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Lead beneficiary	NERC
Lead author	Doug Connelly
Contributors	Pedro Afonso, Frederick Whoriskey, Isabel Sousa Pinto, Neil Davies, Pier Luigi Buttigieg and Jörg Peplies
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Introduction

Whilst the AtlantOS project is directed towards bringing together the existing, but currently disparate observing programmes in the Atlantic Ocean, there are still some gaps in terms of requirements for addressing the collection and curation of data around the Essential Ocean Variables. This deliverable will identify gaps and emerging observing networks. Here we use the term emerging network to classify science areas that are starting to gain importance with respect to EOVS and their measurement and curation, or are existing small scale programmes or communities that might become more important in the future if we can find means of enhancing the collaboration among investigators/groups, increasing resources to the area or using new technological developments.

In the AtlantOS project we have identified a number of areas in which there are gaps in our knowledge and where opportunities exist to enhance current small-scale networks.

The scope of this document is to assess these networks, based on where we are now and where the networks could be in three and ten years' time, respectively. An assessment of the state of the existing networks is useful to identify the level of international organisation and potential for further development in the future. We identify opportunities where synergies are possible with more established global projects, and where small levels of investment in resource and time for governance and coordination can productively and realistically develop the networks. We also identify if there are ways to develop coordinated approaches to metrology technology development.

For this analysis, the networks have been allocated to one of the three groups outlined below.

1. Emerging biogeochemical networks

In an assessment of the current state of emerging networks for biogeochemical measurements we must first understand which emerging networks have been identified. Once the networks are understood we need to assess what measurements can be recorded by the networks. The Global Ocean Observing System (GOOS) ([www. http://goosocean.org/](http://goosocean.org/)) panels have identified a list of EOVS for biogeochemical species in the ocean. These are dissolved oxygen (DO), inorganic macronutrients (MN's), carbonate system parameters (CS), transient tracers (TT), suspended particulates (SP), nitrous oxides (NO_x), carbon isotope (¹³C) and dissolved organic carbon (DOC). GOOS have specialist panels that have collated information around each of these EOVS. The emerging networks identified for the assessment by GOOS were profiling floats, gliders and drifters, moorings and ships of opportunity. For the scope of this deliverable we have summarised the information about future (emerging) observing networks, including the maturity (mature, pilot, concept) of their analytical techniques, the state of current deployments on various platforms that offer ranges of temporal and spatial coverage, and data/metrology oversight.

EOV	Analytical approach	Profiling floats	Glider/Drifter	Surface/sub surface moorings	Ship of opportunity	Data/metrology quality control
DO	Mature	Pilot/mature	Mature	Mature	Mature	Floats-pilot, climatology / in situ calibration procedure developed Repeat hydrography-mature
MN's	Better sensors needed	Pilot	Pilot	Pilot	Mature	Pilot level
CS	Standard methods well understood , sensors needed	Pilot	Pilot/concept	Concept	pCO2 Mature, others at concept level	Mature laboratory / ship based procedures. In situ calibration currently problematic (pH only and drift still evident)
TT	Mature but no in-situ sensors	None	None	None	Concept	Mature
SP	Mature	Concept	Mature	Concept	Mature	None
NO _x	Mature but no sensors	None	None	None	Pilot	Data collated under MEMENTO project ^a
¹³ C	Mature but no sensors	None	None	None	None	Limited
DOC	Mature but no sensors	None	None	None	None	CCHDO, BATS, HOTS, CDIAC

^a <https://memento.geomar.de>

This table is useful for assessing the likelihood that there will be the ability to make the measurements required as identified by the GOOS panels. The AtlantOS project has developed a roadmap for the development of sensors and other enabling technology for earth observations, this can be found in D6.1

Profiling floats

Currently there are over 3700 Argo profiling floats deployed in the worlds' oceans. These are primarily measuring temperature, salinity and velocity over the top 2000 m of the water column, though deep diving floats are being deployed at the pilot level. The plan through Biogeochemical-Argo network (Bio-Argo) is that these platforms will be instrumented with biogeochemical sensors for pH (ISFET), oxygen (Optode), nitrate (UV spectroscopy), chlorophyll (fluorescence), suspended particles (backscatter) and downwelling irradiance (optical sensors). . The initial plans for the network are to deploy up to 600 floats within 5 years in the oceans, and a full implementation plan is in development. The initial budget estimates to deploy and maintain the floats are on the order of \$1.5m per year on top of the Argo network cost. Data management and quality control systems will be developed but will follow the approaches of the Argo program.

Gliders and drifters

The glider community is becoming more organised and there are some funded projects at the national level and international level, particularly in Europe. There is a generally accepted data management process that was developed in previously funded projects (GROOM, and EGO-COST), and data is transmitted by GTS and submitted to global data repositories such as COPERNICUS. Gliders are now identified as part of the GOOS. By contrast, the European drifter community is not as well developed but there is a Global drifter program database operated by NOAA (<http://www.aoml.noaa.gov/phod/dac/index.php>).

Surface and sub-surface moorings

In the European context the largest coordinating body for fixed moorings is the Fixed point Open Ocean Observatory network (<http://www.fixo3.eu>) funded by the European Union FP7 programme. This project builds upon funding from the FP7 projects EuroSITES, ESONET and CARBOCEAN. The project is predominantly a coordination action to ensure that the observatories, operated mainly at the nationally funded level, have a harmonised approach to technology development, shared management procedures, and data services and products. The project has done a full cost-benefit analysis (<http://www.fixo3.eu/download/Deliverables/D6.6%20Cost-benefit%20analysis%20report.pdf>) of the existing international observatories and has also generated a generic costing sheet for fixed-point observatories. In the wider international context the coordinating body of the fixed-point observatories is the OceanSITES project, which covers 30 surface and 30 subsurface arrays in the worlds' oceans. The data is centrally collated and follows international data format standards. OceanSITES is a part of GOOS.

Ships of opportunity

The Ships of opportunity programme (SOOP) is an international effort that began by taking Expendable Bathythermographs (XBT's) from vessels including container ships, cruise ships and research vessels as these transit the worlds' oceans. In addition to the XBT programme, there is now a network of ships carrying automated CO₂ measurement systems, for example as part of the NOAA funded SOOP-CO2 project but also including other groups (e.g. Professor Doug Wallace Dalhousie, Canada). The SOOP Implementation Panel ensures that all of the data generated is broadcast over the Global Telecommunications System (GTS) to national data centres, and makes an annual report on the quality of the data. SOOP comes under the control and funding of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) a joint body between the World Meteorological Organization and the Intergovernmental Oceanographic Commission.

2. Biological observing networks

Whilst one of the acknowledged gaps in our observation of the oceans is around the biological domain there is still a great deal of debate about what can be considered biological EOVS. The GOOS Biology and Ecosystem Panel (GOOS Bio-Eco) was established to decide what essential biological and ecosystem variables should be included in the global ocean observing system. The panel has proposed nine biological EOVS split over two components; those that inform the status of functional groups: phytoplankton biomass and productivity, incidence of harmful algal blooms (HAB's), zooplankton diversity, fish distribution and abundance, apex predator distribution and abundance and those that inform the health of the living ecosystem: seagrass cover, macroalgal cover, live coral cover, mangrove cover. From these nine EOVS two (zooplankton diversity and live coral cover) were considered at a pilot stage while the other seven have been considered merely at concept stage recognising that still a lot of work has to be done to operationalize them.

The networks around these biological observations are much less well developed than the emerging networks considered above for the biogeochemical cycles and measurements. The GEO (Group on Earth Observations) is developing the 2016 work programme (http://www.earthobservations.org/documents/geo_xii/GEO-XII_15_2016%20Work%20Programme.pdf) in which a number of efforts have been identified to develop observatory networks for the Biological and ecological EOVS.

In the framework of GEO BON (GEO Biodiversity Observation Network) a thematic network named MBON (Marine Biodiversity Observation Network) has been formed in 2016. MBON is the follow-up of the Marine Ecosystem Change working group from GEO BON first implementation plan. It was created to help provide the information and knowledge needed to inform the progress towards internationally agreed targets as the global 2030 targets of the UN Sustainable Development Goals (specifically SDG 14), the 2020 Biodiversity Aichi targets of the Convention on Biological Diversity (CBD), and international efforts as the Intergovernmental Platform on Biodiversity and Ecosystem Services (UN IPBES), the second World Ocean Assessment, and provide guidance to the current negotiations for a new legally-binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction.

The goal of MBON is to build a community of practice for the collection and curation of marine biodiversity information and to establish practical measures of biodiversity, defining past or current baselines against which to evaluate change. It will also implement monitoring programs that use standard protocols, and facilitating the comparison of observations collected in different regions.

The MBON mission is to focus the international operational agencies that constitute the GEO to facilitate the planning, implementation, and functioning of a network of marine biodiversity observation efforts. These efforts include facilitating linkages between research and operational groups on an international scale. They also focus on the development of marine Essential Biodiversity Variables (EBVs) to complement the broader Essential Ocean Variables (EOVs) defined jointly with the Global Ocean Observing System.

Furthermore GOOS Bio Eco, MBON and the Ocean Biogeographic Information System (OBIS), have already made an agreement to work together to build a sustained, coordinated, global ocean system of marine biological and ecosystem observations. The aim is to enhance existing observation scope and capacity, further identify essential biological ocean variables and collect the necessary observations to best assess ocean living resources, while enhancing global capacity

for long term global marine biological and ecosystem observations. Resulting information from this network will be delivered through an open access, integrated and quality controlled database and will support management decisions and relevant science and societal needs.

At the moment there are three pilot MBON projects funded by the US at around \$6 million, with the aim of creating and optimising a series of different marine biodiversity observation systems. This and other existing initiatives as the Marine Global Earth Observatory (MarineGEO), directed by the Smithsonian's Tennenbaum Marine Observatories Network (TMON) a long-term, worldwide research program to focus on understanding coastal marine life and ecosystems that led to the first steps of MBON were strategically placed in the Americas. But other initiatives and networks as e.g. the Continuous Plankton Recorder (CPR a monitoring program started 85 years ago in the UK and now the Global Alliance of Continuous Plankton Recorder Surveys) and other national and international initiatives are being brought together to build the global MBON. In Europe there has been some developments and workshops have been organised with AtlantOS and GEO BON in Germany to discuss and draft the structure and implementation plans for the global MBON. The implementation plan for this network is now being drafted.

Understanding global marine biodiversity and how this is changing is challenging but advances in genomic and metagenomic approaches could provide a valuable tool.

Case Study 1. Genomic and metagenomic networks

While no official deliverables regarding microbial observations exist in the AtlantOS DoW, there is considerable opportunity to cultivate a self-sustaining community of practice focused on harmonising marine microbial and molecular observation. Within this domain, several AtlantOS partners are conducting programmes which are deploying similar technologies and developing similar metrology and data processing workflows. These include the AWI's Frontiers in Arctic Marine Monitoring ([FRAM](#)), the MBARI Marine Biodiversity Observation Network ([MBARI MBON](#)), [ATLAS](#), A trans-Atlantic assessment and deep-sea ecosystem-based spatial management plan for Europe, and the development of microbial/(meta)genomic sampler technology and molecular metrology best practice in WP6 of AtlantOS. In particular, these efforts employ advanced and often novel methods involving the extraction, processing, and archiving of nucleic acids from environmental materials coupled to the use of next-generation sequencing and bioinformatic workflows to generate ecological insight.

Given the existing overlap, establishing a structured, coordinated network of microbial and molecular observatories to facilitate knowledge exchange and systematically agree upon best practices would be both readily achievable and of great value to the observing community and its stakeholders. An identifiable consortium of microbial and molecular observatories can serve as a coordination focus and facilitator as techniques and capabilities advance and more ecological observatories inevitably adopt "omics" (meta-genomics, -transcriptomics, -proteomics, etc.) technologies, promoting controlled integration of omics data into future EOVS. Such a body would address the unique case of integrating these methods into multidisciplinary, long-term observatory settings and be better prepared to coherently interface with national and international monitoring initiatives as well as other stakeholders. Further, this consortium would facilitate the emergence of consensus on key issues such as how to ensure comparability given technological and methodological shifts and how to archive sample material for re-analysis (e.g. via

coordination with the [Global Genome Biodiversity Network](#)). Members could provide one another with internal cross-validation of results and methods in aid of controlling technical variance introduced into monitoring results. The consortium would also provide a means to efficiently communicate the 'omics observing community's findings, recommendations, and positions via coordinated peer-reviewed publications and/or whitepapers.

Fortunately, a considerable amount of work has been done in establishing and operating such networks. A notable example is the [Genomic Observatories Network](#) (GOs Network), which recently emerged from the [Genomic Standards Consortium](#) (GSC). The GOs Network mission statement largely echoes the objectives of AtlantOS participants using omics technologies:

- *To build a global network of premier research sites working to generate genomic biodiversity observations that are well contextualized and compliant with global data standards.*
- *To encourage a set of long-term, place-based, DNA-centric programs that quantify biotic interactions in an ecosystem and develop models of biodiversity to predict the quality and distribution of ecosystem services.*
- *To provide training, technical assistance, resources, and best practice guides as a learning platform for sites and organizations wishing to carry out genomic observations, particularly new sites in developing countries (many of which have very high and/or vulnerable biodiversity)*

Indeed, the GSC and GOs Network may provide the framework needed to improve and sustain coordination between the microbial observatories within and beyond AtlantOS. Over the 11 years since its foundation, the GSC has served as a rally point for omics researchers to standardise the reporting of metadata associated with sequences in public repositories. This formal structure facilitated a series of [GSC projects](#) such as minimal information checklists (including [The Minimum Information about a Genomic Observatory \[MIGO\]](#)) which have helped coordinate not only reporting, but also methodological standardisation of initiatives such as the microbial observations at Plymouth Marine Laboratory, the [Moorea Biocode project](#), the [Northern Temperate Lakes LTER](#), and the [Earth Microbiome Project](#). The GSC also provided the framework for launching international projects such as the [Ocean Sampling Day](#) (OSD) series, which employs standardised methodologies and reporting based on the GSC's previous work and consensus building. Indeed, through its efforts, yearly meetings, affiliated journal ([Standards in Genomic Science](#): ISSN 1944-3277), and growing membership, the GSC has now interfaced with large-scale projects such as TARA oceans (and its successor, the [Oceanomics](#) project), gained support from the European Bioinformatics Institute (and other INSDC bodies), and attracted interest and collaboration from continental-scale observatory projects such as NSF's [National Ecological Observatory network](#) (NEON) and the [Critical Zone Observatory](#) (CZO).

It is clear that the emerging networks comprising the omically enabled observatories in the AtlantOS network face unique challenges; however, it is also evident that there is great overlap with the scope of established networks. In the short- to mid-term it would be desirable to approach the GOs Network (and its associated networks) and explore how to fuse these models synergistically and sustainably. Perhaps a co-evolution of the [MBON framework](#) (nested within [GEOBON](#)) and GOs would yield a rapid route towards creating a consortium able to generate evidence-based and robust community standards for omically enabled ocean observation. With these in place, long-term data will be far more actionable and amenable to synthesis in order to address biodiversity challenges in the 21st century.

Case Study 2. The Ocean Tracking Network (OTN)

Another proposed EOVS is the abundance and distribution of marine fishes and apex predators. Despite the great ecological and economic (both directly and indirectly via ecosystem services) importance of marine fishes, sharks, marine mammals and other apex predators, little is still known globally about their survival, movements and migrations, habitat use, and response to the changing ocean. This knowledge gap is a clear impediment to the managers and policy makers striving to balance future “Blue Growth” developments in the ocean with sustaining healthy marine ecosystems and the current human activities that depend upon them. The Canadian-led Ocean Tracking Network’s (OTN) is an international marine animal tracking initiative created in 2009 aiming to achieve a global tracking platform capable of providing the required information about animal movements and distributions. OTN has leveraged new equipment deployments and its internationally recognized data system with existing local and regional scale animal tracking networks to substantially increase the electronic telemetry and oceanographic monitoring equipment in all of the world’s five oceans. The telemetry networks are composed primarily of acoustic receivers maintained by local researchers. This global receiver infrastructure addresses local questions, but also provides a capability to comprehensively examine the local-to-global movements of tagged marine animals such as sharks, sturgeon, eels, and tuna, as well as other marine species including squid, sea turtles, and marine mammals.

OTN is a system of GOOS and therefore clearly identified as a global ocean observing system. It is also an explicit contributor to the AtlantOS DoW. In particular, it is the centrepiece to organize the existing community of marine animal trackers in Europe via the newly created European Aquatic Animal Tracking Network (EAATN). This community has achieved international recognition for its work in marine tracking research but is not yet organized to the point of benefiting from the expanded assets of a network approach to data collecting and sharing.

The main challenges and opportunities in these emerging networks lie in the links to, and inter-operability with, environmental (ocean) monitoring networks, and in the articulation between the different technological tracking platforms used (e.g. acoustic versus satellite telemetry) and science communities. Both aspects are crucial to achieve the needed global biological observing network. Strong synergies are possible among the tracking community/OTN and other components of AtlantOS. For example, acoustic receivers can be placed on observing platforms for physical oceanography (e.g., buoys or gliders), creating novel platforms for oceanic observation. “Animal oceanographers” can also carry acoustic telemetry systems. Large scale funding is another key aspect given the traditional substantially smaller magnitude of funding between this type of biological research compared with the classical oceanographic research and their observation networks. The scale of funding needed to deploy and maintain a large scale Atlantic observation network based on fixed (e.g. acoustic receivers on buoys) and mobile (e.g. satellite tagged animals and receivers deployed on animals/drifted floats/gliders) could be high. However, with their potential as both a scientific and societal flag project to bring together scientific communities and efforts across the Atlantic, this network is not without merit. Cost savings by using and augmenting existing mature networks may be possible.

3. Networks primarily developed for industrial applications

Presently there are more than a million km of telecommunication cables along the ocean floor. There is an interest in using these cables for scientific purposes. There has been a joint task force (JTF) established in 2012 by the International telecommunications Union (ITU), the IOC and the WMO to investigate the use of these cables for ocean and climate monitoring and disaster warning (<http://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx>). The group is developing a strategy and a roadmap looking at the deployment of submarine repeaters equipped with marine sensors. As part of the work the JTF produced a plan looking at the costs and possible funding routes for such a system. Initial estimates are that the development of sensors would be between \$1-6 m and between \$1- and \$20 million for an initial demonstration project. The group also looked at the possible routes for obtaining this funding and concluded that one or more of the international development agencies such as the World Bank would probably be the most likely source of funding.

There are a large number of active and inactive offshore installations associated with the oil and gas industry. A fledgling network based around these operations is involved with using oil company ROV resources to film the deep-sea biology associated with their offshore facilities. The SERPENT project (<http://www.serpentproject.com>) brings together the major offshore oil and gas companies and a large number of academic partners around the globe. The work they have done so far has led to an increased understanding of the biological communities around these offshore platforms. To date the work has been funded predominantly by the oil and gas operators and provides a useful model for other emerging networks of this type.