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Comments	Due to diary conflicts, it was not possible to assemble all the necessary experts for the two workshops early enough in the programme.

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Stakeholder engagement <u>relating to this task</u>*

WHO are your most important stakeholders?	☐ Private company If yes, is it an SME ☐ or a large company ☐? x National governmental body x International organization ☐ NGO ☐ others Please give the name(s) of the stakeholder(s): …
WHERE is/are the company(ies) or organization(s) from?	x Your own country x Another country in the EU x Another country outside the EU Please name the country(ies): …All countries involved in the international OceanSITES programme which coordinates 150 Eulerian observatories worldwide
Is this deliverable a success story? If yes, why? **If not, why?**	x Yes, because there have been some improvements in the way in which we now make fixed point observations. In some areas, progress has been less impressive. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	x Yes, by those working in the field of fixed point observations, both from the scientific and industrial sector. ☐ No, because …..

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult <u>D10.5</u> Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

OceanSITES Networking Report

The European and Transatlantic plan for sustaining Biogeochemical Eulerian Observatories

Summary and Conclusion

During the course of AtlantOS, our ability to provide biogeochemical (BGC) time series and Eulerian data which is of sufficient quality and quantity to approach basin-scale capacity has improved in a major way in some areas but has declined or not progressed in others. Indeed, the increased coordination achieved through AtlantOS has both increased our capacity to collectively further a basin-scale operation, and revealed new challenges in implementation. These outcomes are synthesised in this report to improve future planning for Eulerian capacities in BGC observation.

Areas of significant progress

1. Development of capacity for emerging BGC variables
2. Establishment of a system for developing "Best practice" recording.
3. Transatlantic MOU with Canada
4. Data management and dissemination

The ways to address the areas in which progress has not been made are conceptually simple but practically demanding. In all cases this needs to be carried out at the global scale and therefore under the auspices of OceanSITES. A coherent system which can provide data of sufficient quality and quantity to address societal needs cannot be achieved in isolation by any one Nation state or by Europe and must not be restricted by discipline. It will become self-evident that such an integrated approach will lead to a system which performs at a much higher level than the sum of its component parts. With continuous pressure from the European Commission, further and additional support from member states, continuing political and scientific dialogue with South Atlantic countries and strong management encouragement at all levels, the establishment of an effective eulerian observatory network is anticipated within the coming decade.

Introduction

The most important objective of AtlantOS is to integrate the Atlantic observing systems so that they function as a coherent, single and effective system which can then be used to derive a wide variety of societal benefits. Ultimately this will lead to the design of an appropriate blend of different observing platforms (ships of opportunity, satellites, floats, eulerian observatories etc) and an appropriate suite of sensors and samplers carried by these platforms. All of the platforms have strengths and weaknesses and although integration is a challenge, this is, for certain, the goal in order to achieve effective observation. The Essential Ocean Variables (EOVs,) as defined by UNESCO/IOC GOOS, are those which are currently considered to be of highest importance (impact) and furthermore are achievable with today's technology (feasibility). This report focusses on one particular class of EOV; Biogeochemistry addressed by one particular platform; eulerian (Fixed point) observatories in one particular ocean basin; the Atlantic. However, almost all of the issues are common to all open ocean systems in the global ocean and any recommendations and strategies should not be considered in geographical isolation.

As can be seen in the Stommel diagram below, a mooring network has considerably more power than a single mooring and the objective of this report is to identify the ways in which an effective network can be achieved.

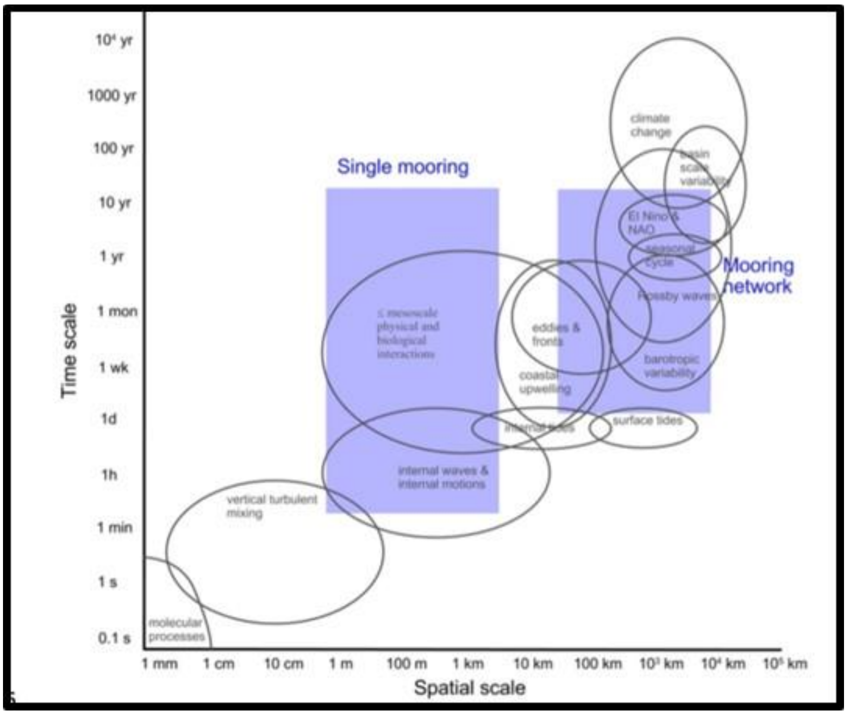

Figure 1 - *Time-space diagram (Stommel diagram) of ocean and earth processes and sampling capabilities of time series stations. The sampling capabilities of both a single time series as well as arrays or networks of moorings are distinguished.*

Essential Ocean Variables (EOVs)

The complexity of the marine carbon and biogeochemistry system and its numerous connections to atmospheric and terrestrial pathways means that a wide range of approaches are necessary to determine what should be considered as "essential" to measure. Neither OceanSITES nor AtlantOS are mandated to make these determinations but EOVs form an essential background to direct our observational strategy. The International Ocean Carbon Coordination Project (which acts as the GOOS Biogeochemistry Panel) coordinates these activities and facilitates the development of strategies, methodologies, practices and standards to homogenize the research community and integrates the ocean biogeochemistry observations with others.

The GOOS Biogeochemistry Panel has the following objectives:

1. Establishment of societal and scientific requirements for biogeochemistry observations and monitoring
2. Identification of a set of high-impact, high-feasibility biogeochemistry-related Essential Ocean Variables (EOVs) to meet the current societal and scientific requirements
3. Assessment of the readiness levels across relevant observing elements for each EOV separately.
4. Coordination of existing infrastructure (observatories and technologies) to leverage its elements for multi-parameter observing across dimensions and disciplines
5. Promotion and, to the extent possible, development of globally acceptable measurement procedures, data-flow standards, data quality control protocols, and data and information product development

The GOOS Biogeochemistry Panel will soon address:

1. Initial system-wide evaluation of the observing system aiding its design
2. Development of requirement-driven observing targets for EOVs
3. Development of metrics allowing the community to monitor the success-rate of reaching the targets
4. Continuous monitoring of the observing system design, promoting new technologies and cross-platform and cross-discipline collaboration

The current GOOS Biogeochemistry EOVs are:

Oxygen
Nutrients
Inorganic carbon
Transient tracers
Particulate matter
Nitrous oxide
Stable carbon isotopes
Dissolved organic carbon
Ocean colour

http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

AtlantOS Task 3.2

One of the objectives of WP3 of AtlantOS (Task 3.2) is to develop a plan by which biogeochemical variables derived from eulerian observatories in the Atlantic can be sustained and integrated. Considerable progress has been achieved in this objective, but a significant impediment has been the fact that, out of financial necessity, AtlantOS provides support for only a subset of the European Biogeochemical observatories situated in the Atlantic and only those in the water column (ie excluding the seafloor), leading to patchiness in effectiveness Furthermore, this support does not of course extend to those observatories funded by countries outside of the EU. In addition, other eulerian networks funded by AtlantOS (TMA (Task 3.3) and PIRATA (Task 3.5)) are considered separately in reporting even when they carry some biogeochemical sensors. The charts below demonstrate this diverse mix of eulerian observatories in the Atlantic each of which was established with different objectives in mind, with a variety of types of sensors and samplers and are maintained by different funding routes which have different levels of temporal security. Almost all funding for the observatories is provided directly by individual nations but with significant integration provided in various ways by other entities such as EU H2020, EMSO ERIC, OOI, JCOMM OPS, DBCP, Global Tropical Moored Buoy Array and OceanSITES.

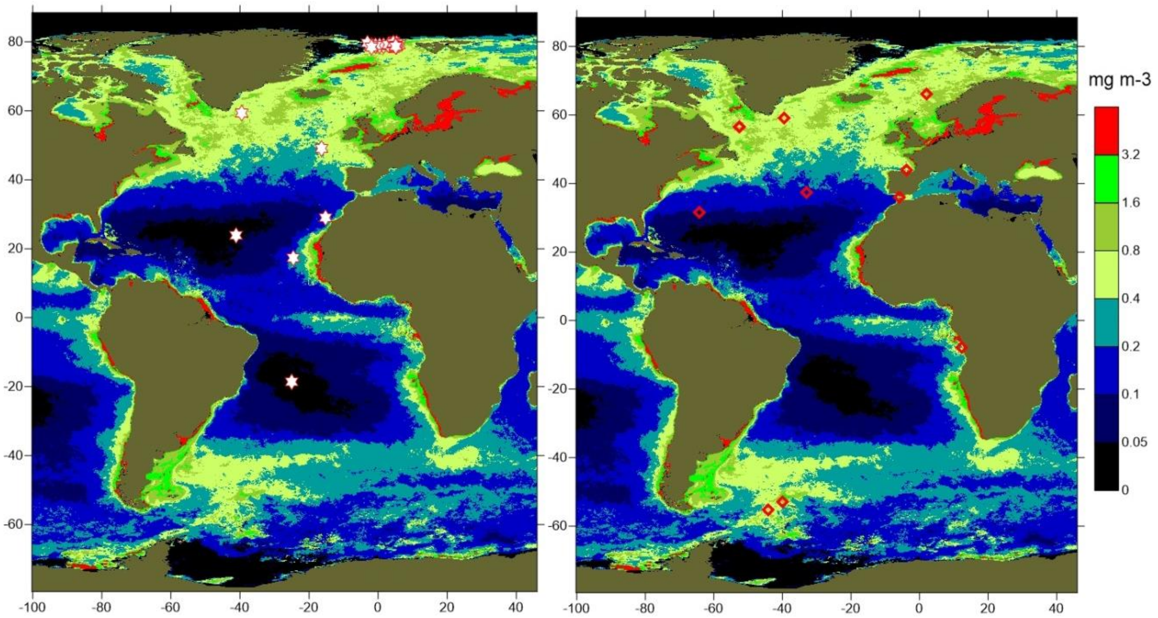

Figure 2 - Chart of 2007 distribution of chlorophyll (data courtesy of NEODASS) and locations of Eulerian observatories in the Atlantic which have a main focus on biogeochemistry. Left: Supported by AtlantOS and Right: Not supported

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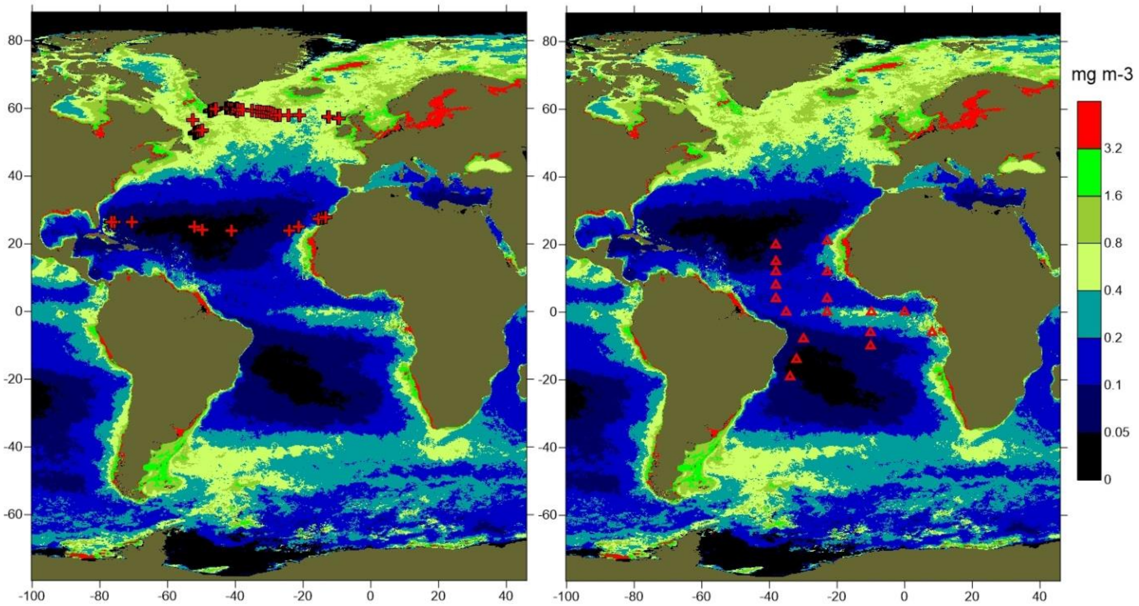

Figure 3 - Chart of 2007 distribution of chlorophyll (data courtesy of NEODASS) and locations of Eulerian observatories in the Atlantic which have a main focus on water transport (TMA)(Left) or Air sea interaction (PIRATA)(Right).

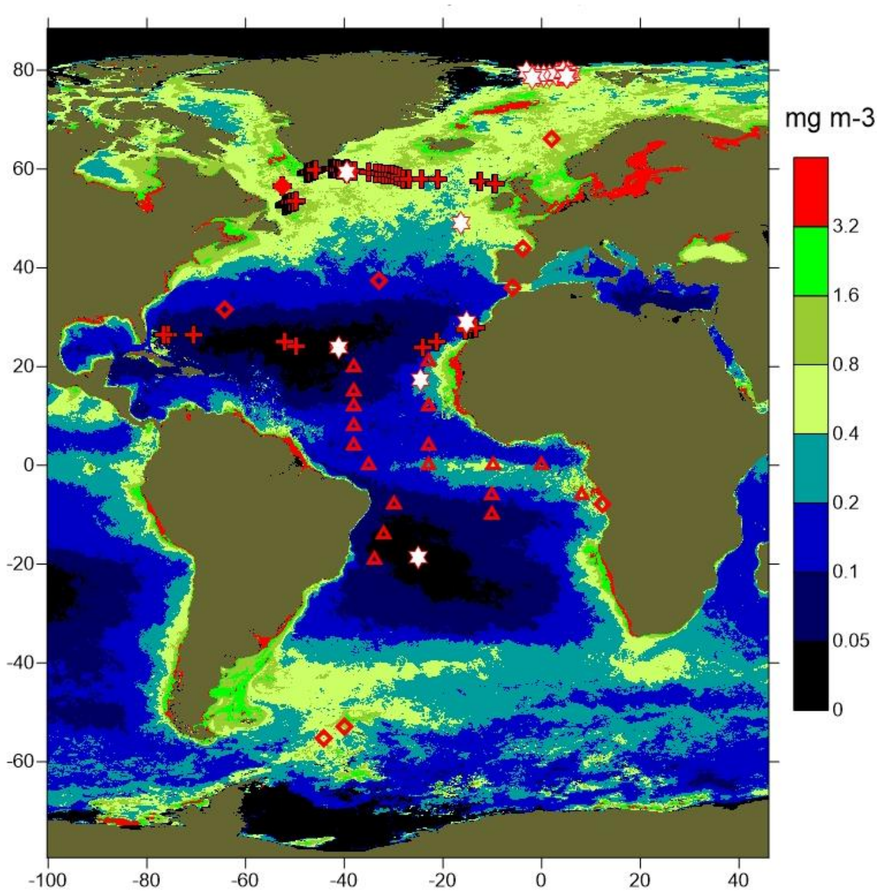

Figure 4 - Chart of 2007 distribution of chlorophyll (data courtesy of NEODASS) and locations of all Eulerian observatories in the Atlantic. Symbols as used in previous figures.

The international programme, OceanSITES has the greatest overview of these networks with a strong commitment to unifying them so that the infrastructure can generate diverse benefits in an efficient, integrated and effective manner. The mission of OceanSITES is to promote efforts, harmonize outputs (through sharing or experiences, production of best practice guides, commitment to common QC/QA protocols and data delivery formats processes), and to produce combined data products that make the sum of the OceanSITES network of time series stations much greater than its parts.
http://www.oceansites.org/

OceanSITES promotes a “joined-up” approach to all aspects of eulerian open ocean observation to include funding, coordination, best practice and data management and, as such, plays a pivotal role in ensuring that the global and hence Atlantic observing networks are integrated. A short introduction to OceanSITES and the three different components of it is therefore useful. Some of this text builds on material which is being used for the OceanObs’19 conference and which is co-authored by several of those involved in AtlantOS WP3.

Rationale behind OceanSITES

The marine environment is extremely complex and consequently observing the ocean is a challenge. The ocean’s physical, biogeochemical and ecosystem states are shaped by diverse processes that operate in parallel and interact with each other. The interactions might be negligible, they might be linear, or highly non-linear and often they are across disciplines, time scales (milliseconds to centuries and longer) and across boundaries (atmosphere, cryosphere, land). Comprehensive observing requires a mix of technology at sea and in space hosted physically by the observing platforms. Efficient use of the platforms, as an interconnected system, requires standardization, interoperability, and harmonized and optimized operations that has to start at the platform level. Such coordination on a platform level is done with groups of operators, scientists, engineers, and data specialists in ocean observing networks. The ocean observing networks operated in the Global Ocean and the Global Climate Observing Systems (GOOS and GCOS) are coordinated by the Observing Coordination Group (OCG) of the Joint International Oceanographic Council (IOC)-World Meteorological Organization (WMO) Technical Commission for Oceanography and Marine Meteorology (JCOMM). Currently the ocean observing networks that are fully represented in JCOMM OCG are OceanSITES (moored and ship based time series), GO-SHIP (research ships), Volunteer observing ships (SOT), surface drifters (DBCP), profiling drifters (Argo), coastal moorings (DBCP), underwater gliders (OceanGlider), and sea-level stations (GLOSS). Other emerging networks exists around HF- radar and animal borne sensors.

By making use of mooring and ships as observing platforms, the International Ocean Sustained Interdisciplinary Time-series Environment observation System (OceanSITES) fills a unique space in ocean observing - collecting long-term, high-frequency and high-quality data at fixed locations in the ocean (Lee 2006). The data covers the full-depth water column as well as the overlying atmosphere, cryosphere, and the sea-floor. The sensors collect physical, biogeochemical, and biology/ecosystem data worldwide and having the capacity to: A: carry sensors that have high power requirements such as acoustic current profilers and bio-acoustic backscatter sensors for zooplankton and fish
B: provide coupled air and sea observations to address the dynamics of heat and CO_2 fluxes, and deliver satellite calibration/validation without ocean/atmosphere aliasing,
C: to re-calibrate sensors to correct for drift collect samples to ground-truth and extend beyond sensor capabilities.
This capability is available on timescales from cloud dynamics (minutes), to surface ocean mixing (hours), to ecological coupling (days to seasons), to weather (weeks to months), to climate, ocean acidification, de-oxygenation, and changing productivity and health (years to decades and beyond).

Resolving long term ocean changes requires sustained observation over many decades, in high quality and sufficiently high temporal resolution to overcome aliasing.

OceanSITES Data Management

The eulerian observatories within AtlantOS (including TMA and the delayed-mode components of PIRATA) are a part of the international OceanSITES observing network. OceanSITES differentiates its data into (1) **Metadata** and (2) **Observational Data**.

(1) **Metadata** describes the facets of the Eulerian observing infrastructure itself including its geolocation, the duration of its operation, personnel responsible for maintaining the infrastructure and data, the ship-based expeditions tasked with deployment and recovery, instrument configuration and links to observational data sets. Until July 2017 the OceanSITES network did not maintain a dedicated metadatabase. Instead, a single spreadsheet comprising general keywords for each site was maintained by the technical coordinator (TC) of OceanSITES. For nearly a year, however, the TC post was unfilled, making it acutely clear that a centralized way of organizing the metadata of a network as complex as OceanSITES is unsustainable. Information about what variables were being measured by whom or the national commitments of the observing effort were not accessible.

This concerning state of affairs also held true for most of the observing networks organized via the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Observations Programme Area (OPA), including the DBCP, GLOSS, GO-SHIP, SOT and others. After discussions within JCOMMOPA Observing Coordination Group (OCG), a single database has been developed to manage all ocean metadata at the JCOMM in situ Observations Programme Support Centre (JCOMMOPS). When this decision was made, JCOMMOPS had a quasi-exclusive link to the Argo observing network (the JCOMMOPS head was also the Argo TC). As a result, the initial metadatabase was very much tailored to suit the specifics of Argo floats. The result was an overspecialization of design, which posed (and still pose) substantial challenges to general use, as frequent modification of the database system is needed to accommodate the varied needs across networks.

In July 2017, a process was initiated to integrate OceanSITES metadata into the JCOMMOPS metadatabase, which has yielded substantial progress. Currently 270 moorings (called “platforms” in the JCOMMOPS vocabulary) are classified as “operational” in the system, with 126 in the Atlantic and Arctic. This global total reflects that a mooring is redeployed almost daily. Such turnover makes clear that a single person (e.g. the OceanSITES TC) cannot maintain the currency of this metadatabase. Instead, the PIs of the OceanSITES observatories are charged with keeping the metadata information for each deployment up-to-date, in a distributed and scalable manner.
While many internal adjustments and additions to the JCOMMOPS metadatabase have been successfully implemented, the commission only recently agreed to use standardized reference vocabularies in its data holdings. The Seadatanet L22 SeaVox device catalogue (http://seadatanet.maris2.nl/v_bodc_vocab_v2/search.asp?lib=L22) is now being used to represent the full spectrum of OceanSITES’ observing capabilities. This is a significant step towards the implementation of the FAIR principles in the OceanSITES metadata system, and links it to the use of FAIR technologies in other AtlantOS outcomes (e.g. the use of terminologies and ontologies in the Ocean Best Practice System; WP6).

Different training opportunities for making use of the JCOMMOPS OceanSITES metadatabase have been offered to the PIs (e.g. a half day session after the 12th OceanSITES meeting, Kiel, Germany; a summary document is available) and the new TC (30% of a FTE) been active in getting in contact with the PIs for individual assistance. By coordinating member metadata through the above solutions, a foundational component of deeper network integration has been achieved. This achievement and its impact on future planning spans beyond the BGC network, as other networks – established and emerging – are converging on FAIR registries of member nodes and their metadata (e.g. the GLOMICON registry: www.glomicon.org, another outcome of WP3).

(2) **Observational data** and their value across stakeholders is, naturally, the primary reason and justification for the existence and operation of eulerian observatories in the Atlantic and elsewhere. As such there is no doubt that this is the most important data for OceanSITES. The observational data have three subcategories: the raw data generated during each deployment period, the quality-controlled (QC) data derived from it, and the various time series products (e.g. synthesis products integrating QC data from multiple deployment periods and time series of QC data processed into volume or property fluxes).

Based on the progress above, the OceanSITES data management team (DMT) has successfully developed and deployed a data distribution strategy, based on formats compliant with the Climate and Forecast (CF) netCDF format, and likewise implemented the strategy for OceanSITES. Two mirrored data centres are in place to ensure that observational data is continuously served via FTP (ftp://ftp.ifremer.fr/ifremer/oceansites/, ftp://data.ndbc.noaa.gov/data/oceansites/) and Thematic Real-time Environmental Distributed Data Services (THREDDS) (tds0.ifremer.fr/thredds/CORIOLIS-OCEANSITES-GDAC-OBS/CORIOLIS-OCEANSITES-GDAC-OBS.html, dods.ndbc.noaa.gov/thredds/catalog/oceansites/catalog.html).

Within these systems, physical data are handled effectively, but BGC data are less well exposed for a variety of scientific and technical reasons. In many cases, BGC data aer not accessible in netCDF format or curated in national data centres due to disciplinary conventions . Further, the data are often freely available, but access is possible only in the shallowest sense, while solutions for integrated cross-deployment and cross site access, and specifically automated harvesting (via machine-to-machine systems) remain difficult to implement. For example, a tropical Atlantic OceanSITES mooring archived under doi.org/10.1594/PANGAEA.867116 at the German World Data Center PANGAEA (www.pangaea.de) can be linked via a DOI to the respective instrument for the respective mooring deployment period, but the link is not associated with a direct downloadable data set and does not resolve to any content compliant to international standards and thus intelligible without pre-processing. The consequence is that any plans for the future of any sustained BGC observing system must include capacities to build such standards and access modes.

Despite the obstacles noted above, the system as it stands does support client-side visualization of the OceanSITES observational data located on its THREDDS servers (links see above). This can be done using different types of freely available software (e.g. FERRET, Phyton, oceandataview, R) or propriety software (Matlab, IDL). As visualization is key to outreach and community buy-in, this capacity must be elevated to promote further integration. Webportals with responsive visualization capacities directly linked to OceanSITES data stores and server-side content negotiation are key routes to pursue in the next decade. In the meantime, local/grouped visualization include the Ocean Observing Initiative (OOI) visualization server (https://ooinet.oceanobservatories.org/) or the *EarthVO* system developed in the framework of the $FixO^3$ project. In terms of data visibility, however, progress has reversed for the *EarthVO* system in the sense that support for the was not continued past 2017.This highlights that the system must be robust to funding lapses by developing portable, hardware-independent solutions which are cheaply deployable and sustainable.

While data is core to the value chain of BGC observation, metadata visualization and analysis for the purpose of actionability and knowledge transfer must not be overlooked. Visualization and analytical availability of national commitments, spatial and temporal distribution of sensing capacities, variables and EOVs, ship expeditions, instruments can aid decision support from global to national or institutional. The JCOMMOPS metadata interface (oceansites.jcommops.org) already provides a foundation for such services, providing a target with good potential for sustained availability for future development alongside the elements described above. Clearly, the community should not extinguish an existing functioning system before a new one is operational but one strategy for the future could be that JCOMM OPS be given support to develop this. The community of scientists, engineers and observatory managers will then be prepared to support and fully engage in this endeavour.

Evolution and current status of OceanSITES

The first sustained network of open-ocean time series sites was provided by the Ocean Weather Station (OWS) programme, established shortly after WWII measuring oceanic and atmospheric parameters at 13 sites in the North Atlantic and North Pacific Oceans. By the end of the 1980s regular ship-survey-based open ocean time series sites were established, such as Hawaiian Ocean Time Series (HOT) and the Bermuda Atlantic Time-series Study (BATS).

Since the 1960s subsurface moorings have been used to observe ocean currents and water properties and in the 1970s the first mooring with surface sensor packages came into operations. The first sediment trap was installed on a deep sea mooring in 1978. The mooring as well as sensor technology improved very much over the years and modern mooring host a suite of multidisciplinary sensors and samplers which provide data on key physical, biogeochemical and biological and ecosystems variables and indicators.

The first International Conference on Ocean Observing Systems was held in 1999 in San Rafael, France, and focused interest on fixed and mobile observing systems. Several oceanographers conceived a global system of "Eulerian observatories" and the international Global Eulerian Observatory (GEO) committee was formed, eventually renamed in 2003 as the "International Ocean Sustained Interdisciplinary Time-series Environment observation System" (OceanSITES). OceanSITES was integrated into the JCOMM OPA as an action group of the Data Buoy Cooperation Panel (DBCP). DBCP also included coastal buoys which are not included in OceanSITES.

The OceanSITES networks comprises repeat ship observations and moored observations. The network is created around the technology - meaning the best use of the technology for the ocean observing endeavour.
Moorings host a suite of multidisciplinary sensors and samplers that provide data on key physical, biogeochemical and biological and ecosystems variables and indicators and with over 200 observatories globally, it is the effective system to coordinate these observatories.

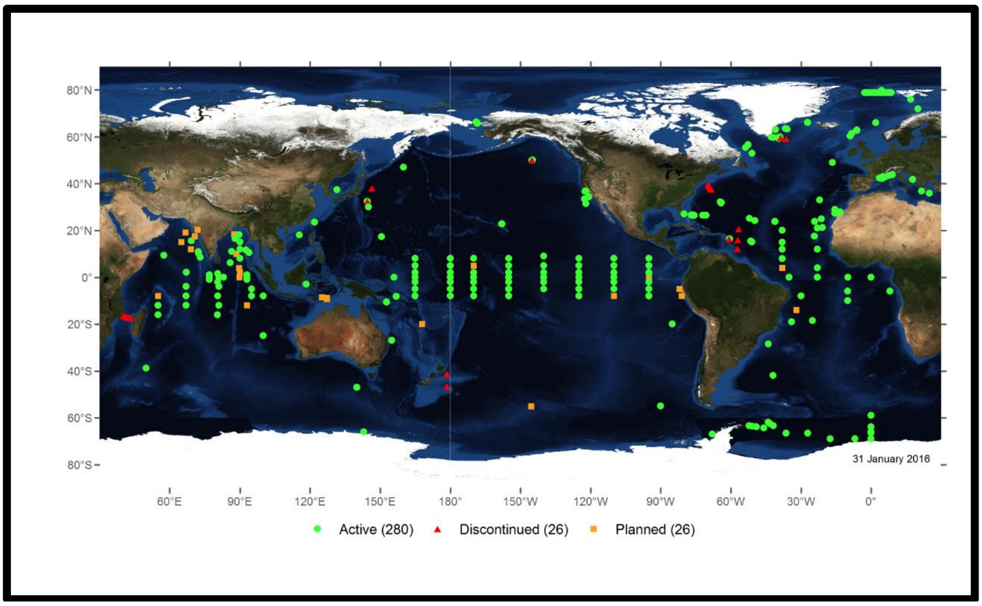

Figure 5 - Distribution of OceanSITES observatories demonstrating a high density of capability in some areas but with massive lacunae in other regions.

Data access for redundancy and operational applications

Improvement of the technology increases the durability and deployment times up to several years can now be realized. Timely data access via surface and subsurface data telemetry system provide data in real-time.

Considering differences in technology and design, two types of telemetry systems may be differentiated: Firstly, systems that are permanently at the surface or are connected by cable to land and thus can provide data in a quasi-real-time stream, and secondly, systems that collect sensor data and samples and store them. In some instances, a subsurface module can release data messengers to be read-out by ships or other surface vehicles (waveglider, surfacing underwater glider). Surface telemetry systems allow rapid data access and as such are in use in the context of data assimilation system where analysis and predictions of “ocean weather“ is targeted (comprising periods from sub-hourly to several days; e.g. CMEMS products, El Nino state analysis and forecast) or geo-hazard warning systems (e.g. DART “Deep-ocean Assessment and Reporting of Tsunamis” buoys, Meinig et al. 2001). A typical surface telemetry system requires a buoy that stays permanently at the ocean surface and transmits data to shore at defined time intervals. A comparably wide spectrum of commercially available surface telemetry system exists (e.g. Fugro, SeaBird, Develogic).

However, a surface buoy on top of a conventional subsurface mooring not only adds substantial costs but also increases stress, wear-and-tear and exposure to fishing activity and ice drift. Moreover, various mooring installations target observing of the deep ocean and an extension to the surface is not envisioned. If no surface buoy can be installed but still a need for data retrieval exists subsurface telemetry systems are required. Typically these systems feature a subsurface data collection and storage unit to be accessed via underwater acoustic communication between the unit and a ship or other suitable platform (glider, waveglider), or via data messenger buoys (also called “pop-up” buoys) that rise to the ocean surface and commence data transmission to shore via satellite. Subsurface data telemetry systems have been sparsely used, mostly in bottom lander installations.

The most frequently used subsurface data telemetry system is implemented in the PIES (Pressure Inverted Echo Sounders, Howden et al. 1994, Watts and Rossby, 1977). The system uses low bandwidth underwater acoustics to read out data at occasional ship visits at the location. The “Multi Year Return Tide Level Equipment” (MYRTLE; Spencer and Foden 1996, Spencer and Vassie 1997) is a system that uses autonomous messenger buoys, rather than ships, to transmit data about bottom pressure. Since the scientific mission of these instruments requires least possible movement during deployment the bottom pressure recorders telemetry systems are exclusively designed for a stable seafloor installation (“lander installation”). A system that was specifically designed for integration into a mooring line (away from the seafloor), is the “Data Capsule Magazine” (DCM) developed during the ULTRAMOOR project (Fyre et al. 2002, 2004). The ULTRAMOOR project started in 2000 with the purpose of designing and testing mooring infrastructures capable of deployment periods up to 5 years. The DCM consists of an acoustic receiver, which collects data from moored instruments that in turn are equipped with single acoustic transmitters. A module in the receiver unit uploads the data into expandable data capsules (original design was up to 10), each holding up to 4Mbyte of data. The capsules are released at pre-defined time intervals via burnwire release (Fyre et al. 2002, 2004).

In addition, a small number of eulerian observatories are connect to land by cable. These are extremely costly but do provide the capability of unlimited power and data transmission and furthermore the data can be transmitted in real time, an essential feature for tsunami warning.

OceanSITES Structure

In OceanSITES, the observatories are classified in a similar way as has been done in AtlantOS: TMA, Air/Sea Flux and Multidisciplinary (including BGC).

Transport Moored Arrays TMA

The transport-moored arrays (TMA) are moored installations that are optimized for the observation of ocean currents and the properties of ocean water masses. The TMAs are used to estimate volume and property transports as their primary ocean observing “product”. These time series serve multiple purposes. The sampling is undertaken with a resolution that enables isolating characteristic time scales of drivers of any observed variability, and may cover sub-diurnal to multidecadal.

The OceanSITES sites that contribute to TMA are in many cases arrays of moorings installed in regions where the flow is mostly under topographic control. The major exchange gateways between ocean regions include flows through shallow (e.g. Denmark Strait, Bering Strait) as well as deep straits and channels (e.g. Vema Channel, Gibbs Fracture Zone, Owen Fracture Zone).
Another group of TMA sites record western and eastern boundary current flow and properties (e.g. the East Australia Current, California Current) again topography is to be considered in order to ensure a sufficient spatial sampling of the signals.
Another group of TMAs are arrays that make use of a geostrophic end-point array approach (RAPID-MOCHA; OSNAP; SAMBA).
For many of the TMAs the instrumentation covers the full depth such that data in the lower part of the water column can support programmes such as the Deep Ocean Observing Strategy (DOOS).

Air/Sea Flux

The air/sea flux reference sites are located in areas where particular ocean/atmospheric and as such atmospheric boundary layer conditions exists, such as the cold tongue /warm pool regions or the Stratus Deck regions. The sites provide the means to identify errors and biases in gridded surface fields in numerical weather prediction models, remote sensing, and climatologies. Further, these sites provide anchors for the generation of new, improved, hybrid and blended air-sea flux fields. These site also include observations in areas were air/sea gas exchange processes (e.g. oxygen, pCO_2) are in the focus (e.g. deep convection areas).

The notion of using ships at fixed sites to collect weather data was put forward in support of shipping and of cross-ocean aircraft routes in the first half of the 20th century. During World War II and in the 1950s, additional oceanographic observations, including T and S profiles and bottle sampling, began at some weather ships. The existence of coincident, frequently sampled, time series of surface forcing and upper ocean temperature and salinity structure from the OWS became the foundation for the development of one-dimensional ocean models (e.g. Denman, 1973; Denman and Miyake, 1973). Surface moorings provide the capability of obtaining time series spanning the surface forcing to the variability of the upper ocean, and the 1970s saw development of more capable surface moorings to support investigation of air-sea interaction and upper ocean dynamics. The Mixed Layer Dynamics Experiment (MILE) conducted in the Gulf of Alaska near OWS Papa fielded two surface moorings (Davis et al., 1981a, b).

Since these early deployments, surface moorings matured as platforms to collect the meteorological observations to compute the air-sea fluxes via the bulk formulae. WOCE (WCRP, 1986) set target accuracy goals: 20% for wind stress and 0.5 to 0.8 m s-1 for wind in up to 10 m s-1, with accuracy in wind speed to obtain sensible and latent heat fluxes to 10 – 15 W m-2. Surface heat fluxes accurate to within 10% of the monthly mean were sought. The goals set by WOCE were initially difficult to achieve. National Science Foundation funding under WOCE and TOGA led to improved surface-buoy meteorological and air-sea flux observational capabilities during field campaigns through the 1980s and 1990s. Incoming longwave radiation sensors were fielded in in the mid-1990s, replacing parameterizations of longwave radiation based on air and sea-surface temperature and cloud cover and in situ precipitation observations became more common in the mid-1990s.

Multidisciplinary Time series

The Multidisciplinary Global Ocean Watch sites are located in areas where local ocean Physics, Biogeochemistry and Ecology time series are expected to represent the temporal evolution of a wider area and with consequences that further propagate into the ocean interior. Typically, these sites are in the representative locations of oceanic gyres or biogeographic provinces or where specific forcing is expected, such as deep convection regions. The sites are typically of multidisciplinary nature, covering biogeochemical, physical, and biological/ecosystem variables.

Biogeochemistry and Ecology is a very large mandate. The task team outlined several major themes as follows:
1. Quantifying ocean CO_2 air-sea fluxes – especially the role of high frequency processes in particular hotspots of CO_2 transfer from the atmosphere to the ocean, and the development of optimal validation and projection methodologies for ongoing ocean uptake assessment.

2. Ocean acidification – especially determining decadal trends in pH and carbonate saturation state, relative to seasonal and diel variations, and secondarily exploration of biological response variables. Notably, seasonal resolution is required to avoid aliasing.

Initial assessment is that important sites include those changing rapidly or in response to specific mechanisms, with emphasis on offshore sites that can inform interpretation of existing or planned coastal OA monitoring effort, such as:
Arctic – rapid meltwater dilution of alkalinity accompanied by unknown biological responses
Antarctic – large region poised close to aragonite undersaturation with changing overturning circulation
Tropical Pacific and Atlantic regions - adjacent to coral reef regions

3. Changing ocean productivity, including role of ecosystem structure. Decadal change is the focus, with seasonal and diel resolution required to understand causes and dynamics of change.

<u>Progress achieved during AtlantOS</u>
Substantial progress in the advancement of OceanSITES has taken place over the past few years, to which AtlantOS has contributed alongside national, European and international endeavours. Several of these achievements and contributions are reported in detail in other AtlantOS reports and are not repeated here, most notably: Best Practice developments (Deliverables D6.4 and D6.7) and Enhancement of autonomous observing networks (Deliverable D3.17))

In addition to these contributions, numerous low-level discussions culminated in two workshops held under AtlantOS auspices to address this deliverable (D3.8). These were at:

1. Oregon Convention Center, Portland, USA 14th Feb. 2018: During the Ocean Sciences conference.

2. GEOMAR, Kiel, Germany, 5th July 2018: During the 12th international OceanSITES meeting (2nd to 6th July 2018).

The Oregon workshop included representation of Ocean Networks Canada (Professor Douglas Wallace) and EMSO ERIC (Professor Juan Jose Dañobeitia, Director General) while the Kiel workshop included a wide range of representatives from across the world covering all aspects of eulerian observatories.

Below, the outcomes of these workshops and associated discussions are be summarised under 8 headings, noting advancements and challenges in furthering biogeochemical observation in the Atlantic through OceanSITES:

1. <u>Enhancing capacities to monitor the GOOS EOVs: sensors, samplers and locations.</u>
   GOOS and its contributing partners are working to extend measurement of the Essential Ocean Variables (EOVs) at a planet-wide scale. To do so, basin-scale coverage and multi-national coordination is essential, but already presents significant challenges. During the AtlantOS meetings and discussions, it was recognised that if the BGC Eulerian network in the Atlantic is to approach a satisfactory assessment of the temporal and spatial trends of Biogeochemical EOVs, significant additional funding – itself coordinated in vision and expressly focused on aligning existing programmes around EOV reporting – is required from nation states. To provide sufficient coverage of the Atlantic basin, it was agreed that additional sensors and samplers are needed at existing locations and new observatory locations are necessary. As can be seen in the chart below, individual observatories reporting on pH provide data which can be considered as representative of only a limited area of the Atlantic ocean, and connectivity between their spatial ranges is not comprehensive.

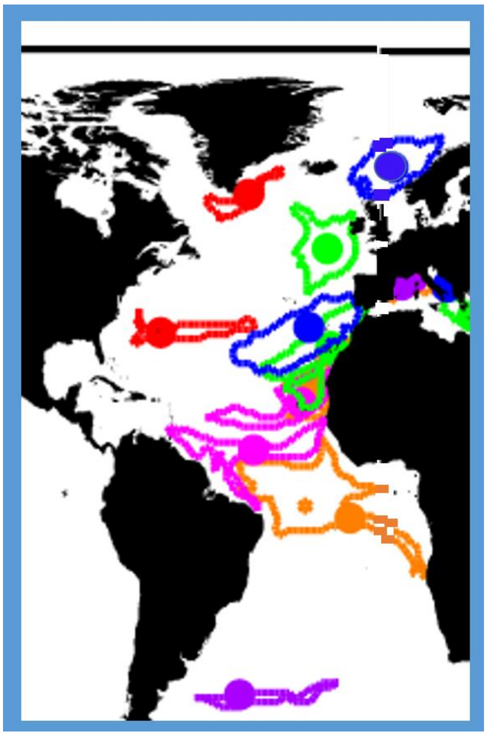

Figure 6 - Spatial footprint chart for pH for Atlantic eulerian observatories (Modified from Henson et al 2016)

However, it was consistently noted that simply adding more stations without a guiding framework developed through consultation with the relevant GOOS EOV Panels could easily impede, rather than promote, basin-scale to global coordination while quickly consuming resources. Indeed, before definitive statements are possible about the level of enhancement required, the level of acceptable uncertainty in each of the BGC EOVs must first be established in their specification sheets. This is not a trivial task and is likely to require periodic revision and refinement over the next decade as data and expertise from observing networks refines initial estimates. Building on the increased coordination between networks achieved through AtlantOS, such coordinated pilot studies increasing sampling density and coverage are now more feasible. The project has thus laid the foundation for more objective and principled assessments of Atlantic observing systems for EOV-specific fitness-for-purpose. This is a prerequisite to meaningfully estimate the level of investment required to ensure a coordinated Atlantic Observing System that meets the emerging requirements of GOOS, in preparation for the UN Decade of Ocean Science for Sustainable Development. Naturally, a mechanism to systematically process any data from pilot studies is needed to provide guidance on system design. To this end, AtlantOS has furnished prototype Observing System Simulated Experiments (OSSEs; D5.4) to pair requirements and capacities. However, at the time of writing this report these OSSEs are not yet actionable,

2. Development of data management and access capability.
   There are several levels of data management required so that BGC data of known precision and with appropriate metadata can be made available to end users. During the FixO^3 programme (2013-2017), the *EarthVO* system was developed so that users could access, visualise, compare and extract data from diverse European open ocean observatories. http://earthvo.fixo3.eu/ This system, that was developed by Blue Lobster IT Limited was restricted to the life time of FixO3.. Hence, although data are still available from national data centres, there is no current means to interrogate all data centres and merge data as required by users. While *EarthVO* was discontinued it may still serve as a basis for future developments of data dissemination capacities, e.g., under the umbrella of EMSO, EMODNET, or JCOMM OPS. Staff at JCOMM OPS have instigated a system to catalogue data and this will, in due course, enable users to be directed to appropriate data bases but at the time of writing this report, very few of the available data sets are in the JCOMM OPS catalogue. EMSO has, in February 2019 appointed an IT manager to develop a system to access data and generate data products and in due course a system similar to, or better than, what was available in 2017 under FixO^3 will be available to users.

3. Establishment of a strategy for recommendation of "best practice".
   The FixO^3 programme consulted a large number of individuals with expertise in all aspects of eulerian observation and created a manual of best practice http://www.fixo3.eu/download/Handbook%20of%20best%20practices.pdf . This was intended to be a "living document" reflecting and synthesising the views of experts in the various aspects of eulerian observation. It was intended that, as new ideas and technology emerge, the document would be modified accordingly and a new consensus view would be published, possibly on an annual basis. This report has been adopted and expanded by AtlantOS to very good effect (Tasks 6.2, 6.4 and 10.2) and it is expected that this will be a durable system to promote the consensus of the best ways of carrying out eulerian observations. This provides a clear path for crucial issues such as version control, user management, cross-indexing, and metadata annotation using some of the same terminologies FAIR metadata (SeaVox, NERC VS)

4. Integration of TMA, PIRATA and OceanSITES BGC networks
OceanSITES has established its role in coordinating multiple aspects related to the technologies (community, data, instruments, backbone infrastructure) that are used for long-term Eulerian observations. Three categories of observatories may be defined from the perspective of their scientific/observing mission: Transport moored arrays (TMA), Air/Sea flux reference sites, and Multidisciplinary or Global Ocean Watch sites. It has to be emphasized that the categories are defined based on the science mission and, as such, a site can serve one, two or even all categories. For the purpose of the AtlantOS project, OceanSITES was supported via three activities in three different tasks: OceanSITES biogeochemistry (task 3.2), OceanSITES TMA (task 3.3), and PIRATA (task 3.5). This "artificial" separation was done to enable a targeted enhancement of specific aspects of OceanSITES.

PIRATA (task 3.5) assumes a special role in this configuration because, from a JCOMMOPA perspective, it contributes to two observing networks: (1) the Data Buoy Cooperation panel (DBCP) that coordinates all aspects around the real-time met/ocean data used for Numerical Weather Prediction (NWP), and (2) OceanSITES which coordinates long-term open ocean time series efforts. DBCP is not represented explicitly in AtlantOS, however also features in task 3.6 (Surface drifter) as a contribution to real-time met/ocean data transmission for NWP efforts.

As with data management, the OceanSITES network provides clear, simple and unified means for managing and presenting the science communities represented in the three tasks of AtlantOS. Common infrastructure, data management and observing technology are brought together in an integrated manner such as the development of agreed data formats. Even so the communities may have separated into three different tasks in AtlantOS they are jointly coordinated under the OceanSITES umbrella.
It is obvious that a separation is not an advantage because as distinct entities, they will continue to behave as such and the full potential of the vast infrastructure array will not be realised.

As a result of AtlantOS activities, several instances of multi-disciplinary coordination have resulted in the deployment of sensors and samples in previously mono-disciplinary observatories, a trend which will hopefully accelerate. Of course, this is contingent on additional funding to allow sensors and samplers to be purchased and maintained, additional ship time secured to deploy more complex moorings and the provisioning of more berth space to accommodate more diverse expertise on board. This is not a trivial undertaking.

5. Implementation of BGC capability at other sites (TMA and PIRATA)
As a result of AtlantOS support and developments of national commitments, there has been considerable progress incorporating BGC sensors on TMA and PIRATA arrays. Whereas previously these arrays provided data collected during cruises to service the moorings (Stramma et al 2008), BGC sensors and samplers are now being incorporated in different basins (Leung et al submitted) including in the Atlantic. Examples are the oxygen sensors and Remote Access Sampler (McLane Research Laboratories, Inc.) that have been added to some components of the TMA arrays and the intention is for this to be done in PIRATA (Deliverable D3.19). This reflects the significant appreciation by the community that there are massive benefits in using the infrastructure to address a variety of scientific objectives and societal needs. Over time it is expected that this trend will continue with major benefits to the user communities (eg Fishing communities, Maritime industry, Climate change scientists).

6. Capacity building in least developed countries to populate the South Atlantic.
As can be seen in the charts (above), there are large geographical gaps in the array particularly in the South

Atlantic. This is largely due to the fact that this region is bounded by Least Developed Countries (LDC), the criteria for which are: human assets, economic vulnerability and gross national income per capita. There is no doubt that the overall system of eulerian observatories would benefit from more sites in these areas to fill the gaps. Furthermore the capacity-building associated would have major benefits in terms of cooperation between countries with differing levels of development. Progress has been slow to enhance coverage in these areas but, as stated above under item 1, the objective analysis which will be done in due course to identify needs will provide a fundamental and substantial basis on which to promoted this collaboration in a vigorous and well defined manner.

7. Development of capacity to address and complement emerging BGC variables
As stated above, the EOVs currently identified are those which are feasible and have high impact. Several other EOVs, from other thematic foci of GOOS, are considered to be of great importance in BGC observation but are not currently feasible for prolonged autonomous operation on eulerian observatories. Notable progress has been made in Task 3.2 to develop ways to address these variables, including direct participation in the relevant GOOS Biology and Ecosystems Panel (via the leadership of the Microbial EOV)These are reported in Deliverable D3.17 with success in linking actions of the AtlantOS-supported the Global Omics Observatory Network (GLOMICON; www.glomicon.org) to GOOS drives to integrate global efforts. These efforts have built upon previous insights on the need to integrate disciplines around ocean observing infrastructures (Buttigieg et al 2018). Several other successes are reported in D3.17 some of which, such as the quest for a sensor for total alkalinity are of major oceanographic importance. In addition to the development of sensors and samplers, the continuation of new platform development has also been a significant achievement with a profiling float providing an important component in the armoury of Eulerian platforms (Fieldler et al 2013). Somewhat less success was achieved in developing a time-series zooplankton sampler. During the AtlantOS programme, the commercially available ZPS (McLane Research Laboratories, Inc.) was found to have fundamental technical problems. The concept of a solution was found by NOC scientists and engineers and a NDA was signed with the company to design the hardware but additional funding could not be found to implement these developments.
During 2018, there was significant optimism that there would be funding to develop emerging variables under the G7 'Augmented Observatories' initiative. Several members of Task 3.2 were heavily involved in this development although progress has been slower than expected. This should, in due course, lead to some significant development.

8. Preparation of Canada-EMSO-Eric MoU to strengthen cross-Atlantic integration
This is another area in which Task 3.2 has made a significant contribution although it cannot take the majority of the credit. After a series of discussions and face to face meetings with key individuals, an MOU between EMSO ERIC and Canada has been signed (see appendix). This will formalise interactions between Europe and Canada and enhance collaboration in this important field.

Planning of a future Eulerian array

It is essential that systematic, cross-validated, and reproducible processes can be employed to support the planning of the Atlantic Eulerian observatory array. Through these, the impact of altering the array's magnitude, density, systemic resilience, and other core design features can be tested to scope how varied operational scenarios (and their costs) will align with scientific and societal needs. This design must factor in the variables to be measured, the accuracy of such measurements, their temporal resolution and the spatial coverage and resolution of the array. During AtlantOS, the development of OSSEs aimed to provide part of this ability to make appropriate decisions although further work is required. It is vital to pursue such approaches and integrate them with statistical and expert-led planning processes to create robust planning capacities for basin-scale observation. When combined with appropriate political developments, and alignment of national funding agencies, an effective eulerian array is an objective which is well within the grasp of the Atlantic community.

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Appendix I

Memorandum of Understanding (MOU)

Between

Ocean Networks Canada Society
University of Victoria,
2300 McKenzie Avenue,
Victoria, British Columbia
Canada

And

European Multidisciplinary Seafloor and water-column Observatory
European Research Infrastructure Consortium,
Via di Vigna Murata, 605, 00143 Rome (Italy)

Concerning

Collaborative Agreement

Ocean Networks Canada and the European Multidisciplinary Seafloor and water-column Observatory European Research Infrastructure Consortium are individually referred to as a "Party" and together referred to as the "Parties".

WHEREAS the Ocean Networks Canada Society ("ONC") is a not-for-profit society owned by the University of Victoria ("UVic") with the responsibility for the management, development, promotion, and commercialization of UVic's research assets, the VENUS and NEPTUNE observatories of ONC. Ocean Networks Canada enhances life on earth by providing knowledge and leadership that deliver solutions for science, society and industry;

AND WHEREAS the European Multidisciplinary Seafloor and water-column Observatory European Research Infrastructure Consortium ("EMSO*ERIC") EMSO-ERIC aims to further explore the oceans, to gain a better understanding of phenomena happening within and below them, and to elucidate the critical role that these phenomena play in the broader Earth systems. EMSO is a system of observatories distributed in the European seas that provide key data and constant monitoring of marine environments. Eleven key areas have been selected across the Arctic Ocean, the Atlantic Ocean, the Mediterranean Sea and the Black Sea where facilities are located to screen and study environmental processes. EMSO offers data and services to a large and diverse group of users, going from scientists and industries to institutions and policy makers. It is an extraordinary instrument to provide relevant information for the design of environmental policies based on scientific data. After a preparatory phase financed by the European

Commission and coordinated by Italy, the EMSO research consortium was established in September 2016. EMSO is now a European research infrastructure consortium (ERIC);

AND WHEREAS ONC and EMSO-ERIC recognize the importance of research and technology development to understand Earth system processes and to stimulate economic growth;

AND WHEREAS ONC and EMSO-ERIC recognize the acute need for a knowledge base in ocean systems that can inform actions to improve ocean environments and develop new ocean technologies;

AND WHEREAS ONC and EMSO-ERIC desire to build on the groundbreaking achievements of ocean observing systems, and to develop substantive cooperation with other earth and ocean sciences and technology programs and initiatives in the European Union and Canada;

AND WHEREAS ONC and EMSO-ERIC recognize that the desire to cooperate exists in ocean science, technology and innovation (including next generation sensor technology, autonomous vehicles, deep ocean and coastal observing systems, and data management technologies);

NOW THEREFORE the Parties agree as follows:

1. INTENT OF THE PARTIES.

1.1, The Parties agree that activities undertaken jointly pursuant to this MOU are to be implemented on the basis of equality, reciprocity and mutual benefit of the Parties. Financial contributions to support related planning and development activities will be determined by each Party in accordance with the availability of funds.

1.2. The Parties agree to cooperate in the subject areas identified in Annex A.

1.3. The parties will establish a Joint Monitoring Committee (JMC) within 3 (three) months following the signature of this MOU, for the implementation, control, monitoring, evaluation and communication of the envisaged actions of this MOU and other actions resulting from it.

1.3.1. Specifically, the JMC is responsible for the following tasks:

1.3.1.1. Develop an action plan and identify specific research or technology development areas for collaboration.

1.3.1.2. Propose and execute opportunities for collaboration through specific separate agreements.

1.3.1.3. Monitoring all activities and resolving any query that may arise from the interpretation and execution of this MOU.

1.3.2. The JMC shall consist of 4 (four) members, 2 (two) from each Party, who will be selected by the respective entity, acting to coordinate for activities under this Agreement. One member of the Committee will be selected as the Chair and the position will alternate between the Parties annually after the signing of the Agreement.

1.3.3. The members of the JMC will be designated within the first month following the signing of this MOU. The JMC will hold an ordinary meeting once a year and an extraordinary meeting as many times as it is deemed appropriate, at the request of any of the parties. Meetings can take place either in person or via teleconference.

of

2. INTELLECTUAL PROPERTY (IP) OWNERSHIP.

The Parties acknowledge and agree that IP developed by either Party or arising from projects undertaken by either party may be subject to terms and conditions derived from funding regulations or contracts applicable to such research projects or activities. The Parties, therefore, agree that the following provisions shall be subject to the terms and conditions resulting from said contracts or regulations that may be applicable to each specific research project or activity.

2.1. The Parties acknowledge and agree that IP developed by ONC will be owned by ONC and treated in accordance with the University of Victoria policies.

2.2. The Parties acknowledge and agree that IP developed by EMSO-ERIC will be owned by EMSOERIC and treated in accordance with EMSO-ERIC policies.

2.3. The Parties agree that, unless otherwise stated in mutual written agreements regarding specific cooperative R&D initiatives under this MOU, IP generated jointly by both parties shall be jointly owned. Joint owners shall agree in writing on the allocation and terms of exercise of their joint-ownership as well as on possible protection measures of such IP assets.

3. CONFIDENTIALITY.

The Parties agree that they are responsible for maintaining confidentiality of any information provided by the other Party that is designated in writing as confidential, provided that this obligation will not apply to (a) information which is publicly available (through no act of the Party receiving such information) at the time of disclosure; (b) information which is disclosed to a Party by a third party which did not disclose it in violation of a duty of confidentiality; (c) information which was known to the Party receiving such information before such information was provided to them or their representatives by or on behalf of the Party disclosing such information; (d) information which was developed by an employee, agent or contractor of a Party independent of (and without any knowledge of) any disclosure to such Party or any of or its representatives by or on behalf of the Party disclosing such information; or (e) disclosures which are required to be made by a Party under legal process by subpoena or other court order or other applicable laws or regulations (provided that such Party makes reasonable efforts to provide copies of such information to or informs the other Party before or at the time of disclosure or as soon as possible thereafter).

4. AGREEMENT ADMINISTRATION.

4.1. Neither Party shall issue any press release or other public announcement related to this MOU, written or oral, without the prior written consent of the other party, which consent shall not be unreasonably withheld, conditioned, or delayed.

4.2. Nothing in this MOU shall be construed as creating any legal relationship between the Parties and the Parties agree that this MOU is not enforceable in law or equity, except for the provisions of articles 2 and 3.

4.3. No financial or resource obligations are implied by this MOU. Specific activities that may be mutually agreeable, that may require a proposal to a third party, or funds and/or resources from one of the Parties will be considered on its own merits. Each such activity would require a separate agreement.

4.4. Cooperation between the Parties under this MOU is subject to the availability of funds and is subject to the limitations of applicable laws of the province of British Columbia and the European Union.

4.5. This MOU will be in effect for five years after the signing date. The term of the MOU may be extended upon mutual agreement by the Parties.

4.6. This MOU may be terminated at any time by either Party upon 90 days written notice to the other Party.

4.7. Upon termination or expiration of the cooperation under this MOU, the Parties will (mutually) agree on ways and means to assure orderly completion of any project or program initiated under this Memorandum, but not yet completed, in accordance with the terms of the agreement governing such project or program.

4.8. This MOU may be amended with the written consent of both Parties.

4.9. Notifications and communications regarding this MOU shall be made with the designated contact persons indicated (or their successors):

For ONC:

Scott McLean
Director, Ocean Networks Canada Innovation Centre
University of Victoria
TEF160 - 2300 McKenzie Ave., PO Box STN CSC, Victoria, BC v8w 2Y2, Canada Phone: +1.250.853.3961 Email: sdmclean@uvic.ca

For EMSO-ERIC:

John Picard
Director, International Strategy
European Multidisciplinary Seafloor and water column Observatory
European Research Infrastructure Consortium
Via di Vigna Murata 605
00143 Rome, Italy
Phone: +39 06 51860339 Email: j.picard@emso-eu.org

On behalf of:

Ocean Networks Canada Society

Signature: ______________________

Name (print): Dr. Kate Moran

Title: President and CEO, Ocean Networks Canada

Date. 2018-05-07

On behalf of:

Of

European Multidisciplinary Seafloor and water-column Observatory European Research Infrastructure

Signature:

nfrastructure Consortium

nt): Dr. Juanjo Dañobeitia

Name (print): Dr. Juanjo Dañobeitia

Title: Director General EMSO-ERIC

Date: 2018-05-07

Annex A — Areas of Mutual Cooperation
Version A Dated: 2018-05-07

The Joint Monitoring Committee OMC) will be responsible for managing Annex A, including updating and prioritizing areas of mutual cooperation.

Areas of mutual cooperation between the Parties include:

- Data management (including data acquisition, visualization, products, quality, interoperability, search, distribution, ownership, and multi-source integration)
- Best practices (including infrastructure maintenance, operations, calibration, data management, environmental and ethics)
- Communications (including website design, and presentation of core services)
- Innovation readiness (including industry partnerships and technology development)
- Citizen science
- Personnel exchange (including joint workshops, technical and scientific training)
- Observatory governance
- Modelling
- Polar ocean observing
- Technology areas related to:
  - Tsunami detection
  - Autonomous underwater vehicles and docking stations
  - Next generation sensor technologies
  - Ocean observation infrastructure technologies
  - Underwater acoustics