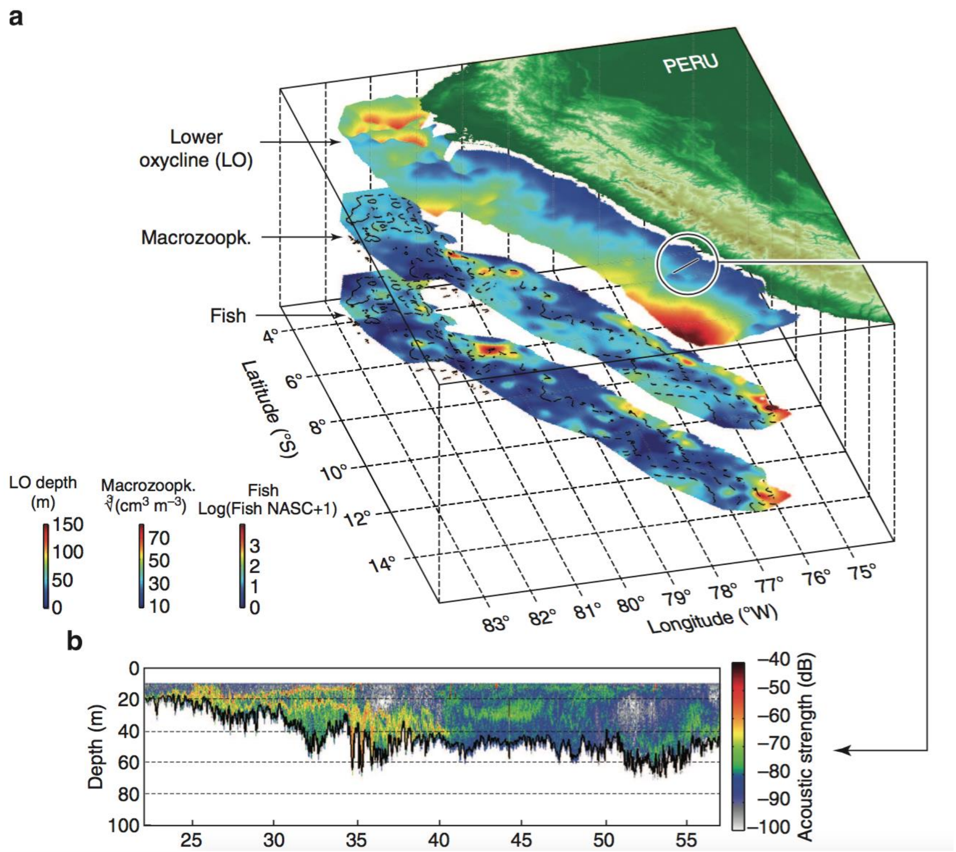

Figure 14a. Southeast Pacific OMZ region off Peru: a) Upper volume: acoustically estimated lower oxycline (in m). Intermediate surface: zooplankton biovolume above the lower oxycline. Lower surface: fish biomass above the lower oxycline. (b) Acoustic echogram along a given transect (see a) with the lower oxycline (black solid line). (see Bertrand et al. 2014)

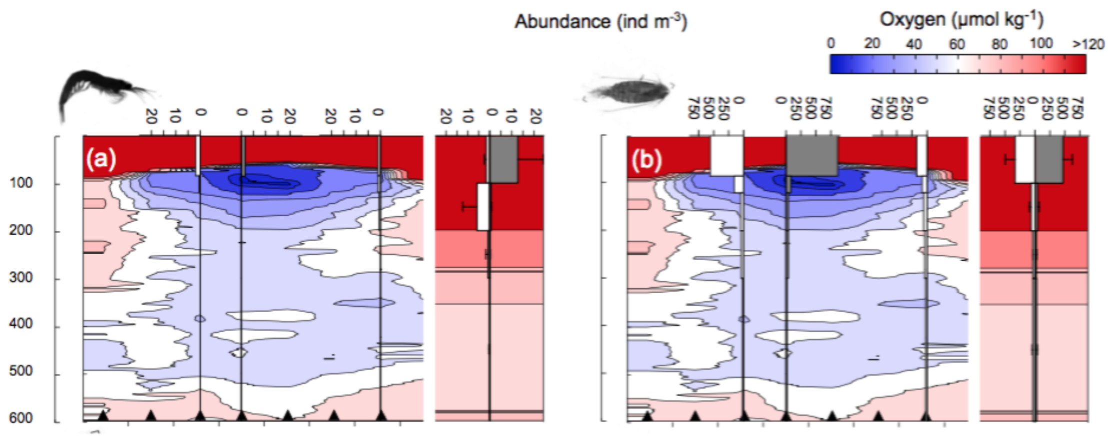

Figure 14b: Low oxygen eddy off West Africa: Oxygen contours (µmol O2 kg−1) across a low oxygen eddy (from NE to SW) with superimposed bar plots of multinet-based abundance (individuals m−3) of euphausiids (a), and calanoid copepods (b). A very sharp oxycline is found at 60m depth (from saturation (>250µmol kg) to 5µmol kg-1 over a distance of 10 m. White and grey bars indicate daylight and nighttime hauls, respectively. Triangles denote CTD stations used for the O_2 section. (see Hauss etal. 2016; data sets: https://doi.pangaea.de/10.1594/PANGAEA.858323)

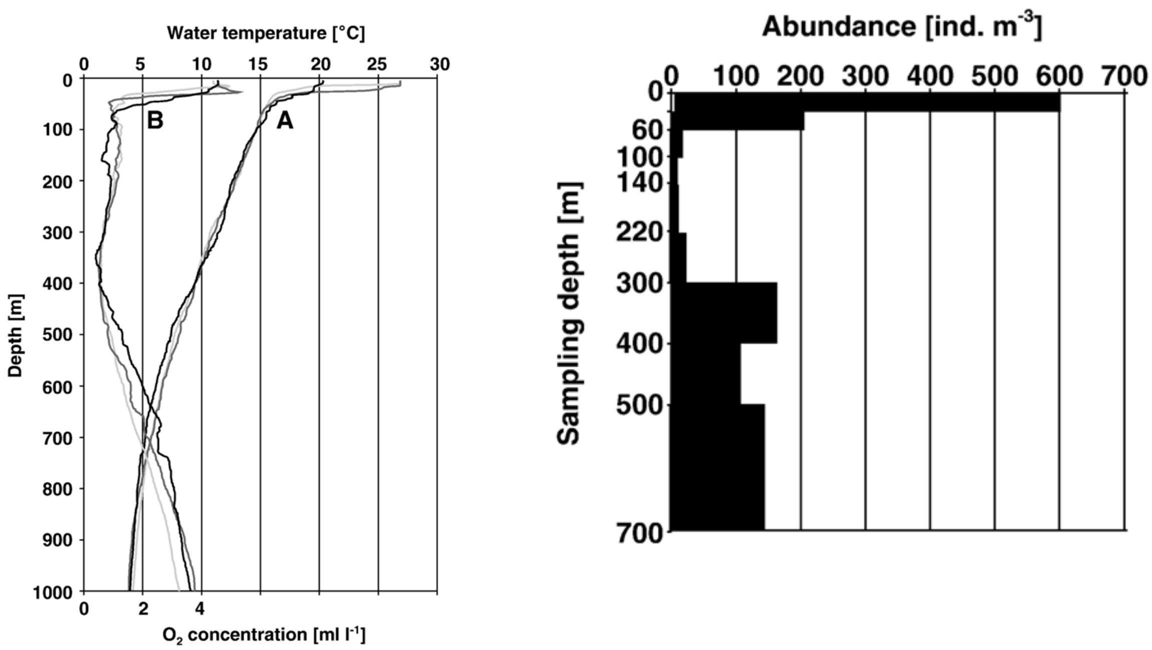

Figure 14c: Angola/Benguela frontal system: (left) Profiles of water temperature (A) and oxygen concentration (B) at the stations T2-7 (light grey), T4-1 (dark grey) and T4-5 (black) (right) Vertical distribution of mean total abundance [ind. m^{-3}] of calanoid copepods (excluding C. carinatus) at the stations shown in a). (see Auel and Verheye 2007)

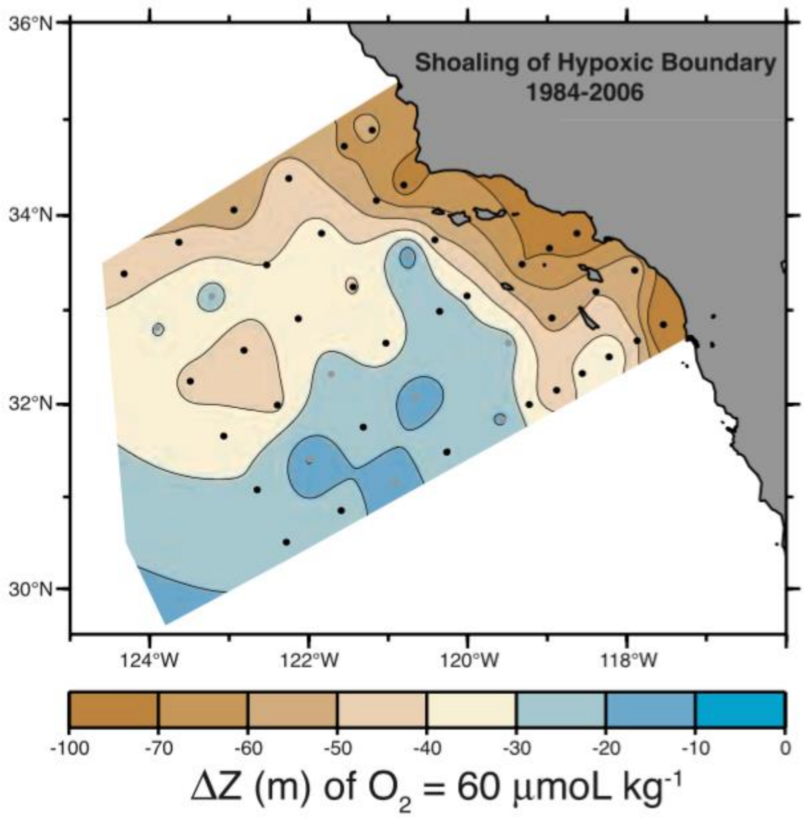

Figure 14d: North Pacific California Current region: Total change in the depth (m) of the O_2 = 60 mmol/kg surface on the CalCOFI survey grid (see Bodrad et al. 2008)

Minimum requirements for temporal scales of measurements:

- Oxygen concentration varies on scales from sub-daily to inter-decadal, as well over millions of years.
- Frequency domains of driving mechanisms and ecosystem responses:
  - Physical variables, primary production and lower trophic level processes and response occur in the higher frequency domain.
  - Higher trophic levels respond in the lower frequency domain due to buffering of responses through food webs.

Minimum requirements for spatial scales of measurements:

- Measurements performed on fundamental oceanic scales of phenomena, e.g. deformation radius; width of upwelling zone; water column depth.
- Optimal sampling resolution:
  - Horizontal: 1-100 km
  - Vertical: higher resolution at a steep oxycline
- Need to consider pelagic vs. benthic organism movement scales

In terms of the technological requirements for a fit-for-purpose observing system, it was agreed that a single platform may provide a biased view (i.e. aliasing effects, non-synoptic), and that sampling a wide range of scales through a combination of available platforms would be necessary. A multi-platform design would ensure an adequate overview of the variabilities associated with oxycline dynamics and impacts on ecosystems. Among platforms potentially available and considered in the project implementation are:

- <u>Ships:</u> target sampling from process study cruises and through globally coordinated Ship of Opportunity Programme (SOOP) and GO-SHIP Repeat Hydrography cruises
- <u>Gliders:</u> global coordination through the OceanGliders network
- <u>Profiling floats:</u> global coordination through Argo and Biogeochemical Argo programmes. An off-shore component of the OMZ observing system.
- <u>Moorings and other fixed-point observatories:</u> global coordination through OceanSITES
- <u>Drifters:</u> global coordination through Data Buoy Coordination Panel (DBCP)
- <u>Autonomous Surface Vehicles (ASVs)</u>

Similarly, observations would ideally require employing a range of sensors and techniques. Apart from CTD casts, bottle sampling and tow nets, Underwater Vision Profiler (UVP) sampling could be considered, enabling species identification on a >1mm level. In order to monitor the biological activity from the level of bacteria to marine mammals and seabirds, techniques ranging from genomics to fish/acoustic surveys and animal tagging would be ideally used. Novel ideas, such as the use of miniaturized oxygen sensors attached to animal tags, could be considered for providing better environmental context of large fish migration pathways.

The 5-year project implementation plan presented below was considered for the 2017-2022 period, with a potential need to continue beyond. Two stages were identified, with goals set on a 2-year and a 5-year time line for the preparatory and implementation stage, respectively. Each project phase was discussed in varying levels of detail, with consideration of technological and programmatic requirements as well as the level of support required. An initial list of associated milestones and deliverables was suggested for the preparatory stage, and will be refined over the coming months.

"Variability in the Oxycline and its ImpaCts on the Ecosystem (VOICE) project"

The goal of the VOICE project is to deliver information needed to estimate the variability in the oxycline and its impacts on the ecosystem by leveraging existing observing systems with minor modifications and improvements performed, spanning several OMZs across the global ocean (e.g. California Current System, Benguela and Canary Current Systems off West Africa, Northern Indian Ocean with a focus on the Bay of Bengal, Southeast Pacific OMZs off Chile and Peru; Fig. 12).

Specific questions to answer are listed below.

- What are the processes that create and maintain an oxycline?
- What are drivers for spatial and temporal variability of the oxycline from subdiural to multiannual time scales?
- What are drivers in vertical extend and depth range of the oxyclines?
    - Do mesopelagic fish/crustaceans/cephalopods affect the oxycline to an extent comparable with the role microbes have?
    - What is the role of zooplankton Diel Vertical Migration (DVM)?
- What are the impacts of oxycline variability in space or time on fish biomass, abundance, community structure, and susceptibility to fishing gears?

Providing answers to these questions would require bringing together communities from three disciplines: physics, biogeochemistry, and biology & ecosystems.

The main anticipated outcome of the VOICE project would be a blueprint of a multi-disciplinary sustained OMZ observing system, outlining a minimum and optimized set of observational and modelling requirements for a fit-for-purpose system, capable of informing the society about the variability in the oxycline and its impacts on the ecosystem, applicable within the global ocean observing system, and contributing to the overarching question: "How do changing Oxygen Minimum Zones (OMZs) affect the spatio-temporal distribution, productivity and trophic structure of the benthic and pelagic communities?".

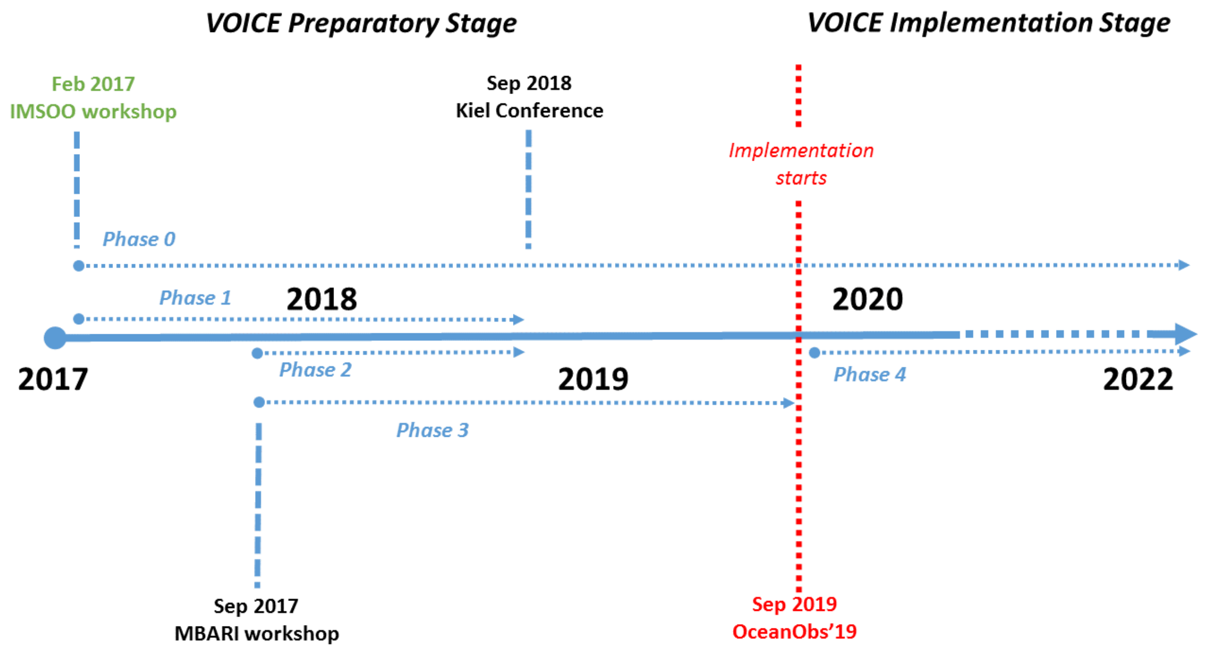

Figure 15. Approximate time line for the VOICE project.

VOICE Preparatory Stage (2017-2019)

The VOICE preparatory stage consists of four phases leading up to the project implementation stage. They are described in detail below.

The main anticipated outcomes from the VOICE preparatory stage include:

- a number of national and international project partnerships built,
- scientific objectives defined based on literature review
- first set of relevant phenomena and EOVs defined
- data sharing agreements reached,
- a preliminary assessment of the fitness-for-purpose of the system with respect to observing oxycline variability performed,
- a proposal to fund the 3-year implementation stage of the project submitted.

Phase 0: Communication and coordination efforts

This phase, spanning the entire period of the project, assumes first and foremost taking responsibility and charge over establishing a lasting and active communication within the IMSOO OMZ Demonstration Theme Group. The GOOS Biogeochemistry Panel through the office of the International Ocean Carbon Coordination Project (IOCCP) has the capacity to oversee the process, pending sufficient dedicated resources are available for coordination of this activity.

The main task for this phase is to engage all partners and any other experts with interest in the four OMZ sites included in this project. This is a key requirement for the successful set-up and preparation for the first workshop devoted to the project activities, to coincide with the planned Global Ocean Oxygen Network (GO_2NE) meeting at MBARI in Monterey Bay, CA, USA, in September 2017. Immediate actions require organizing the workshop venue, developing an agenda and creating a list of invitees. Additional travel funds for participants from developing countries would be required.

Other tasks to be accomplished in this phase are:

- To set-up a connection with GO_2NE through communication with the IOC officer Kirsten Isensee, as well as the GO_2NE Chairs Marilaure Grégoire and Denise Breitburg.
- Pending a positive decision on funding for the SCOR Working Group on OMZs, supported by IMBER and SOLAS, with a proposal to be submitted in April 2017, identify opportunities for synergies between the two groups.
- Interface with relevant fish and fishery partners, and with partners from the climate modelling community.

Phase 1: Historical data analysis towards a conceptual framework developed

The main goal in this phase is to inform the process of developing a conceptual model of the effects of oxycline variability on changes in intermediate and upper trophic levels based on a literature review and a detailed historical data analysis, considering several OMZ systems. To this end, there are three objectives set for this phase of the project:

- Objective #1: To perform a literature review on the subject of oxycline variability and its effects on intermediate and upper trophic levels.
    - Time line: prior to the MBARI workshop in September 2017.
- Objective #2: To engage all relevant partners in a historical data analysis as a useful exercise from the perspective of answering questions relevant to deoxygenation/OMZ effects on intermediate and upper trophic levels.
- Objective #3: Identify and agree on pathways towards data sharing.

The MBARI workshop was listed as a key milestone in this phase of the project, as its outcomes would determine timely and efficient realization of the three objectives.

The workshop was proposed as a 2-day event, with planned partial overlap with the GO_2NE meeting taking place just prior to that. Apart from the members of the IMSOO OMZ group, workshop participants would include representatives from all four geographical regions considered in the project, two of which, India and Peru, have already confirmed their attendance at the GO_2NE meeting. Additional invitations would be sent to scientists from the Bay of Bengal countries other than India, as well as to Mexico, Mauretania, Senegal, Nigeria Angola, Namibia, South Africa, and potentially others.

One of the objectives for the workshop would be to enable all potential partners to present examples of science performed in areas of interest. Experts on higher trophic levels should be present at the workshop, alongside experts on fish and fisheries.

Central point of the workshop would be a demonstration of the recent developments in bringing together datasets from the California Current System, i.e. from CalCOFI and the Baja California LTER, in the context of oxygen variability impacts on ecosystems. A discussion on how a similar approach could be applied in other OMZ systems is expected. As common access to historical data is a critical requirement in this process, potential partners will be expected to identify and agree on pathways towards sharing those data.

Phase 2: Identification of ongoing and planned observing and modelling opportunities.

In this phase of the project potential and different options for project goal implementation would be scoped and initially pursued. A consolidated list of opportunities within programs and projects would be outlined at the first project workshop in September 2017. An initial list of potential opportunities, from observational and modelling efforts to data management activities, is presented below and would need to be refined at the MBARI workshop. Corresponding budgetary needs would also have to be identified and met to utilize any potential VOICE implementation opportunity. Assuring the necessary funds could be achieved by securing up front the relevant resources required to participate in all identified activities, or for each individually on an ad hoc basis.

- GOOS – identify opportunities for implementation through GOOS
- IIOE-2 (2nd International Indian Ocean Expedition) – cruise opportunities scheduled for 2018 and beyond.
- UK Natural Environment Research Council (NERC) proposals for 2019 to be focused on investigating the Mauretania upwelling (April-May 2018) and the Benguela upwelling (Jan-Feb 2019).
- EU FP7, HORIZON 2020 and Research Infrastructures:
    - An upcoming call for the South Atlantic, to be out in mid boreal summer 2017.
    - AtlantOS WP5 task on ‘Climate and ecosystem in the South Atlantic and sub-polar North Atlantic – a comparison’ and WP2/WP3 observing networks
    - JERICO-NEXT project offers opportunities, e.g. in the framework of transnational access to using gliders.
    - PREFACE – Enhancing prediction of Tropical Atlantic climate and its impacts
- Regular Polarstern cruises offer opportunities for requesting ship-time; sampling during transit.
- South African ship-time requests for January and July surveys – for opportunities contact Francis Marsac.
- Fishing vessels Nansen – Walther Herwig – FAO cruises and assessments
- Observing networks and existing observing facilities:
    - Consider all Biogeochemical Argo profiling floats and OceanSITES fixed-point observatories in the vicinity of OMZ regions of interest.
    - PIRATA array – 3 buoys with oxygen sensors + Ocean Tracking Network (OTN). Activities also part of the EU H2020 AtlantOS project.
    - Ad hoc glider deployments off the coast of Senegal
- IODE African databases – evaluate the level of data availability

Phase 3: Development of the conceptual framework and observing system design for observing oxycline variability and its impacts on ecosystems.

The main objective for this phase of the project is to develop the conceptual framework and an observing system design fit to answer the question of what drives the variability in the upper oxycline and what are the impacts on the intermediate and upper trophic levels.

The successful development of the conceptual model would strongly depend on the outcomes of historical analysis performed prior and after the MBARI workshop.

An important milestone in this phase of the project would be a critical review of the current status of the ocean observing system with respect to the oxycline feature of OMZs, to be accomplished through a VOICE side meeting to the International Conference "Ocean Deoxygenation: Drivers and Consequences – Past – Present – Future", held on 3-7 September 2018, in Kiel, Germany.

The anticipated outcomes from the first 2-year stage of the project are expected to be delivered at the OceanObs'19 Conference, taking place in September 2019 in Honolulu, HI, USA, a year after the Kiel Conference. The presented results would address the value of sustained multi-disciplinary ocean observations in the context of one particular OMZ feature, the oxycline, and would form the basis for submitting a proposal to fund the implementation stage of the VOICE project.

<u>Preliminary list of VOICE Preparatory Stage milestones and deliverables:</u>

- Milestone #0: IMSOO workshop in February 2017. Month 0.
- Milestone #1: First VOICE workshop organized in September 2017 at MBARI, jointly with the GO_2NE meeting. Phase 0. Month 8.
- Milestone #2: Literature review. Phase 1. Month 8.
- Milestone #3: Demonstration of observing capability and data availability from the California Current System OMZ. Phase 1. Month 8.
- Milestone #4: Opportunities for VOICE within existing and planned observation and modelling activities initially identified. Phase 2. Month 8.
- Milestone #5: Data sharing agreements reached between partners from all OMZ study sites. Phase 1. Month 20.
- Milestone #6: Second VOICE workshop organized as a side-meeting to the International Conference on "Ocean Deoxygenation: Drivers and Consequences – Past – Present – Future", 3-7 September 2018, Kiel, Germany. Phase 0. Month 20.
- Milestone #7: A critical review of the current status of the ocean observing system related to OMZs. Phase 3. Month 20.
- Milestone #8: Third VOICE workshop organized as a side meeting to the OceanObs'19 Conference, in September 2019 in Honolulu, USA. Phase 0. Month 32.
- Milestone #9: Conceptual framework for observing oxycline variability and its impacts on ecosystems developed. Phase 3. Month 32.
- Milestone #10: A minimum set of observation requirements for VOICE implementation across all four OMZ sites determined. Phase 3. Month 32.

- Deliverable #1: Historical data analysis in the California Current System, i.e. from CalCOFI and the Baja California LTER, in the context of oxygen variability impacts on ecosystems. Phase 1. Month 8.
- Deliverable #2: Historical data analysis performed by engaged partners in all four OMZ study areas. Phase 1. Month 20.
- Deliverable #3: Conceptual framework and a minimum set of requirements for observing oxycline variability and its impacts on ecosystems paper published. Phase 3. Month 32.
- Deliverable #4: VOICE project proposal for funding the 3-year implementation stage submitted. Phase 3. Month 32.

Table 9. Tentative budget for the VOICE Preparatory Stage.

Itemized Budget	**Cost description**
Organization of the first VOICE workshop, held jointly with the GO_2NE meeting, September 2017, MBARI, CA, USA.	3-4 day meeting + travel support Cost: ca. 50,000 USD
Historical data analysis across four OMZ sites.	4 x 6 person month salary (4 x 0.5 FTE at postdoc level) Cost: institute dependent
Organization of the second VOICE workshop as a side meeting to International Conference on “Ocean Deoxygenation: Drivers and Consequences – Past – Present – Future”, 3-7 September 2018, Kiel, Germany	2-day meeting + travel support Cost: ca. 25,000 USD
Organization of a VOICE side meeting to the OceanObs’19 Conference.	2-day meeting + travel support Cost: ca. 25,000 USD
Coordination activities related to the above and additional tasks related to VOICE Phase 0.	6 person month salary for two years (0.5 FTE) Cost: institute dependent
TOTAL BUDGET:	**Travel and logistics: 100,000 USD** **Salary: TBD**

VOICE IMPLEMENTATION STAGE (2019-2022)

The goal of the VOICE Implementation Stage (Phase 4) would be to have in place an Ocean Observing System that measures EOVs and associated phenomena necessary to inform about one selected key aspect of OMZ regions, the upper oxycline. The data will enhance the understanding of impacts but also on dependencies of oxycline variability on intermediate and upper trophic levels, and improve modeling capabilities, across a number of OMZ systems.

Deliverables and milestones for the VOICE implementation stage will have to be defined during the consecutive VOICE workshops in MBARI and in Kiel in 2017 and 2018, respectively, as well as in the interim period, but might focus on the following aspects:

- Optimal sampling strategy design.
- Analysis of observing system gaps with respect to observations, data availability, sustainability and technology; and estimates on cost of their closing.
- Technical enhancements and other observing system adaptations in response to the analysis of gaps.
- Integrated data management.
- Stakeholder engagement in evaluating fitness of information product generation for societal benefit applications.
- Assessment of the observing system performance.
- A blueprint of a multi-disciplinary, sustained and fit-for-purpose OMZ observing system, outlining a minimum set of observational and modelling requirements for global implementation.

A successfully completed 5-year VOICE project would be a critical element in designing and implementing, as well as securing funding for an observing system that is capable of addressing the overarching question of "How do changing Oxygen Minimum Zones (OMZs) affect the spatio-temporal distribution, productivity and trophic structure of the benthic and pelagic communities?" within a 10-year time frame.

Report-out and important caveats

The first version of the proposed project (both stages) was presented to the IMSOO plenary by Kevin Weng, after the end of the third breakout session. A wealth of feedback was collected and whenever possible used to refine the project goals and implementation steps. Some of the most critical comments included: (i) the choice of project focus and potential implications of it being too narrow, because it largely excluded processes that occur in core OMZ waters, (ii) the need to evaluate impact of shoaling OMZs on apex predators (birds and mammals), (iii) disproportions in available historical records of physical vs biogeochemical and biological parameters, and the potential of models to fill some of these gaps, and (iv) opportunities for synergies with already planned workshops and conferences devoted to the OMZ topic.

The working group acknowledged that there are many critical processes that occur within and beneath OMZs that are not included in the VOICE project: e.g. carbon flux and carbonate system dynamics affecting sequestration, key microbial activities that may provide climate feedbacks, evolutionary adaptation, redox exchanges with the sea floor and probably more. As such, the proposed project (VOICE) is not intended to test all possible OMZ-related hypotheses but address some of the critical issues and provide a foundation for further/expanded studies of the OMZ The group agreed that the project focus needs to be narrow enough to enable a relatively timely inception of a purpose-modified observing system, and flexible enough to enable progressive additions and adjustments resulting from additional observing requirements.

Further scoping meeting(s) similar to IMSOO would be required to develop a coherent strategy to add observing elements to VOICE or its legacy. Future observational work that will extend further into the OMZ is encouraged, possibly through engagement with relevant elements of the global ocean observing system.

Demonstration theme 3: Open Ocean, Shelf and Coastal Ocean Interactions

Chairs: John Wilkin, Toste Tanhua

Note-taker: Robert Todd

Attendees: Lisa Beal, Francisco Chavez, Dan Costa, Kim Currie, Masao Ishii, Eric Lindstrom, Frank Muller-Karger, SWA Naqvi, Ananda Pasqual, Dan Rudnick, Tim Moltmann

Rapporteurs: Dan Rudnick, Francisco Chavez, Tim Moltmann

Facilitator: Katy Hill

Breakout Session 1. Framing demonstration themes and associated requirements

The goal of this session was to focus on scoping potential integrated, multidisciplinary projects, activities or focal regions/topics for each demonstration theme. This will include identifying impacts or significance of the proposed activities/project as well as setting requirements.

Discussion topics to refine the list of projects/activities included: Societal impact(s) of the project(s), gap assessments, technology requirements, financial feasibility, any new observations, data and modelling requirements, and implementation challenges.

An important consideration was to evaluate possible overlap with the other two major IMSOO workshop themes: 1) Plankton Community Changes (including ocean colour), and 2) Oxygen Minimum Zones.

The breakout session began with introductions of the attendees who had a range of interests from open ocean and coastal physical oceanography, plankton through to top predators, and numerical modelling. Discussions followed on the current status of boundary current/shelf observations, and the types of boundary current systems which should be considered, as well as what the societal drivers are for measuring in these regions.

These included:

- Subtropical Western Boundary Currents (Gulf Stream, East Australian Current, Agulhas, Kuroshio, Brazil Current)
- Eastern Boundary Currents (California, Humboldt, Canary, Benguela, Leeuwin)
- Also discussed were Subpolar Boundary currents, Enclosed sea coastal currents, (such as in the Mediterranean) and Low Latitude western boundary currents.

Boundary currents (especially Western Boundary Currents) represent a key climate mechanism via their significant role in the meridional transport of heat and freshwater. Eastern Boundary Currents are strategic locations for societally relevant impacts of climate processes, whose variability is linked to global scale processes through equatorial dynamics and long-wavelength coastal trapped waves.

Following discussions on the drivers for multidisciplinary observations of boundary current/shelf regions, the following issues were identified to focus discussions:

1. Inter-annual variability of currents and water properties has fundamental effects on ecosystem structure/dynamics in all boundary current systems
2. Cross-shore overturning is key exchange between shelf and deep ocean
3. Episodic events (e.g., upwelling) are key in the translation of physics to biology, as are sub-mesoscale processes, and ecological hotspots
4. Land-deep ocean connectivity,

It was noted that:

- Relevant processes vary in importance in different locations.
- Different societal drivers exist in each boundary or coastal system
- Technical needs/implementation challenges vary by system

Photo 5. Discussions during one of the breakouts of the Open Ocean, Shelf and Coastal Ocean demo theme. From left to right: John Wilkin, Toste Tanhua, Francoise Pearlman, Wajih Naqvi.

The group also noted that while it is tempting to build on the well-studied/observing regions, it is important that the approach developed cognizant of the potential to develop basic observing networks in less well studied parts of the world; particularly developing regions where fisheries productivity of boundary current/upwelling systems are so centrally important.

Dan Rudnick was the rapporteur for session 1 to the plenary.

Breakout Session 2. Technical implementation planning

The goal of this breakout session was to focus on what is needed for technical implementation of the identified activities, regarding the project/activities' current feasibility and any developments that will be needed to realize them.

Building on the Send et al. proposed areas for observations, it was noted that such a design was largely developed for climate applications as discussed above. For western boundary currents it was designed to capture the heat, mass, and salt fluxes; hence, the ‘boxes’ identified for measurement, were limited in extent. For multidisciplinary applications and in particular eastern boundary currents where the climate links are societally relevant processes, it is likely that observations will be needed along the current as well as across it. Similarly, the synergies with other themes were highlighted, in particular, the Oxygen Minimum Zones and Plankton.

The group then went on to discuss candidate systems for a multidisciplinary design study. The group discussed key boundary current systems, their societal importance (e.g. for food fisheries and food security, as well as role in climate feedbacks), and to what extent they were well observed. Certainly the connection to societal importance needs to be further discussed and articulated; given the expertise in the room, however, it was discussed in general terms but other expertise and groups outside of GOOS would need to be engaged for a more specific conversation.

Initially, it was decided to focus on what can be learnt from well observed boundary current systems, including testing approaches to evaluating a multiplatform observing system design, before applying these approaches in priority areas where observing systems need to be developed. It was important to identify candidates from both eastern and western boundary currents given the striking physical and biological differences

Three examples were identified and discussed further (see diagrams in Figure 16):

- The East Australian Current (where the observing system was designed through a top down planning/design process as part of Australia’s Integrated Marine Observing System, IMOS)
- The California Current (where the observing system has developed through bottom up activities with many different players)
- Balearic Islands Ocean Observing and Forecasting System (SOCIB).

Other Boundary current regions were discussed including;

- Areas of the Gulf of Mexico where there are large seasonal oxygen minima zones on the shelf, boundary currents and plankton blooms, and the Gulf Stream. Like the California Current, the Gulf Stream is a region where there are many observations, as well as many different groups participating.
- The Kuroshio and Agulhas observing systems known to the group have largely focused on the observations required for physics and climate applications to date; but these systems could be built on into the future for more multidisciplinary applications.
- Given the connection to food security and the overlap with oxygen minimum zones as well as the need to expand systematic observations, the Benguela (off the West Coast of Africa) and Peru-Humboldt (off the west coast of South America) current systems were identified as priority regions for future efforts.

The group then discussed the potential for review papers or observing system reviews of these systems.

Principles for such a review were then discussed including;

- Focus on addressing a particular economic problem – e.g. Collapse of the Californian Sardine Fishery: connecting with fisheries is a natural link in coastal systems.
- The pathway for observations to connect with models and forecasting.
- Census of assets in the water and evaluation of their effectiveness.

These ideas were further refined in the breakout sessions that followed.

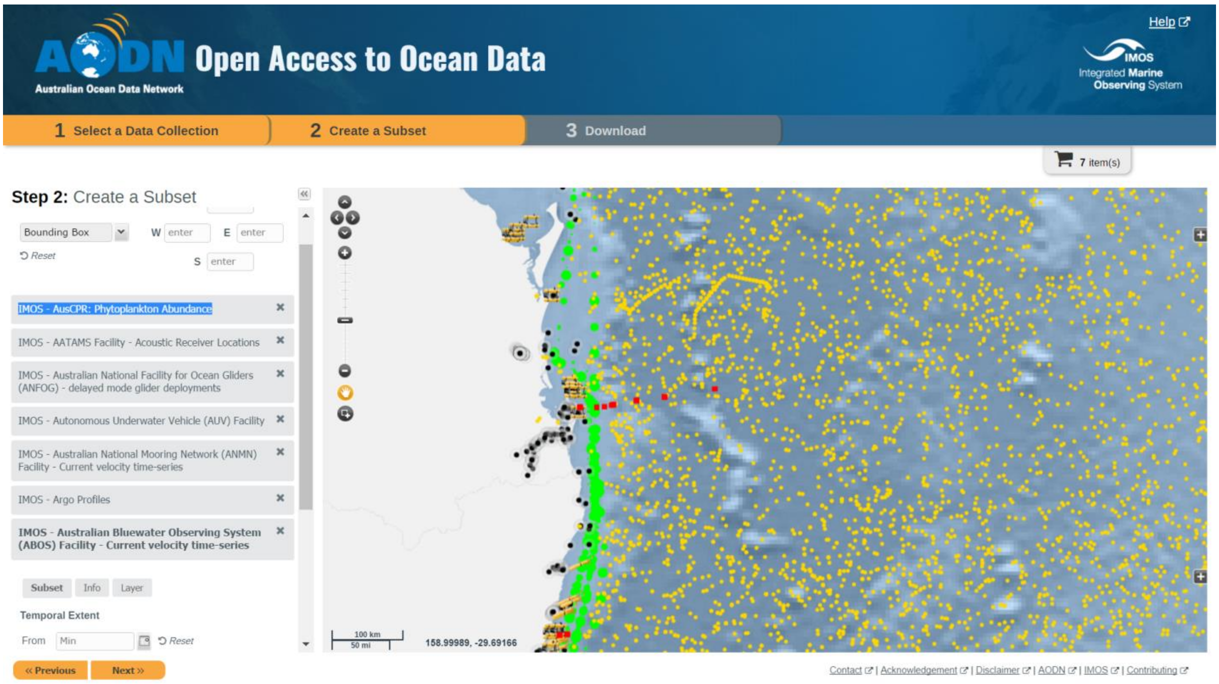

Figure 16a. A view of ocean observing assets in the East Australian Current as part of the Integrated Marine Observing System.

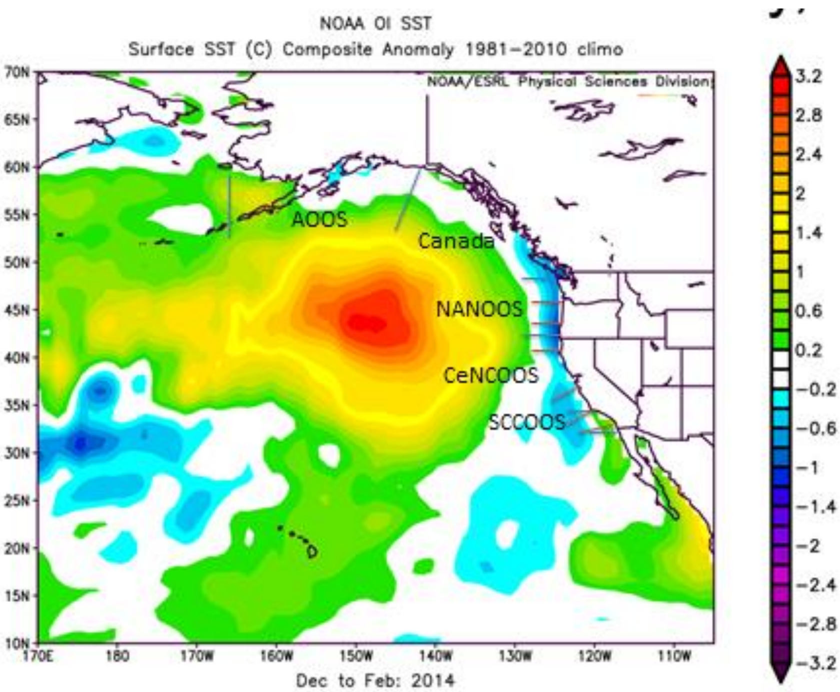

Figure 16b. A representation of regional groups and activities in the California Current System.

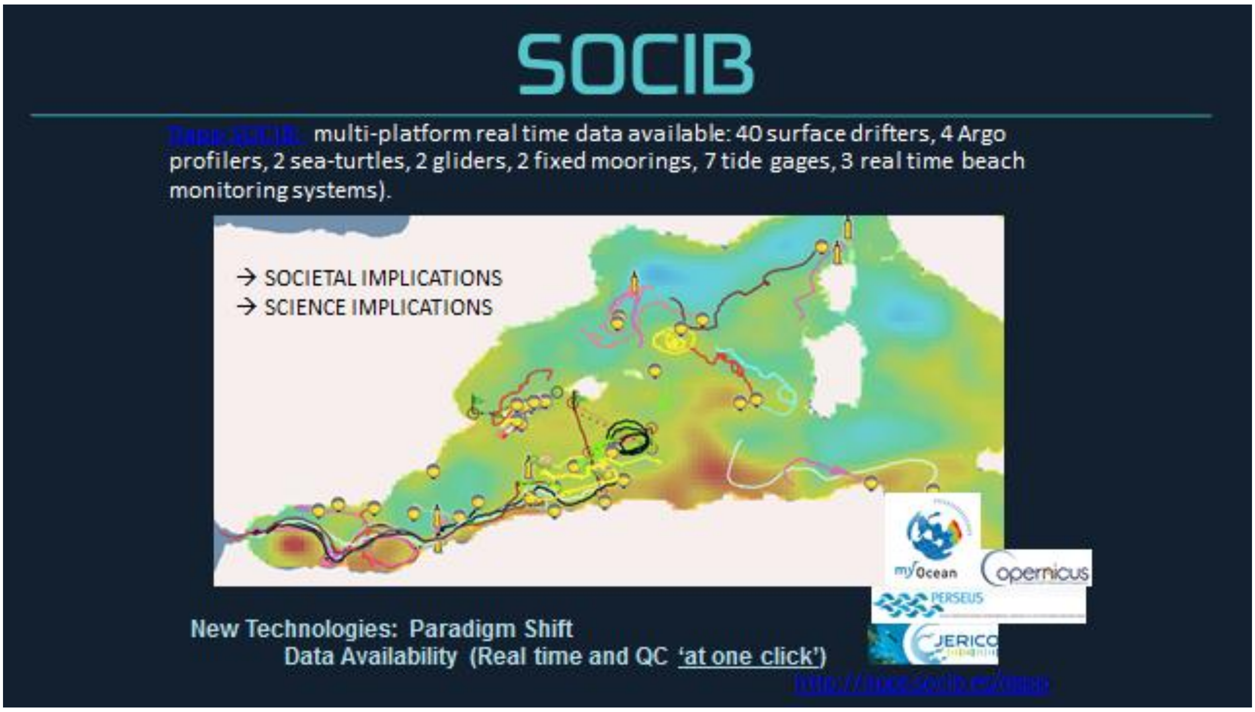

Figure 16c. A map of the Balearics Ocean Observing and Forecasting System (SOCIB).

The group discussed how to design an integrated system, including how to choose the optimum mix of assets (moorings, gliders, etc.), maturity of sensors, and the potential to leverage existing expertise in observing systems operation. The use of Observing System Experiments and Observing System Simulation Experiments (OSE/OSSEs) was discussed, with the maturity of these approaches being quite different for physics, biogeochemistry, and ecosystems. The group felt strongly that a way forward in terms of designing or evaluating these observing systems should be rooted in the issues identified in break out 1:

1. Inter-annual variability of currents and water properties has fundamental effects on ecosystem structure/dynamics in all coastal and boundary current systems
2. Cross-shore overturning is key exchange between shelf and deep ocean
3. Episodic events (e.g., upwelling) are key, as are sub-mesoscale processes, and ecological hotspots
4. Land-deep ocean connectivity

Tim Moltmann summarized the discussion during the session 2 breakout summary

Breakout Session 3. Programmatic implementation considerations

The goal of this session was to think about programmatic implementation and what is needed to make these projects happen in a practical sense with regard to: (1) Project/Activity milestones for both a 2 year and a 5 year project, (2) Schedules and detailed needs for implementation (including project management), and (3) Funding requirements.

At the beginning of this discussion, the group decided to revisit the science questions in light of the discussions to date (and merged 4 questions into 3).

The 3 issues were refined as:

1. How is ecosystem structure/dynamics in coastal and boundary current systems affected by inter-annual variability of currents and water properties, including O_2/OMZs, pH/ocean acidification…
2. Cross-shore exchange between land, shelf and deep ocean (mesoscale)
3. Ecological hotspots, episodic (e.g. fronts, eddies, upwelling) and persistent (e.g. canyons, headlands, shelf break)

The group then identified the processes/phenomena that needed to be captured to address each issue. The time and space scales were also discussed for Question 1; the process needs to be followed for Question 2 and 3. The process followed, once refined, could potentially be a blueprint for evaluations of boundary current/shelf observation systems.

1. How is ecosystem structure/dynamics in coastal and boundary current systems affected by inter-annual variability of currents and water properties, including O_2/OMZs, pH/ocean acidification…

For issue 1, the processes/phenomena that need to be captured included:

- Depth of thermocline
- Terrestrial inflow of nutrients
- Plankton diversity and abundance
- Higher trophic distribution and abundance
- Volume and heat flux
- Carbon budget, Nutrients and Oxygen
- Eddy fluxes
- Water masses

Table 10 details the EOVs and related temporal and spatial ranges and scales of measurements needed for each of these processes.

2. Cross-shore exchange between land, shelf and deep ocean (mesoscale)

Processes

- 2.1 Terrestrial inflow of nutrients and carbon
- 2.2 Eddy fluxes (heat, freshwater, carbon…)
- 2.3 Bottom boundary layer
- 2.4 Vertical fluxes – upwelling, mixing, eddy pumping
- 2.5 Wind stress, curl
- 2.6 Plankton composition and transport, including larval transport
- 2.7 Sediment transport, deposition, and nutrient flux processes (nutrient fluxes etc.)
- 2.8 Surface carbon and N_2O fluxes

3. Ecological hotspots, episodic (e.g. fronts, eddies, upwelling) and persistent (e.g. canyons, headlands, shelf break)

Processes

- Bottom up (physics), sub-mesoscale
- Top down - aggregation, blooms
- Bottom cover
- Anthropogenic pressures

General discussion followed regarding identifying Essential Ocean Variables (EOVs); should the need for all of the EOVs be articulated, or just a subset; scales of phenomena of relevance, the size of the domain of interest, and the role of topographic features.

Table 10. Analysis of Processes, Variables, and scales to capture to address question 1.

Process	EOVs	Spatial Range and Resolution	Temporal Range and Resolution	Depth Range and Resolution
Depth of Pycnocline	Temperature Salinity	Across shore, 1-10 kms out to 200km, alongshore 1-200km	2-4 weeks	1-10m down to thermocline, lower res below.
Terrestrial Inflow of nutrients	River flow Nutrients, Carbon, DIC, Sediments Atmospheric deposition Groundwater discharge		Daily Weekly ?	
Phytoplankton (inc. Chla)/ Zooplankton Diversity and Abundance	Ocean Colour Phytoplankton Biomass and diversity Zooplankton Biomass and Diversity	across shore 10's kms, alongshore 100 km	2-4 weeks? (enough to resolve annual cycle in diversity, phenology, biomass)	10's metres top of the TC (MLD), lower res below (50's m to 500m)
Higher trophic distribution and abundance	Fish Abundance and Distribution Marine turtles, birds, mammals abundance and distribution	Across shore 10's km, alongshore, 100km	2-3 months (seasonal)	Top 300 metres + surface?
Volume and heat flux	Temperature, Salinity, Currents	Across shore: 1-10s kms, along shore 100-200km	2-4 weeks (enough to resolve annual cycle)	1-10m through thermocline, lower res to full depth
Carbon, nutrients and oxygen	Surface Carbon flux Carbonate system through Water column	across shore 1-10's kms?, alongshore 100-200km	2-4 weeks? (enough to resolve annual cycle)	1-10 metres through the TC, lower res below
Eddy Fluxes	Temperature, Salinity, Currents	across shore 1-10's kms?, alongshore 1-10's kms	days	1-10 metres through the TC, lower res to full depth
Watermasses	Temperature, Salinity	across shore 1-10's kms?, alongshore 100-200km	2-4 weeks? (enough to resolve annual cycle)	1-10 metres through the TC, lower res to full depth

This analysis, is still to be done for issues 2 and 3:

2. Cross-shore exchange between land, shelf and deep ocean (mesoscale)

3. Ecological hotspots, episodic (e.g. fronts, eddies, upwelling) and persistent (e.g. canyons, headlands, shelf break)

The summary of breakout session 3 was given by Francisco Chavez.

Breakout Session 4. Reviewing Implementation strategy and developing recommendations for pilot projects.

The goal of this session was to bring consistency to the emerging project/activity plans across the demonstration themes and ultimately perhaps identify 1 or 2 projects from the workshop overall as a priority of development ahead of Ocean Obs'19. Major discussion points to address: (1) the creation of a consolidated project/activity plan, (2) identifying opportunities for ongoing collaborations and communication, and (3) identifying potential opportunities for funding support for integrated multi-disciplinary projects/activities.

In this session the group continued to work through the process of articulating how to address questions and processes required, by identifying EOVs and Platforms, following through with Issue 1. Issue 2 and 3 will need to be addressed at a later stage. The group then discussed the analysis of requirements and capabilities in Candidate Systems, design criteria (including Observing System Design studies), and considerations for selecting pilot projects including identification of Boundary Current Shelf interactions system, scales of processes (large, mesoscale, hotspots), societal impacts, and intersection with Plankton and OMZ groups. The group also discussed the concept of a 'backbone' sustained component of the observing system, and flexible, moveable components. It was suggested that perhaps a backbone system would be required to address issue 1 (large scale), and 2 and 3 (mesoscale and hotspots) would be addressed through moveable components.

Table 11 outlines the relationship between Processes, EOVs, Scales and Platforms.

Table 11. Analysis of Processes, Variables, and scales to capture to address question 1, and potential observation platforms able to meet these requirements.

Process	EOVs	Spatial Range and Resolution	Temporal Range and Resolution	Depth Range and Resolution	Platforms
Depth of Pycnocline	Temperature Salinity	Across shore, 1-10 kms out to 200km, alongshore 1-200km	2-4 weeks	1-10m down to thermocline, lower res below.	Gliders, Moorings (where essential) XBT
Terrestrial Inflow of nutrients	River flow Nutrients, Carbon, DIC, Sediments Atmospheric deposition Groundwater discharge	Daily Weekly ?			Where available from terrestrial observing networks Potential of satellites? CDOM, Salinity, Susp Sed (ship-based, autonomous)
Phytoplankton (inc. Chla)/ Zooplankton Diversity and Abundance	Ocean Colour Phytoplankton Biomass and diversity Zooplankton Biomass and Diversity	across shore 10's kms, alongshore 100 km	2-4 weeks? (enough to resolve annual cycle)	10's metres top of the TC (MLD), lower res below (50's m to 500m)	Satellite Ocean colour + bio-optics Bio-optics Bio-Acoustics (echo sounders) CPR, Nets and bottle samples (microscopy + genomics) LOPC, FlowCam and other Imaging, ESP (+genomics)
Higher trophic distribution and abundance	Fish Abundance and Distribution Marine turtles, birds, mammals abundance and distribution	Across shore 10's km, alongshore, 100km	2-3 months (seasonal)	Top 300 metres + surface?	Bio-acoustics Animal tagging Ship-based surveys (fisheries, fisheries independent…) Passive acoustics
Volume and heat flux	Temperature, Salinity, Currents	Across shore: 1-10s kms, along shore 100-200km	2-4 weeks (enough to resolve annual cycle)	1-10m through thermocline, lower res to full depth	Gliders (T, S), + Mooring(s) where essential XBTs (frequency? not until across the shelf break?) Current meters Surface drifters Coastal altimetry
Carbon, nutrients and oxygen	Surface Carbon flux Carbonate system through Water column	across shore 1-10's kms?, alongshore 100-200km	2-4 weeks? (enough to resolve annual cycle)	1-10 metres through the TC, lower res below	Gliders (T, S), + Mooring(s) where essential XBTs (frequency? not until across the shelf break?) Current meters Surface drifters Coastal altimetry Sediment traps
Eddy Fluxes	Temperature, Salinity, Currents	across shore 1-10's kms?, alongshore 1-10's kms	days	1-10 metres through the TC, lower res to full depth	Gliders (T, S), + Mooring(s) where essential Current meters

					Surface drifters Satellite constellation, high resolution
Water masses	Temperature, Salinity	across shore 1-10's kms?, alongshore 100-200km	2-4 weeks? (enough to resolve annual cycle)	1-10 metres through the TC, lower res to full depth	Gliders, Moorings (where essential) XBT

The observation platforms were then scored in terms of feasibility and impact. How feasible the measurement is, and its impact in terms of capturing that process. Each was scored out of 3: 3 high, 2 medium, 1 low, Blank = n/a

Table 12. Assessment of impact /feasibility for key platforms to capture key processes.

Q1 Inter annual variability...	Gliders	Moorings	Ship based SOOP	Ship based RV	Satellite	Wave Glider	Animal Tagging	
1 Depth of pycnocline	3/3	2/2	1/1	3/1				
2 Terrestrial inflow	3/3		1/2	3/1	2/3			
3 Plankton div & abund	2/2	1/1	2/1	3/1	2/2	2/2		
4 Higher trophic d&a	1/1	2/2	1/3	3/2		1/1	3/3	
5 Volume & Heat flux	3/3	3/3	2/2	2/1	1/1			
6 Carbon, Nut + O2	1/2	2/2	1.5/2	3/1	2/2	1.5/2		
7 Eddy Fluxes	2/2	3/2			3/3	2/2	2/2	

The scores were summed for impact and for feasibility, to assess target investment. See Fig. 17 below. On reflection, it was noted that impact should be the sum total, whereas feasibility should be the average value; the process taken will be updated as this activity is taken forward.

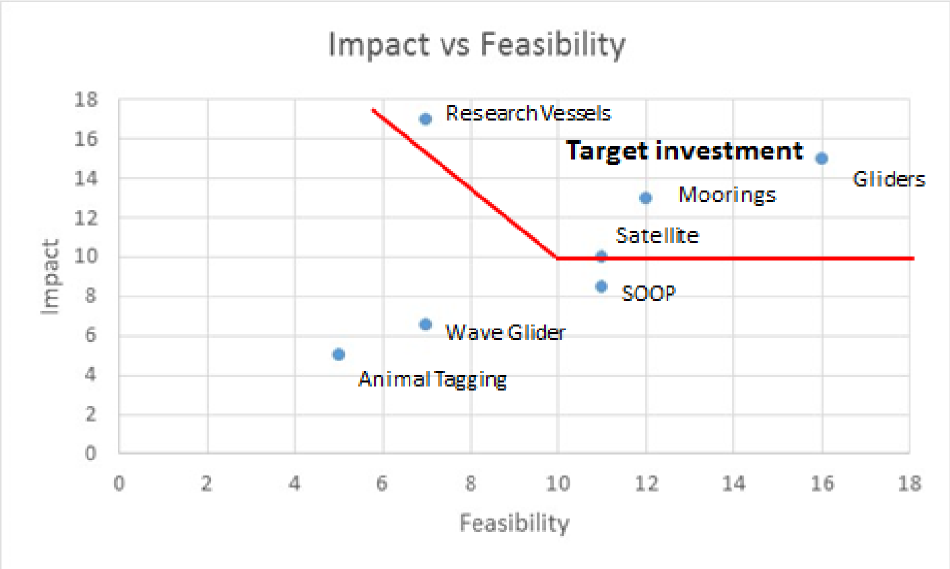

Figure 17. Assessment of impact verses feasibility of various observing techniques to address multidisciplinary questions in boundary current/shelf interactions. Top right section (outlined in red) indicates target investment area.

Key conclusions and next steps

The group agreed that the next step would be to test the method for analysis of requirements and capabilities in an eastern and western boundary current system which is already well observed; the California Current and East Australian Current, refining the approach taken above to address questions, phenomena/EOVs, and feasibility/impact of observation approaches. Approaches to observing system design and the role of observing system evaluation/observing system simulation experiments was discussed, noting that GODAE OceanView (including task teams for Coasts and Shelf Seas, Data Assimilation, Marine Ecosystem Analysis and Prediction, Observing System Evaluation) would be important partners in observing system design processes. GOOS needs to work with other partners (such as GEO, Future Earth) to improve the identification societal drivers of the geographic locations to examine, and observations required to underpin the delivery of fit for purpose products and information to meet decision making needs.

Action: GOOS to develop a plan to engage partners in capturing existing and potential future societal drivers for sustained observations and their information needs, particularly focused on the 3 societal benefit areas. (GOOS, RCN engaging GEO, Future Earth).

The group also discussed considerations for selecting pilot projects; while it is tempting to build on the well-studied/observing regions, the most important outcome is that the method being developed be helpful in developing a basic observing network in less well studied parts of the world; particularly developing regions where fisheries productivity of boundary current/upwelling systems are so centrally important.

The concept of a backbone observing system was discussed; sustained network required to capture key features large scale of the system, which could be planned and coordinated at the international level; and flexible/moveable assets for capturing the higher spatial and temporal aspects. It was agreed that a backbone should address issue 1 (large scale), and flexible, moveable assets could be deployed to address issues 2 (mesoscale) and 3 (hotspots).

Step 1. Building on existing experience (1-2 year timeline)

As a first step, the group initially test and refine the approaches outlined in breakout 3 and 4 on two existing boundary current systems with multidisciplinary observations in place:

- The US west coast (California Current), where a comprehensive observing system is in place, but the observing system has been developed through a bottom up process with many stakeholders and motivations. A review is proposed to address requirements for a multidisciplinary backbone (i.e. to address question 1).

Action: Organise a review of the California Current system observation requirements to address issue 1. (Lead: Francisco Chavez). The proposed timeline is to start in September 2017 and to submit a paper for OceanObs19 that summarizes Step 1 and provides a concept/blueprint for Step 2 (below). Partners include the US West Coast regional associations (NANOOS, CeNCOOS and SCCOOS) and associated academic and user communities;). Engagement with GOOS Panels, IMSOOO participants coordinated through GOOS Physics and Climate Panel.

- The East Australia Current System; where a comprehensive multidisciplinary ocean observing system is in place, implemented through a nationally coordinated planning process as part of Australia's Integrated Marine Observing System (IMOS); however, it is timely to review the observing system to meet multidisciplinary requirements specific to the boundary current/shelf system, given elements of IMOS have now been operating for over 10 years. A write up of the observing system in the context of the multidisciplinary questions and process developed here was proposed for international peer review.

Action: Develop a white paper on the East Australian Current regional observing system for international peer review, covering drivers, design, delivery and impact. (Lead: Tim Moltmann). The process would be for the IMOS community to develop the white paper during September 2017 to March 2018, have it reviewed during April 2018 to September 2018 so as to enable presentation of the results at OceanObs'19 in Hawaii in September 2019. Partners include the Bluewater and Climate, Queensland, New South Wales and South East Australia Nodes of IMOS along with all relevant IMOS Facilities. Support will be required from all three GOOS expert panels, as well as international peer reviewers drawn from IMSOO participants and their colleagues, connecting through GOOS Physics and Climate Panel.

The refinement of design criteria, in particular the role of observing system design and evaluation studies will need to be considered in the context of these reviews, particularly engaging GODAE OceanView. Reviews of other boundary current systems could also be considered. The results from the eastern and western boundary current studies (above) will refine the approach taken to developing a multiplatform, multidisciplinary observing system design (rather than develop a 'one size fits all' design per se). Reviews should also be cognizant of lesson/recommendations which could aid the development of systems in less well observed boundary current regions. The outcomes will feed into the development of a whitepaper ahead of OceanObs19.

Step 2. Developing concept/blueprint for a Multidisciplinary Backbone observing System (2-3 Years)

The group decided that a next step would be to develop the concept of a multidisciplinary boundary currents backbone observing system for broader implementation, including a generic design process, building on the experience of existing comprehensive systems and review process implemented in step 1. It was suggested that different levels of system should be proposed, so that the design process is scalable according to regional resources. The priority would be to propose a minimum, ”threshold” system, and consider ”breakthrough”/“goal” options. It is important that this approach helpful in developing a basic observing network in less well studied parts of the world; particularly developing regions where fisheries productivity of boundary current/upwelling systems are so centrally important.

The Feasibility verses impact assessment (e.g. Table 12, Fig. 17) will be a useful framework in this context, and the design framework will need to balance costs with feasibility, impact of sensor, resolution choice. The modelling communities, including GODAE Ocean View, will need to be engaged from the start of the design, particularly in the joint design of experiments to effectively inform observing system design options.

Step 3: Develop concept for multidisciplinary relocatable observing system pilot for observing finer scales (3-5 years).

As a 3rd Step, the group recommended to develop observation requirements for finer scales (mesoscale, hot spots) through the development of pilot flexible/relocatable observing systems. The Platform/sensor suite selected to deliver EOV suite relevant to region or process specific high level societal goals, and again, a generic design process would enable such an approach to be rolled out/compared across a range of boundary current systems. Limited time deployment with high resolution combined with model resources would then inform the subsequent sustained observation network for GOOS. Again, the ultimate aim would be to identify goal, breakthrough and threshold options, by testing analysis/synthesis skill with reduced resolution. The duration of these pilots would need to be long enough to reveal trends from among variability. The long term vision would be to have a continuously deployed nested observation system where the fixed assets focused on the interannual and climate scale variability and high resolution/fast assets would adapt to the problem du jour.

A number of candidate locations would need to be selected, based on type of open ocean/coastal system (Western, Eastern Boundary Currents, Enclosed Sea, Subpolar). Scales of processes and their relative importance/impact, societal impacts, and intersections with the Plankton and OMZ demonstration themes.

Tim Moltmann gave the summary of Breakout 4 at the plenary.

5 – Synthesis

The early sections of this document provide background for the workshop and Section 4 addresses the work of the teams on the three demonstration themes. This section will look across demonstration themes to the similarities in the recommendations and plans to move forward.

The tendency in reviewing the workshop may be to assume that the workshop objectives are focused on three themes and the outcomes are measured by the recommendations and proposed directions of the themes. These themes are important as they were designed to provide a framework for interdisciplinary collaboration, with a focus on improving the communication and partnerships across disciplines. It is, however, the umbrella of interdisciplinary ocean sciences that is the core objective.

There were a number of common insights and discussions across the three demonstration themes. Primary was the dependencies and impacts of each theme on the other two. For plankton, the oxygen in the water is essential for vitality, and the upwelling of deep water in the coastal regions provides nutrients. The plankton, in turn, impact the characteristics of the oxygen minimum zone. The ocean is a connected environment and thus the isolation of phenomena will limit the ability to effectively model and understand ecosystem dynamics. All of this occurs in three dimensions with the complexity of scales ranging from single cell organisms to micro-eddies to basin wide gyres and large scale overturning. With the levels of fishing, growth of aquaculture and the broader efforts of resource extraction from the ocean floor and below, understanding the oceans is an imperative, not a luxury.

Therefore, recommendations from the themes recognized that the measurements need to be cross-disciplinary. This is an important outcome of the workshop. There was also recognition that new capabilities and new observation systems must be built. The plankton community noted that "combinations of in-situ and remotely-sensed observations are vital to understanding changes in planktonic communities and to assess the impacts of those changes." While the satellite observations inherently provide regional (from geosynchronous orbit) or global coverage, it is impractical for in-situ monitoring to sustain such a capability. Even with the "extensive" ARGO coverage, the practical result is that this coverage is a distributed series of point profiles. While these are important and a significant step forward, much of our understanding of the ocean conditions comes from conceptual models and newer coupled biological–physical oceanographic and earth system simulations.

Expanded in-situ coverage comes from greater replication of existing capabilities, with larger scale production reducing cost, or from innovations providing new capabilities. The new capabilities should be both disruptive and non-disruptive. Since long-term continuity of measurements is a priority, extensions of existing capabilities should be done with minimal impact on the current operations. This is true across the spectrum of ocean disciplines, observation platforms and observation objectives.

New measurement capabilities lead to a re-examination of EOVs, addressing what additional EOVs could be considered as part of the inventory of key observations. EOVs are selected as a balance of impact and feasibility. With the advances in technology, feasibility evolves and thus new EOVs can be defined and adopted. The evolution of eDNA is just one example of such advances. Where the measurement techniques are mature, EOVs may not change much, but the need for more pervasive observations is a priority. Evolution of platforms such as gliders is serving this purpose, but the scale of the oceans makes comprehensive coverage a formidable, perhaps “impossible’, task. Thus, the importance and role of modelling in understanding ocean (and ecosystem) dynamics is appreciated.

Modelling plays a key role in addressing the three demonstration themes. Modelling capabilities differ depending on whether local, regional or global estimates are considered, and this has consequences for how well the direction and magnitude of change in the physical environment, the ocean productivity and ecosystem dynamics can be represented. Further expansion of models and closer coupling of models with observations was noted as a priority; it is through models (anchored in observations) that an improved understanding of the dynamic relationships between the ocean circulation, biogeochemical and biological processes can be achieved. More comprehensive observations will allow assessment of the reliability of model forecasts and predictions.

There was concern across the three themes that support of ocean information needs to include many facets of data management. There are occasions where the archiving, discovery and access of data have insufficient support as an element of the full data life cycle. Common formats, persistent identifiers, timely and open contributions of data and best practices are continuing points of discussion. While the trends are encouraging [Gallagher et al., 2015], there remain many challenges that need to be addressed across the community.

Capacity building was another common thread. This includes the use of existing standards and best practices for data management and could include the creation of best practices manuals and similar documentation. Capacity building must account for the technology and resource availability in different regions and countries.

The challenges discussed by the demonstrations themes are not new. The emphasis on multi-disciplinary information and collaboration was a step forward in expanding traditional dialogues. The planning with a multi-year perspective offers the opportunity for advances that otherwise could take a decade of evolution. The near term outcomes of the workshop are a clear series of directions and actions for the three demonstration themes including efforts of collaborations across disciplines, observation platforms and networks. The three themes will set their own collaboration opportunities including workshops, observations types and locations and the interfaces with modelling. The first steps are a series of planning and implementation meetings and workshops planned for 2017 and 2018. Only a few of the planned actions fall within currently funded activities; therefore, the groups have started to address securing required resources through funding avenues identified at the workshop.

A survey of participants following the workshop illustrated the value and importance of the workshop. The objectives of the workshop were a major reason that participants decided to attend and a large number indicated that the workshop lived up to their expectations. More than 75% of the respondents said they would stay engaged with the planned projects. Follow-on activities are currently being discussed.

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Appendices

Agenda

Implementation of Multi-Disciplinary Sustained Ocean Observations
February 8-10, 2017

Wednesday, Feb 8

07:30 *Breakfast*

08:15 Registration

08:45 Welcome from FIU – Provost Emeritus Doug Wartzok

09:00 Introduction to the Workshop and Desired Outcomes – Jay Pearlman

09:15 Ocean Observing since OceanObs'09: GOOS, EOVs, and the road ahead. – Albert Fischer

09:45 Introduction to Demonstration Themes – Frank Muller-Karger (Plankton Community Changes), Lisa Levin (Oxygen Minimum Zones) and John Wilkin (Open Ocean, Shelf and Coastal Ocean Interactions)

10:45 *Coffee*

11:15 Opportunities for Implementation of the Demonstration Themes:

In-situ observing capacities – Sam Simmons, Maciej Telszewski

11:45 Opportunities for Implementation of the Demonstration Themes:

Modelling perspective – Marion Gehlen

12:15 *Lunch*

13:20 Introduction and charge for breakouts – Jay Pearlman

There will be four breakout sessions each with a different focus:

1. Scope potential integrated multidisciplinary projects, activities or focal regions/topics for each demonstration theme. This will include identifying impacts or significance of the proposed activities/project as well as setting requirements
2. Identify what is needed for technical implementation of the identified activities ('down in the weeds) regarding the project/activities, current feasibility and any developments that will be needed to realize them.
3. Take a step back and reflect on programmatic implementation and what is needed to make these projects happen in a practical sense.
4. Work to bring consistency to the emerging project/activity plans across the demonstration themes.

The workshop participants will be divided into three groups, one for each Demonstration Theme.

13:45 **Breakout Session 1**: Framing Demonstration Themes and Associated Requirements. Discussion topics include:

- Scoping multidisciplinary projects/activities for the demonstration theme
- Societal impact(s) of the project(s)
- Gap assessments
- Technology requirements
- Any new observations, data and modelling requirements
- Identifying possible implementation challenges

15:30 *Coffee*

16:00 **Reports and Discussion** from Breakout Session 1 Moderator: Eric Lindstrom

17:15 Daily Summary – Sam Simmons

17:30 *Adjourn*

Conference Dinner to follow (not hosted)

Thursday, Feb 9

07:30 *Breakfast*

08:30 **Breakout Session 2**: Technical Implementation Planning

- Addressing implementation challenges
- Identify near-term innovation priorities for observing platforms and sensors, data and modelling to enable multi-disciplinary observations
- Identify programmatic and professional expertise to support demonstration theme
- Scoping an implementation plan for the project(s)/activities

10:30 *Coffee*

11:00 **Reports and Discussion** of Breakout Session 2 – Moderator: John Gunn

12:00 *Lunch*

13:30 Approaches and Options for an Integrated Plan for Demonstration Theme Implementations – Bernadette Sloyan

14:00 **Breakout Session 3**: Programmatic Implementation Considerations.

- Project/Activity milestones for both a 2-year and a 5-year project
- Schedules and detailed needs for implementation (including project management)
- Funding requirements

15:15 *Coffee*

15:45 Breakouts continue

17:00 Daily Summary – Patricia Miloslavich

17:15 *Adjourn*

Friday, Feb 10

07:30 *Breakfast*

08:15 **Reports and Discussion** of Breakout Session 3 – Moderator: Nic Bax

09:00 Implementation Strategy – Moderator: Sam Simmons

10:00 *Coffee*

10:30 **Breakout Session 4**: Reviewing Implementation Strategy and Developing Recommendations for Pilot Projects

- Draft a consolidated project/activity plan
- Identify opportunities for ongoing collaborations and communication
- Identify potential opportunities for funding support for integrated multi-disciplinary projects/activities

12:15 *Lunch*

13:15 **Reports and Summaries** of Breakout Session 4 – Moderator: Katy Hill

14:15 Integrated Program Definition and Consensus – Moderator: Maciej Telszewski

15:00 **Recommendations for OceanObs'19** - Moderator: Eric Lindstrom

15:30 **Workshop Summary** – Jay Pearlman

15:45 *Adjourn*

Requested participation in breakout sessions by demonstration theme

	Demonstration Theme 1	Demonstration Theme 2	Demonstration Theme 3
	Plankton Community Changes	**Open Ocean, Shelf and Coastal Ocean Interactions**	**Oxygen Minimum Zones**
Co-Chair	Sam Simmons	John Wilkin	Veronique Garçon
Co-chair	Bernadette Sloyan	Toste Tanhua	Johannes Karstensen
Note Taker:	Patricia Miloslavich	Robert Todd	Artur Palacz
	Albert Fischer	Dan Costa	Arne Koertzinger
	David Legler	Dan Rudnick	Bob Houtman
	Emmanuel Boss	Eric Lindstrom	Francis Marsac
	Fei Chai	Francisco Chávez	Kenneth Rose
	Herve Claustre	Frank Muller-Karger	Kevin Weng
	LuAnne Thompson	Kim Currie	Kyla Drushka
	Marion Gehlen	Lisa Beal	Lisa Levin
	Peter Thompson	Masao Ishii	Mark Bourassa
	Rik Wanninkhof	Wajih Naqvi	Pierre Testor
	Sonia Batten	Tim Moltmann	Raphael Kudela
	Takafumi Hirata	Yasumasa Miyazawa	Tony Koslow
	Tony Richardson	Ananda Pascual	
Facilitators	Jay Pearlman	Jay Pearlman	Jay Pearlman
	John Gunn	Katy Hill	Maciej Telszewski
	Nic Bax		

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	Family Name	Given Name	Affiliation	Country
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4	BOSS	Emmanuel	University of Maine	USA
5	BOURASSA	Mark	Florida State University	USA
6	CHAI	Fei	University of Maine	USA
7	CHAVEZ	Francisco	Monterey Bay Aquarium Research Institute (MBARI)	USA
8	CLAUSTRE	Hervé	Laboratoire d'Océanographie de Villefranche-sur-Mer (LOV)	France
9	COSTA	Dan	University of California, Santa Cruz	USA
10	CURRIE	Kim	National Institute for Water & Atmospheric Research (NIWA)	New Zealand
11	DRUSHKA	Kyla	University of Washington	USA
12	FISCHER	Albert	Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), Global Ocean Observing System (GOOS)	France
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14	GEHLEN	Marion	Laboratoire des Sciences du Climat et de l'Environnement (LSCE) Institute Pierre Simon Laplace (IPSL)	France
15	GUNN	John	Australian Institute of Marine Science (AIMS)	Australia
16	HILL	Katy	World Meteorological Organization (WMO)	Switzerland
17	HIRATA	Takafumi	Hokkaido University	Japan
18	HOUTMAN	Bob	US National Science Foundation (NSF)	USA
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23	KUDELA	Raphael	University of California, Santa Cruz	USA
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25	LEVIN	Lisa	Scripps Institution of Oceanography	USA
26	LINDSTROM	Eric	National Aeronautics and Space Administration (NASA)	USA

27	MARSAC	Francis	Institut de Recherche pour le Développement (IRD)	France
28	MILOSLAVICH	Patricia	Australian Institute of Marine Science (AIMS), Universidad Simón Bolívar	Australia, Venezuela
29	MIYAZAWA	Yasumasa	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	Japan
30	MOLTMANN	Tim	Integrated Marine Observing System (IMOS)	Australia
31	MULLER-KARGER	Frank	University of South Florida	USA
32	NAQVI	Wajih	National Institute of Oceanography (NIO)	India
33	PALACZ	Artur	International Ocean Carbon Coordination Project (IOCCP)	Poland
34	PASCUAL	Ananda	Instituto Mediterráneo de Estudios Avanzados (IMEDEA)	Spain
35	PEARLMAN	Jay	Institute of Electrical and Electronics Engineers (IEEE), University of Colorado	USA
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37	ROSE	Kenneth	Louisiana State University	USA
38	RUDNICK	Dan	Scripps Institution of Oceanography)	USA
39	SIMMONS	Sam	Marine Mammal Commission	USA
40	SLOYAN	Bernadette	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia
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45	THOMPSON	LuAnne	University of Washington	USA
46	TODD	Robert	Woods Hole Oceanographic Institution (WHOI)	USA
47	WANNINKHOF	Rik	NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML)	USA
48	WENG	Kevin	College of William and Mary, Virginia Institute of Marine Science (VIMS)	USA
49	WILKIN	John	Rutgers University	USA

Demonstration Theme Breakout session presentations

Combined presentations from all four breakout sessions of each Demonstration Theme can be downloaded from the workshop website, www.goosocean.org/imsoo, under 'Documents' using the links below:

IMSOO - Demonstration Theme 1: Plankton Community Changes - Breakout presentations combined

IMSOO - Demonstration Theme 2: Oxygen Minimum Zones - Breakout presentations combined

IMSOO - Demonstration Theme 3: Open Ocean, Shelf and Coastal Ocean Interactions - Breakout presentations combined

Glossary of terms

A **GOOS Essential Ocean Variable** (EOV) is a sustained measurement or a group of measurements necessary to assess state and change at a global level, and to increase societal benefits from the ocean.

[Note that regional priority needs are not included, and so the essential sustained observations in a particular region may include other priority variables, needed for more local societal benefit. Observations for process studies are not included either.]

In the GOOS context, a **phenomenon** is an observed process, event, or property, with characteristic spatial and time scale(s), measured from one or a combination of EOVs, and needed to answer at least one of the GOOS Scientific Questions.

List of acronyms

ADCP – Acoustic Doppler current profiler

AGU – American Geophysical Union

ASV – Autonomous Surface Vehicle

BGC – Biogeochemistry

CalCOFI – California Cooperative Oceanic Fisheries Investigations

CBD – Convention on Biological Diversity

CDOM – Coloured Dissolved Organic Matter

CeNCOOS – Central and Northern California Ocean Observing System

CMIP – Coupled Model Intercomparison Project

CPR – Continuous Plankton Recorder

CTD – Conductivity Temperature Depth

DBCP – Data Buoy Coordination Panel

DIC – Dissolved Inorganic Carbon

DNRA – dissimilatory nitrate reduction to ammonium

DSL – Deep Scattering Layer

EBV – Essential Biodiversity Variables

ECV – Essential Climate Variable

EEZ – Exclusive Economic Zone

EOV – Essential Ocean Variable

FOO – A Framework for Ocean Observing

GCOS – Global Climate Observing System

GEO – Group on Earth Observations

GHG – Green-House Gas

GODAE – Global Ocean Data Assimilation Experiment

GO_2NE – Global Ocean Oxygen Network

GOOS – Global Ocean Observing System

GO-SHIP – Global Ocean Ship-based Hydrographic Investigations Program

HAB – Harmful Algal Bloom

HF Radar – High Frequency Radar

ICSU – International Council for Science

IFCB – The Imaging FlowCytobot

IGMETS – International Group for Marine Ecological Time Series

IIOE-2 – 2^{nd} International Indian Ocean Expedition

IMARPE – Instituto del Mar del Perú

IMOS – Integrated Marine Observing System

IMSOO – Implementation of Multi-disciplinary Sustained Ocean Observations

IOC – Intergovernmental Oceanographic Commission

IOCCP – International Ocean Carbon Coordination Project

IODE – International Oceanographic Data and Information Exchange

IPBES – Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services

IPCC – Intergovernmental Panel on Climate Chante

JCOMM – Joint Technical Commission for Oceanography and Marine Meteorology

LME – Large Marine Ecosystem

LOPC – Laser Optical Particle Counter

LTER – Long Term Ecological Research network

MARCATS – MARgins and CATchments Segmentation

MBARI – Monterey Bay Aquarium Research Institute

MBON – Marine Biodiversity Observation Network

NANOOS – Northwest Association of Networked Ocean Observing Systems

NERC – natural Environment Research Council

OBGCM – Ocean Biogeochemistry General Circulation Model

OBIS – Ocean Biogeographic Observation System

OHI – Ocean Health Index

OMZ – Oxygen Minimum Zone

OOPC – Ocean Observations Panel for Climate

OSE – Observing System Experiment

OSSE – Observing System Simulation Experiments

OTN – Ocean Tracking Network

PICO – Panel for Integrated Coastal Observations

POGO – Partnership for Observation of the Global Oceans

POM – Particulate Organic Matter

QC – Quality Control

SCCOOS – The Southern California Coastal Ocean Observing System

SCCWRP – Southern California Coastal Water Research Project

SDG – Sustainable Development Goal

SIDS – Small Island Developing States

SOCIB – Balearic Islands Coastal Observing and Forecasting System

SOOP – Ship Of Opportunity Programme

SSH – Sea Surface Height

SST – Sea Surface Temperature

TBD – To Be Determined

UNESCO - United Nations Educational, Scientific and Cultural Organization

UNFCCC – United Nations Framework Convention on Climate Change

UVP – Underwater Vision Profiler

VOICE – Variability in the Oxycline and its ImpaCts on the Ecosystem

WAMS – World Association of Marine Stations

WBC – Western Boundary Current

WOA – World Ocean Assessment

XBT – eXpendable BathyThermograph