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REVIEW OF REQUIREMENTS OF CURRENT AND PLANNED DEEP WATER OBSERVATORIES, DEEP WATER MOORINGS AND DEEP-WATER RESEARCH CURRENTLY AND BASED ON FUTURE REQUIREMENTS

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1 Introduction and background

Modern-day oceanographic research aims to provide society and policy makers with a vision of the ocean as a system, based on the processes that take place and that connect the oceans with other parts of the Earth, the atmosphere and the continents. Such a system-wide approach requires observations over very large scales, both in terms of space and time, which has led to an increasing interest in the development of observational systems that can handle such time scales, for example permanent observatories in coastal areas and key ocean basins. Such installations and the instruments attached to them need permanent care and maintenance, which, in turn, requires the availability of the proper tools to carry out this maintenance. In addition, the amount of data produced by the instrumentation requires special tools to process and transfer these data streams. Here, we give an overview of the requirements for the deep-water observatories, European and non-European. We will give a general description of the observatories, with technical details about instrumentation and weight and size of the components and with requirements for the vessels used to maintain and service the observatories. Finally, we will summarise the plans for further developments, both on a 1-3-year time scale and on 5+ year time scales.

The earliest observations of the ocean were made from ships, starting with ships of opportunity from the sailing tradesmen and pirates of the ancient world to the purpose-built research vessels of the 20th century. In those early days, measurements were mainly made of the surface ocean, using buckets, shallow nets and simple observational instruments such as Secchi disks. Exploration of the deeper parts of the ocean required vessels with additional capabilities, longer cables and instruments that could withstand the high pressures at greater water depths.

Historically, the observations of the deep ocean were point observations, with limited resolution in time and space. During research cruises the water column and the seabed were sampled, samples were analysed on-board or at home in the laboratory and results were extrapolated to larger areas, sometimes even to entire ocean basins. Time resolution could be realised by repeating measurements over multiple years, during annual expeditions to the same area, for example the WOCE sections and the Ellett line CTD transect in the North Atlantic. Spatial resolution could be achieved by sampling an area in detail, but this is only feasible for limited areas This approach, however, requires availability of ships to carry out the research cruises. Moored instrumentation is a better way to increase time resolution, because instruments such as current meters and moored profilers can provide continuous information about the physical properties of the water column over periods of up to 2 years or sometimes even longer. Other instruments such as sediment traps provide information about particle fluxes to the seafloor, thereby connecting the processes in the surface ocean to the sediment record.

Even though this approach greatly improved time resolution, spatial resolution over larger areas was still lacking in the observations. Some attempts were made with seabed crawlers, but this again is hardly feasible for large scale exploration. To combine temporal and special resolution, more or less permanent observatories, consisting of a number of mooring lines containing different sets of instruments and sensors and spaced out over an area of interest have been installed in the last 2 decades, in various parts of the ocean. Such moorings, however, still need annual or bi-annual servicing which in turn requires a vessel. For closer-to-shore sites, connecting the observatories to shore stations via cables could provide an option to limit the need for expensive vessel time while at the same time enabling transport of large volumes of data.

Recently, the development of autonomous and semi-autonomous instrumentation, gliders, AUVs (Autonomous Underwater Vehicles), ASVs (Autonomous Surface Vehicles) and ROV’s (Remotely Operated Vehicles) has resulted in a new dimension in oceanographic observations. Gliders and AUVs can be programmed and explore parts of the ocean autonomously, requiring a vessel only for deployment and recovery. ROVs are not autonomous because they are connected to and piloted from a vessel, however, this makes it possible to adjust the mission planning, when necessary, while the mission is underway.

The most advanced visions of future observations of the deep ocean combine all tools available to today’s researcher: multiple moorings, preferably coupled to nodes via cables and with surface buoys to enable near real-time data transfer to shore and with AUVs and gliders moving between the nodes. In such a system, platforms and sensors systems measure physical, chemical, geological and biological properties and processes from the seafloor to the air-sea interface.

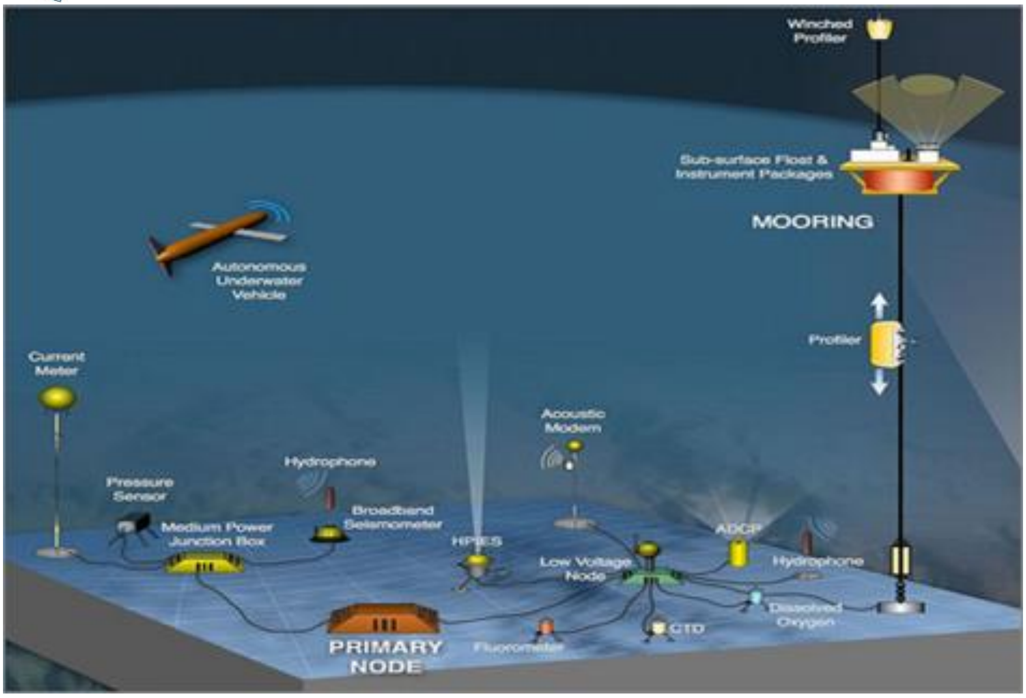

Figure 1: Schematic overview of a cabled deep-sea observatory

2 Main Objectives

A wide range of surface buoys, moorings and mooring arrays are currently operational, both in coastal areas and in the deep ocean, in and outside Europe. In the sections below, an overview will be given of current initiatives and of the requirements to extend and maintain these initiatives in future years.

2.1 Overview of existing European arrays and initiatives

In Europe, several organisations and projects such as EMSO ERIC, EOOS and FixO3 have been or are currently coordinating European Ocean Observation Initiatives.

The most prominent example is EMSO ERIC. **EMSO** (the European Multidisciplinary Seafloor and water column Observatory) is a consortium of partners sharing in a common strategic framework a set of regional facilities, operated and supported by different European nations and placed at key sites around Europe. EMSO includes 8 regional observatories (large dots) and 3 test sites (small dots). More information on the EMSO observatories is available on the EMSO website {www.emso.eu).

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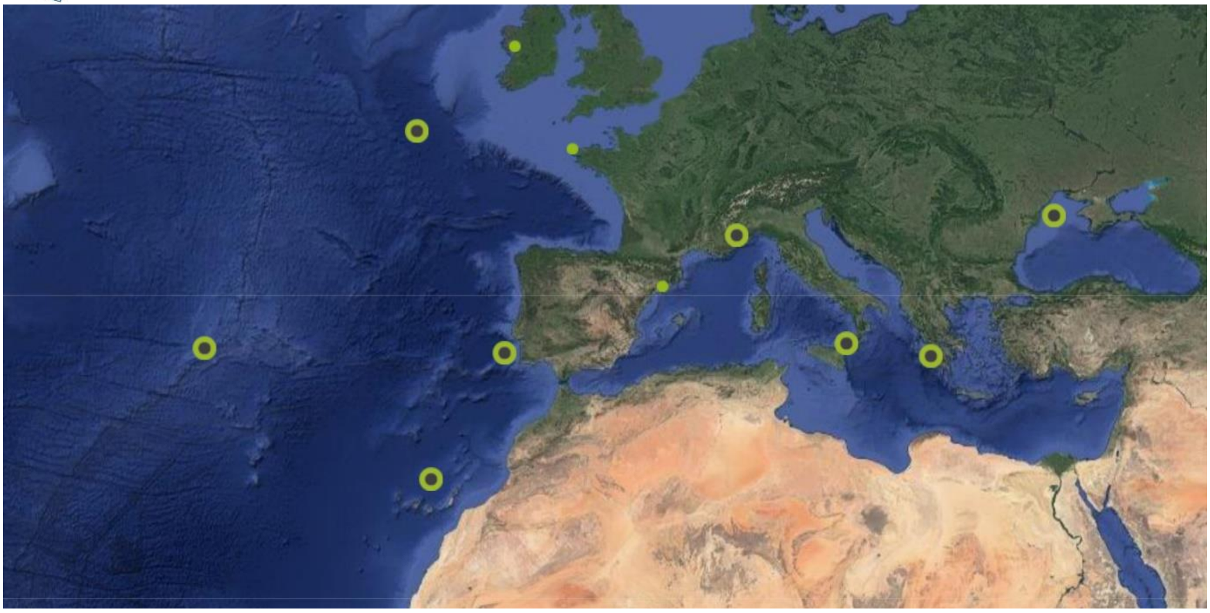

Figure 2: EMSO observatories and test sites (from: www.emso.eu)

EMSO ERIC	Coordination platform			
EMSO Observatory	*Supporting country*	*Water depth*	*Deployed since*	*Cabled?*
Azores	France	1700	2010	no
Black Sea	Romania	95	2013	no
Canaries	Spain	3630	1994	no
Hellenic Arc	Greece	1700	2007	yes
Ligurian Sea:	France			
Western Ligurian		2400	2007	Yes
E. Ligurian, Nice		35	2015	yes
E. Ligurian, Dyfamed		2300	1998	no
Porcupine Abyssal Plain PAP)	UK	4850	2002	no
Western Ionian	Italy	2100	2001	yes
Iberian Margin	Portugal	200/3000	July 2020 (planned)	

Table 1: EMSO observatories

The technical details and vessel requirements for the EMSO observatories will discussed in more detail in chapter 2.3.

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EOOS (the European Ocean Observing System) is a coordinating framework designed to align and integrate Europe’s ocean observing capacity, resulting in a systematic and collaborative approach to collecting information on the state and variability of the oceans and seas in order to promote sustainable management of the marine environment and its resources. EOOS is the European component of GOOS, the Global Ocean Observing System. GOOS was created in 1991 by the IOC, the Intergovernmental Oceanographic Commission, in response to calls from the 2nd World Climate Conference in Geneva, 1990. Both GOOS and EOOS do not actively coordinate research activities, but GOOS has succeeded in coordinating a collaborative system of sustained observations unified by GOOS principles. With its unique status within the UN system, GOOS is able to marshal the resources of the UNESCO/ IOC Member States to build a network around independently-managed and independently-funded observing elements (satellites, buoys, ARGO floats, science cruises (a.o.Go-ship). Networked Observations are coordinated by JCOMM, the Joint Technical Commission for Oceanography and Marine Meteorology, which provides a mechanism for international coordination of oceanographic and marine meteorological observing, data management and services.

FixO3 , the fixed point open ocean observatory network project was an international FP7 funded project that ran from 2013 – 2017 and aimed at integrating in a single network all fixed point open ocean observatories operated by European organisations, to harmonise operational procedures and coordinate technological, procedural and data management across the stations. After the project finished, some of the project achievements were migrated into EMSO, thereby conserving the project legacy. Some of the observatories that were part of FixO3, such as PAP, Hellenic Arc, Western Ionian and Dyfamed have also been integrated into EMSO.

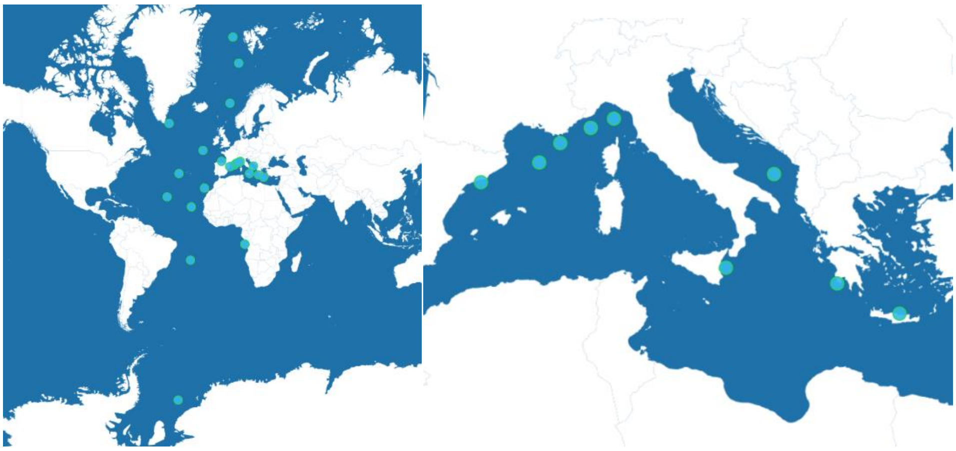

Figure 3: Observatories integrated in FixO3 (From: www.fixo3.eu)

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2.2 Overview of existing non-European arrays and initiatives

Most of the countries outside Europe that have been important contributors to oceanographic research such as the USA, Canada, Australia and Japan, have developed observatories, in most cases to monitor the oceans and seas around their countries. The most striking example is the OOI, the Ocean Observatories Initiative.

OOI is an NSF funded initiative combining coastal and global components (Figure 4). OOI operates arrays on the US West and East coasts, including an offshore array at Axial Seamount off the Oregon Coast. The global component of the OOI design includes a network of moorings at critical, yet under-sampled, high-latitude locations such as Station Papa in the North Pacific, the Irminger Sea in the North Atlantic, the Southern Ocean array and the now discontinued array in the Argentine Basin.

Table 2 gives an overview of the arrays deployed in OOI.

Figure 4: The Ocean Observatories Initiative arrays (From: www.oceanobservatories.com)

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OOI arrays	Water depth	Ocean Basin	Cabled?	Science target
Axial Seamount	2600	NE Pacific	yes	Vulcanic observatory
Continental Margin	2900	NE Pacific	yes	Methane hydrates
Coastal Endurance	25-600	NE Pacific	yes	Coastal upwelling
Coastal Pioneer	90-450	NW Atlantic	no	current interaction
Global Irminger Sea	2800	NE Atlantic	no	Moored profilers
Global Southern Ocean	4800	SE Pacific	no	Moored profilers
Global Station PAPA	4200	N Pacific	no	Moored profilers
Global Argentine Basin	discontinued			

Table 2: overview of the arrays of the Ocean Observatories Initiative.

Other non-European observatories

The majority of the non-European observatories are operated in the Pacific Ocean. Countries with an extensive marine area such as Australia operate their own integrated system, IMOS, the Integrated Marine Observing System with 13 facilities operating arrays around the Australian continent. Furthermore, Australia operates an observatory in the Southern Ocean, the Southern Ocean Time Series Observatory. Other countries operate observatories to answer specific scientific questions, such as the Monitoring of Waves on Land and Seafloor (MOWLAS) network in Japan which covers both land and sea to monitor earthquake and tsunami hazards, the Canadian Salish Sea and Bay of Fundy observatories, looking at the impacts of oxygen concentrations on the ecosystem (Salish Sea) and tidal power generation (Bay of Fundy). Dedicated Coral Reef observatories are operational in Japan, near Okinawa Island and in Hawai'i. The Canadian observatory NEPTUNE is discussed in more detail below. The non-European observatories are summarised in table 3.

Observatory name	*country*	*Ocean basin*	*Cabled?*

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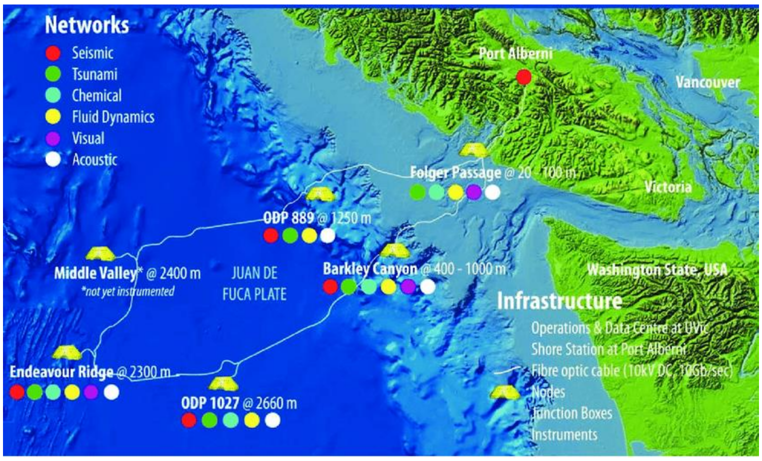
IMOS	Australia	Pacific/Indian	no
Southern Ocean Time Series Observatory	Australia	Southern Ocean	no
NEPTUNE	Canada	N Pacific	yes
Salish Sea	Canada	N Pacific	yes
Bay of Fundy	Canada	N. Atlantic	yes
Fixed Point Chiba	Japan	Tokyo Bay	no
OceanCube Coral Reef observatory Okinawa	Japan	Pacific	no
DONET observatory (MOWALS)	Japan	Coastal Pacific	yes
S-net (MOWALS)	Japan	Coastal Pacific	yes
Kilo Nalu Nearshore Reef Observatory	Hawai'i	Pacific	no
Station Aloha	USA	Pacific	yes
PacIOOS Pacific Islands Ocean Observing System	USA	Pacific	yes
Martha's Vineyard Coastal Observatory	USA	NE Atlantic	no
PLUTO Panama LJL Underwater Tropical Observatory	USA	Equatorial Pacific	no

Table 3: overview of other non-European observatories

Neptune Canada



NEPTUNE (North-East Pacific Time-series Underwater Networked Experiments) Canada, the world's first regional-scale cabled observatory network, is located off the west coast of Vancouver Island, British Columbia. The observatory is operated by Oceans Network Canada and extends across

Figure 5: the NEPTUNE observatory (from Barnes et al., 2011)

the Juan de Fuca plate, gathering live data from a rich constellation of instruments deployed in a broad spectrum of undersea environments.

NEPTUNE Canada is based around an 800-kilometer (500-mile) loop of fiber optic cable that lies on the seabed. Along the cable are six nodes that provide power and two-way communications to hundreds of instruments such as current meters, hydrophones, bottom pressure sensors, seismometers and plankton samplers. Each node is located in a unique area, allowing for a greater variety of studies. That database, containing both live and archived data, can be freely explored by anyone with Internet access. Key areas of research are underwater volcanic processes, ocean-atmosphere interactions, climate change and ocean productivity.

Maintenance takes place annually using a variety of vessels such as Canadian Coast Guard Research ships, US UNOLS vessels, Commercial cable ships or others, with vessel selection based on planned activities. Due to the nature of the facility flexibility is key and the support vessel is chosen based on the work to be carried out. Standardized platforms are used wherever possible to ensure that deck and ROV interface issues can be managed across different vessels.

2.3 Current and Future requirements for deep sea observatories

For a long-term sustainable and successful operation of ocean observatories, a long-term vision and a reliable, long-term funding stream is a necessity. Without a solid funding basis, significant technical innovation can never be achieved. In the US, the Ocean Observations Initiative, fully funded by NSF, is an excellent example of what can be achieved when coherent scientific goals of societal importance are supported by policy makers and sustained by long-term funding. Already -in 2006, the US National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology developed the Charting the Course for Ocean Science for the United States for the Next Decade: An Ocean Research Priorities Strategy (ORPP) document, which provides a framework for research investments to advance current understanding of critical ocean processes and interactions that facilitate responsible use of the ocean environment. The ORPP identifies three critical cross-cutting elements, one of which was *ocean observing* for research and management. Even though the goals were clearly defined and funding available, it took another 10 years before the OOI was finally commissioned.

The European research and infrastructure landscapes are much more divided than those in the US and despite the existence of coordinating platforms such as EMSO and EOOS and EU funded project such as FixO3, ocean observatories are national facilities that have to be supported by the national governments alone. Without large scale common funding on a European scale it will be difficult to align political and scientific interest in the different countries and define a European goal, to coordinate technical specifications and design. European funded initiatives such as the FP7 project

FixO3 made excellent progress to integrate existing European fixed-point observatories and enhance cooperation amongst the involved scientists, its impact remains limited beyond the lifetime of the project.

The establishment of EMSO ERIC is a significant step forward towards a true European infrastructure, however, a true European vision and strategy, similar to the strategy formulated in the US in the 2006, is needed to move forward. Platforms such as EMSO ERIC and EOOS are the main players to convince policy makers at the EU level that a long-term strategy in required. The 'Decade of the Oceans' and the ever-growing awareness that Climate Change urgently requires action may be key elements towards the development of such a strategy.

On a more practical level, the move from point observations towards development of seafloor observatories is enhanced by the scientific demand to investigate deep-sea processes in-situ and on their actual time scales, from seconds to days to years. Such detailed monitoring of long-term global processes will lead to a better understanding of deep ocean interactions to unravel the main sources of major global events such as Climate Change. Measurements in real time or near-real time are increasingly important to clarify the global phenomena that affect Earth. The complex observations platforms can be stand-alone moorings linked to surface buoys connected to satellites or fixed-point multi-sensor cabled seafloor observatories, with an unprecedented capacity for sampling and data transfer. Presently, the transfer capacity of stand-alone systems via satellite is relatively limited, but with the arrival of the Low Earth Orbital (LEO) satellites, foreseen within the next 5 years, bandwidth will increase 10-fold or more, at much lower cost, thus increasing the capacity for near-instant data transfer from these stand-alone observatories.

In Europe, observatories are deployed across the European seas in key environmental sites such as in the EMSO-ERIC configuration, both near-shore and out into the ocean. Especially for the offshore sites, capable vessels supported by autonomous vehicles are needed to deploy, service and maintain the observatories. To further integrate the European observatories into a true Pan-European facility it is of utmost importance to harmonise technical developments and operational procedures. A start towards this goal was made in FixO3 and it is expected that EMSO ERIC will drive this process in future years.

In the section below, the EMSO observatories, their technical specifications and the vessel requirements for maintenance and servicing are described. In the final section, we will provide an overview of planned technical developments on short-term and longer-term time frames.

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2.3.1 EMSO observatories, a technical description

Because of the large diversity within the EMSO range of observatories it will not be feasible to describe the vessel requirements for each observatory separately. We have therefore decided to divide the observatories into groups based on their complexity: complex cabled observatories, observatories consisting of a single mooring and surface buoys. Of each group a representative observatory will be discussed in detail. This approach will provide information on the requirements for the end members of the observatory range, the most complex one's and the simplest one's, thereby covering the entire range.

Examples of complex observatories are the Azores observatory managed by IFREMER and the PAP observatory managed by NOC. The Azores observatory consists of several modules with acoustic transmission to a surface buoy, located at 1750m water depth. The Porcupine Abyssal Plane (PAP) mooring is a single mooring but its location at 4850m water depth adds complexity to the deployment and recovery operations. The Western Ionian is another example of a cabled observatory, but this observatory is cabled to shore and thereby relies on different modes of data transmission. These three observatories will be discussed here in more detail.

In addition, the Smartbay Observatory will be discussed as an example of an observatory of medium complexity. Finally, the ESTOC surface buoy will be discussed as the simplest form of observatory.

The technical data for all EMSO Observatories, with a description of the components of the observatories, are given in Table 4. Table 5 describes vessel requirements and maintenance frequencies for the observatories while future plans, both short-term and on a 5+ year timescale are given in Table 6.

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	Type of Equipment Deployed	Size/Dimensions	Weight
Porcupine Abyssal Plain	Surface Buoy, subsurface Sensor (30m) and A PAP-3 mooring has sediment traps at various depth to 3000 m depth. A bathysnap (4850 m depth) takes seabed images.	Bathysnap Benthic lander - 415.00cm H x 450.00cm ODAS Met Buoy - 400.00cm H x Large ODAS type met buoy Anchor weight - 100.00cm H x 150.00cm W - 2000.00kg 300.00cm W - 4000.00kg Sensor frame - 150.00cm H x 100.00cm	Bathysnap Benthic lander -300.00kg Wt ODAS Met Buoy 4000.00kg Wt - Large ODAS type met buoy Anchor weight - 2000.00kg Wt – Sensor frame - 300.00kg Wt -
SMARTBAY	GPS, Surface Buoy, Met Data, Date Time The mooring consists of 2 x 75 Hz ADCPs at 500m and 1000m and of an array of 10 Seabird SBE37 CTD Sensors at the following depth intervals: 500m, 625m, 750m, 1000m, 1250m, 1500m, 1750m, 2000m, 2500m, and 3000m. The CTD array sensors were fully calibrated by Seabird in Germany both pre- and post- deployment. The mooring is retrieved by acoustic release and contains an iridium transponder and flashlight to aid retrieval on return to the surface.	Total Length: 3012M Mooring components: 2 x Sub Surface Floats 10 X CTD with frame 4 glass floats Acoustic Release Chain Clump weight	Weight: 2511kg 2 x Sub Surface Floats x 420kg in water 10 X CTD with frame x 7.3 kg in water 4 glass floats 17kg each in water Chain Clump weight 1500kg in water
EMSO-AZORES	Seabird Microcat SBE37, RBR-TR1060 & RBR-TR1050, Aquadopp current meter, CTD (1700m) and EGIM at Lucky Strike, Array of vent temperature probes, Turbidity (Seamon E, 1700 m) ECOBBRTD, and EGIM at Lucky strike, Iron analyser (Seamon E) Chemini FE, Seafloor images, Axis Q1765, Ocean bottom seismometer at SEAMON W and array of Broadband seismometers Seamon W, Paroscientific 8CB4000-1	Borel surface buoy size: h6.75m x diam2.20m Seamon E size: 3.00m x 2.32m x h2.05m Seamon W size: 2.72m x 2.32m x h2.05m.	Borel surface buoy weight: 1600kg Seamon E weight (air): 430kg Seamon W weight (air): 380kg
ESTOC	Surface Buoy and Mooring Surface Waters (0-100): Mooring CTD (80-100m) (seabird CTD-DO) & Microcat CT recorder SB37SMP-ODO, Mooring Chlorophyll (80-100m) (ECO-FLNTU), Mooring Nutrients (150m) (Envirotech nutrient sensor), ADCP (80-100 m, line) Nortek Aquadopp profiler. Water column (below 100 m): CTD-DO probe Seabird SBE337SMP-ODO(150 m and 1600 m), Slocum glider (0-1000m), Slocum glider (0-1000m), Mooring Dissolved oxygen (150m) (seabird microcat do), Slocum glider (0-1000 m) Wetlabs ECO FLNTU, Slocum glider (0-1000m) and 150 m, frame Nortek Aquadopp profiler, PARFLUX Sediment Trap, McLane Mark 78H-21 (1600 m), RTSYS Hydrophone, 150 m - frame	Surface buoy: 6m long, 2,3 m diameter of the float Sensors @80 and 100 m: 0,7 m long, 0,1 m diameter Frame @150 m: 1 m long, 1 m diameter Floater @300 m: 1,5 m long, 1 m diameter	Surface buoy: 1,5 tn Sensors @80 and 100 m: 3 x 3 kg Frame @150 m: 90 kg Floater @300 m: 370 kg Floating spheres @1400 and @2500: 6 x 23 kg Sediment trap @1600 m: 70 kg Floater @3400m: 450 kg Releasers @3600m: 100 kg Anchor: 2,3 tn

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		Floating spheres @1400 and @2500: 3 x 0,45 m diameter Sediment trap @1600 m: 1,65 m long, 0,9 m diameter Floater @3400m: 1,5 m long, 1 m diameter Releasers @3600m: 1 m long, 0,7 m diameter Anchor: 1x1x1 m	
LIGURIAN SEA	Water column (below 100 m): ALBATROSS, the Autonomous Line with a Broad Acoustic Transmission for Research in Oceanography and Sea Sciences, is a standalone deep sea mooring dedicated to the long term monitoring of hydrological and biogeochemical properties. The data are transmitted in real time to the shore using the inductive cable along the mooring line and an acoustic link with the MII. Seabird SBE 37 SMP (6 sensors, depths from online = 200, 700, 1000, 2000 m) & Fast resolution Temperature sensor (3 x depths), Seabird SBE 37 ODO (2 sensors, 2 depths), Nortek Aquadopp ADCP, Mooring, Sediment traps (200 & 1000 m, Technicap PPS5). The ALBATROSS mooring line is composed of a dead weight, an acoustic release system, two wire ropes (8.4 mm diameter and 1000 m length) and two instrumented buoys, one in the middle of the mooring line and the other at its top. This line will be deployed at a distance of 2 to 3 kilometers from the MII. SeaBed: SJB, Instrumented junction box. The SJB, Secondary Junction Box, is a sea floor extension to the cabled neutrino telescope MEUST. It is devoted to environmental science, in particular to the study of the meso and sub meso scale hydrological features and of the hydrological events happening at the basin scale. Previously connected to ANTARES, the SJB will be deployed in May 2020.http://www.emso-fr.org/EMSO-Western-Ligurian-Sea/Infrastructure-description. MII, Instrumented junction box. The Module Interface Instrumented "MII" was deployed in May 2019 and connected on the MEUST Node#1. It is cabled to the shore via the MEUST cable.	The main operations are: the deployment of the SJB assembly size: 6 x 2.4 x 1.4 M seismometer with its frame size: 1.7 x 1 x 1, 4 m, benthic robot with its cage (size: 2 x 2 x 2 m,), radiometer with its frame (size: 2 x 2 x 2 m, biocamera with its frame (size: 2 x 2 x 2 m,	SJB assembly, weight in air: 3400kg seismometer with its frame weight in air: 400kg benthic robot with its cage weight in air: 700kg biocamera with its frame weight in air: 450kg radiometer with its frame weight in air: 450kg
WESTERN IONIAN	An underwater cable run on the seafloor from Catania harbor and splits in two branches at about 20 km off the Eastern Sicily coasts and at about 2100 m w.d. The North branch hosts the geophysical and oceanographic station SN1, managed by INGV, and the South branch hosts the acoustic station Onde, part of the KM3NET test site managed by INFN. A mooring system, managed by CNR, was also recently operative near the North branch in autonomous mode to monitor sea water column properties.	Information not available at this time	Information not available at this time
HELLENIC ARC	A) Surface Buoys. B) Autonomous seabed platform. C) Cabled seabed observatory.	Buoys: 1) Seawatch type: W 1,2m L 7 m 2)Wavescan type: W 2 m L 5m Autonomous seabed platform:	Surface buoys with telemetry devices inside buoy hull (included in the weight of the buoy) 850 kg with an anchoring

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	The Pylos station is a part of POSEIDON buoy network that currently consists of 6 oceanographic mooring sites monitoring in the Aegean and Ionian Seas. The infrastructure operates since May 2007 in the SE Ionian Sea at a depth of 1670m, comprised of three major parts: the water column component with a surface buoy; an autonomous seabed platform and the cabled seabed observatory. It delivers near real time data for a variety of meteorological, water column and near seabed oceanographic parameters. An inductive mooring line provides salinity, temperature and pressure real-time data from surface to 1000 meters' depth. An autonomous seabed platform was also deployed during 2008 to monitor deep sea (1670m) temperature, salinity and dissolved oxygen data as well as high frequency pressure measurements for tsunami detection. The cabled platform will extend the measurements for the Pylos observatory, providing real time measurements at a depth of approximately 1600m and capturing HD video and still images. The mooring line also hosts a set of Passive Aquatic Listeners (PALs) for rainfall estimates and marine mammal acoustic detection. The PAL systems have been recently evaluated against X-band radar measurements in this area and were found to provide very realistic estimates of precipitation.	Length 2.5 m Diameter 1.2 m Cabled seabed observatory: L,W,H approx. 3 m	weight of 900kg for Seawatch type and 1200kg for Wavescan type. Weight of the Autonomous seabed platform is about 350kg with an anchoring weight of 600 kg. Cabled seabed Observatory weight is approx. 1000 kg.

Table 4: technical specifications of the EMSO-observatories

EMSO Azores, an Integrated Study Site

The EMSO Azores observatory is an integrated study site that combines studies in ecology (biodiversity, spatial distribution, food web, in situ experiments in resilience and chronobiology, fluid chemistry and Exploration (Capelinhos discovery, inactive areas, deep corals).

Figure 7: The EMSO Azores observatory (www.emso.org.)

The EMSO Azores setup consists of a cabled network focussing on 2 locations (nodes) around the Lucky Strike vent field, with ecological monitoring focussing on the Eastern node, the Tour Eiffel vents, a ca. 15 m-high and up to 40 m-wide sulphide mount. Two sensor packages are currently connected here: a module with HD video camera, optodes, a dissolved iron analyser and turbidimeter, and a colonizer and low-temperature fluid sampler for microbiology. The Western node focusses on seismic activity measurements and vertical deformation of the seafloor, deploying OBSs. In addition to the cables nodes, there are a number of unconnected components: an array of 4 Autonomous OBS, 2 autonomous pressure gauges, > 30 Temperature probes, a physical oceanography mooring, colonization substrata (ecology/microbiology) and 3 Autonomous current meters. Data from observatory to shore are transmitted via a Borel surface buoy.

Technical data describing the components of the EMSO Azores observatory are given in table 4.

The weight of the components of the observatory are between 380kg (Western node) and 1600kg (Borel surface buoy).

Maintenance of the EMSO Azores observatory is carried out on an annual basis. A complex observatory such as the EMSO Azores observatory requires a DP capable vessel that can deploy an ROV and AUV simultaneously. The vessel needs to have sufficient deck space to store all equipment that needs to be deployed and recovered. Examples of vessels with the required specifications are the global vessels in the European fleet: *RV Pourquoi Pas?, RV l'Atalante, RV Discovery* and *RV James Cook*. These vessels and most others in the European fleet are described in detail in the recent European

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Marine Board position paper nr 25: Next Generation European Research Vessels: Current Status and Foreseeable Evolution".

Porcupine Abyssal Plain

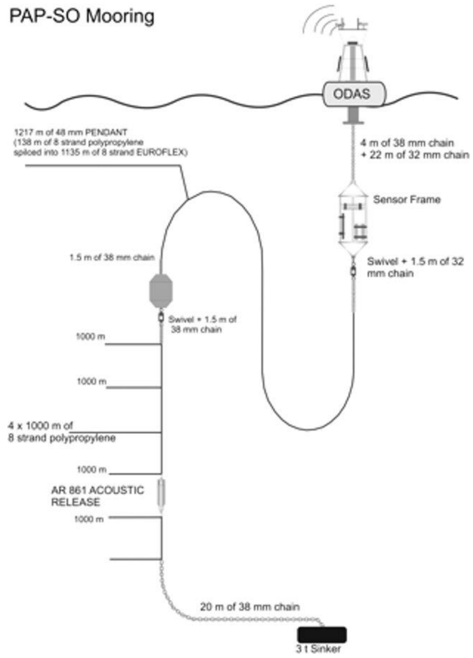

Figure 8: the PAP mooring (www.noc.ac.uk)

The Porcupine Abyssal Plain is a vast plain situated at a water depth between 4000 and 4850 m and 500k from land in the North Atlantic Drift Region. This site has been studied from the surface to the abyss since the mid-1980s. It is positioned between the North Atlantic current and the Azores Currents and it is crossed by clockwise and anticlockwise swirls and eddies. The scientific objective of the site is to study the connections between the lower atmosphere, water column and seafloor at a deep ocean site in the Northeast Atlantic, understanding ecosystem function especially related to carbon sequestration dynamics. The observatory has multiple arrays, one surface meteorological buoy (air and 1m depth) and a subsurface sensor frame (30 m depth) that measure many essential Ocean variables (PAP1). A PAP-3 mooring has sediment traps at 3000 to 4750 m depth. A Bathysnap (4850 m depth) takes seabed images.

The surface buoy and full depth mooring can host additional instrumentation for atmospheric, air-sea interface and upper ocean monitoring. The data collected includes Atmosphere: Wind speed and direction, Relative humidity, Air temperature, sea temperature, Atmospheric pressure, significant wave height and period. Water column: Salinity, temperature, currents, pCO2, dissolved oxygen, nutrients, Chlorophyll-a. The Sub-surface sediment trap mooring can host additional instrumentation at depths between 3000 – 4800m depth collating particle flux and currents data. Finally, the lander system with Bathysnap time-lapse camera positioned on the seafloor at 4850m depth. Additional sensors can be mounted on module. Communication with surface via acoustic modem. Time-lapse photography for seafloor ecosystem studies is collected.

Technical data describing the mooring components of the PAP mooring are given in table 4.

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Maintenance of the Observatory includes a combination of cleaning sensors, sensor calibration, sensor replacement, software upgrade, replacement of cable and connectors which takes place annually and requires a deep sea research vessel such as the *RV Discovery, RV James Cooke* or the *RV Celtic Explorer* which has been used in the past. An A Frame up to 10t and dynamic positioning is necessary to carry out maintenance at the PAP site.

Further information about maintenance schedules and vessel requirements are given in Table 5.

Western Ionian

The Western Ionian Sea observatory is located 25 km off Catania harbour at 2100 m water depth. The observatory has been in place since 2005, with main science objectives being Geo-hazard observations (Tsunami, Seismic and Volcanic monitoring), Oceanographic monitoring (seafloor and water column), Environmental monitoring (acoustic noise) and bio-acoustic tracking of marine mammals.

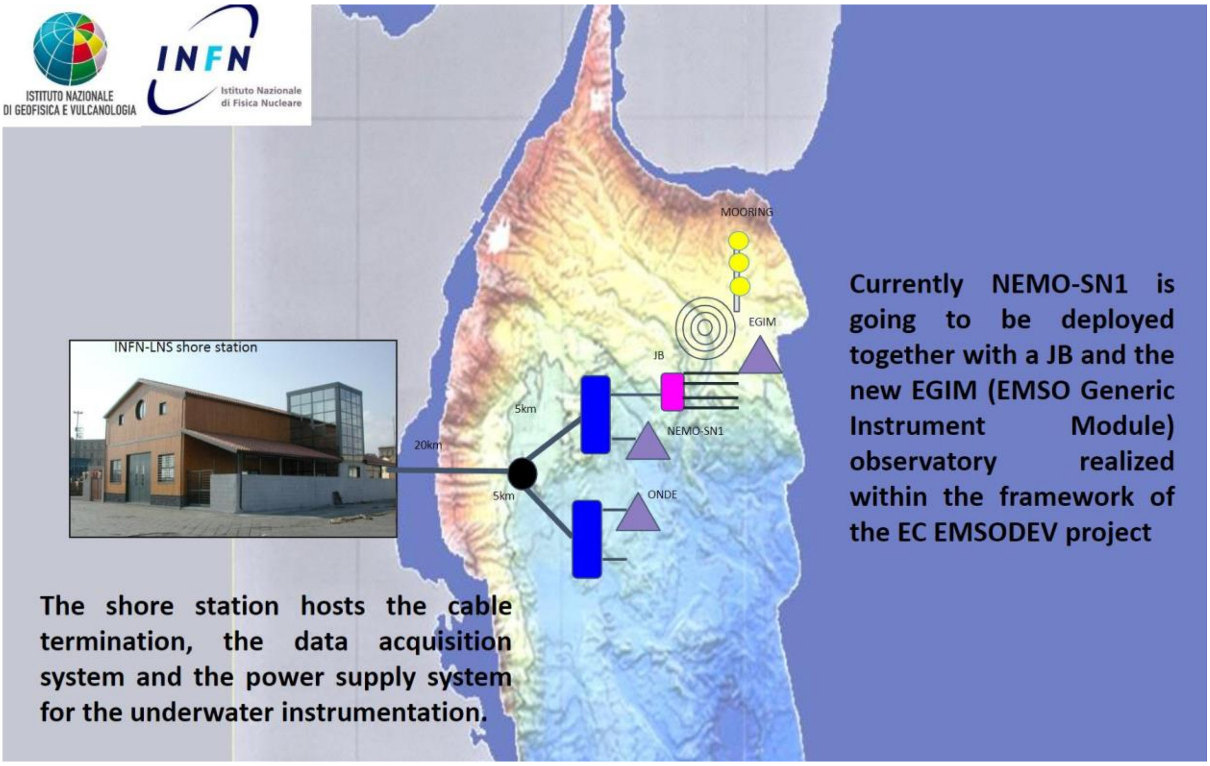

Figure 9: The Western Ionian observatory (from Marinaro, 2019)

The Western Ionian observatory infrastructure consists of a shore station connected to the observatory through a 28 km E/O cable, that splits in two branches at about 20 km off the Eastern Sicily coasts and at about 2100m water depth. The shore station hosts the cable termination, the data acquisition system and the power supply system for the underwater instrumentation. The North

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branch of the observatory hosts the geophysical and oceanographic station NEMO-SN1 module while the South branch hosts the acoustic station Onde, part of the KM3NET test site. A mooring system, EMSO Generic Instrument Module (EGIM), managed by CNR, was also recently operative near the North branch in autonomous mode to monitor sea water column properties.

Technical data describing the mooring components of the Western Ionian observatory are given in table 4.

An additional complication for the maintenance of the Western Ionian observatory is the lack of suitable research vessels in Italy. Currently, it is difficult to find a vessel with DP2 and the capability to operate an ROV to up to 3000m. In principle, however, maintenance will be scheduled annually.

Further information about maintenance schedules and vessel requirements are given in Table 5.

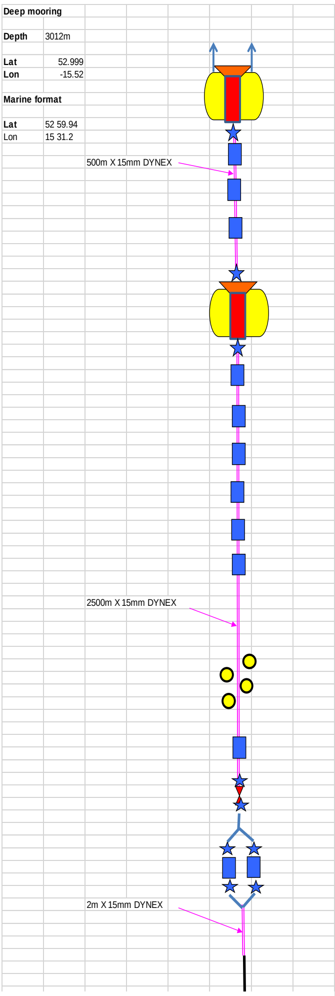

Figure 10: The South Rockall Trough Water Mooring

South Rockall Trough Deep Water Mooring

The recently deployed South Rockall Trough Deep Water Mooring (PILOT) is a multi-sensor Observatory situated 400 kilometres from land in the north Atlantic and runs to a depth of 3000 metres. The observatory consists of two subsurface floats deployed at 500m and 1000m below the surface, with the 500m float fitted with a current meter collecting information about the ocean current profile between 1000m and the sea surface. The reminder of the mooring is fitted with 10 CTD sensors which measure pressure salinity and temperature at depth fitted at points from 500m below surface to 2500m. The mooring is fitted with an acoustic release which is attached to a clump weight of heavy dynes rope strop. Total weight of the observatory is 2511kg in water.

Technical data describing the mooring components of the Smartbay observatory are given in table 4.

The Smartbay observatory must be fully recovered every 12 months to allow for a full swap out of the moorings, sensors and buoys. Service requirements of the South Rockall Trough Deep Water Mooring necessitate a vessel with a 10 tonne A frame required for deployment and recovery coupled with Dynamic Positioning and large deck space to

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accommodate the length and complexity of the mooring. The Observatory is currently serviced using the *RV Celtic Explorer* who has both DP and a 25t A-frame.

Further information about maintenance schedules and vessel requirements are given in Table 5.

ESTOC observatory

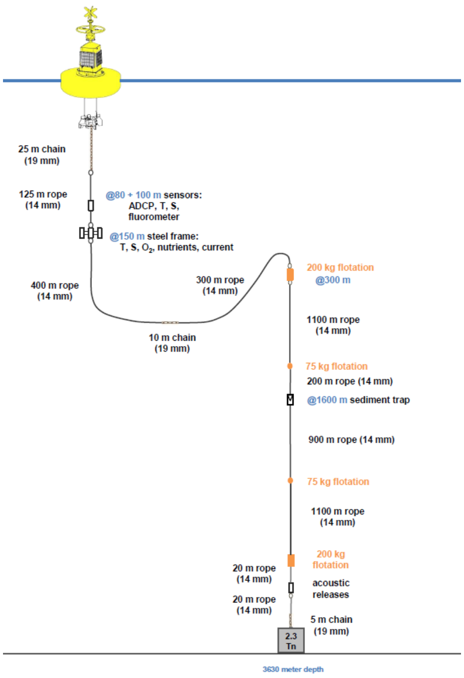

Figure 11: the ESTOC observatory

The ESTOC observatory is an observatory that, even though deployed at 3600m water depth, focusses mainly on the surface waters of the Atlantic Ocean near the Canary Islands. The mooring consists of a surface buoy and instruments to carry out measurements in the upper 150m of the water column: CTD, ADCP and nutrient sensors. In addition, a number of sediment traps to capture larvae are deployed along the mooring line and gliders will be used to collect additional data.

The ESTOC observatory is serviced bi-annually. Vessel requirements for ESTOC type observatories are limited: a medium sized vessel with a 5 tonnes A-frame is sufficient to carry out the operations and ESTOC therefore represents the lower end of the observatory requirements range.

2.3.2 EMSO observatories, vessel requirements

The number of European research vessels capable of carrying out the missions to deploy and service major components of deep-water observatories, in particular the more complex observatories, involving simultaneous deployment of AUVs, ROVs, is limited and few significant new builds are expected in the near future (EMB PP25). However, other initiatives such as the development of the next generation of AUVs and ROVs, with enhanced instrumentation, manoeuvring and processing capabilities, are ongoing and should be aligned with the development plans for the observatories.

The table below shows the vessel requirements and maintenance and servicing frequencies for the EMSO observatories. Most of the observatories are serviced annually, but this is ultimately dependent on vessel availability

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Name	Mooring Type	Acoustic Release	Anchor Type and Weight	Frequency	Current Vessel Used
Porcupine Abyssal Plain	32mm/38mm Chain, 8 strand Polypropylene Rope spooled into 8 strand euroflex. The mooring is over 6.5 kilometres in length and sits in 4850 metres (m) of water giving it a 4 kilometre plus watch circle. The majority of the scientific instruments are house in the Autonomous Sensor Platform (ASP) suspended 30 m below the surface buoy. Most years the top end of the mooring including the ODAS buoy and the ASP and chain are all that is replaced.	Y	3tn Sinker	Annually	Research vessel with dynamic positioning (Discovery or James Cook)
SMARTBAY	15mm Dynex	Y	Chain clump Weight A1800kg/W1500kg	Annually	R/V Celtic Explorer/ILV Granuaile
EMSO-AZORES	1686M Mooring Line 1700kg Ballast Weight	N	1700kg Ballast Weight	Annually	R/V Pourquoi pas? or R/V Atalante
ESTOC	The mooring line hosts a suite of sensors ABD sediment traps and is a mix of chain inox steel cable and rope.	Y	2.2t Sinker	Bi Annual	National fleet Research Vessel
LIGURIAN SEA	Ligurian Sea Dyfamed Mooring MII Instrumented interface module EMSO-Ligure ALBATROSS Mooring: The ALBATROSS mooring line is composed of a dead weight, an acoustic release system, two wire ropes (8.4 mm diameter and 1000 m length) and two instrumented buoys, one in the middle of the mooring line and the other at its top.	Y	Albatros Mooring: Deadweight	1-5years	OU#1 DYFAMED: L'ATALANTE or LA THALASSA JB#1 MII: R/V Pourquoi Pas? OU#2 ALBATROSS: NO TETHYS II
WESTERN IONIAN	N/A	N/A	N/A	Annually	Cable-laying vessel "ANTONIO MEUCCI" or DSS
HELLENIC ARC	Seawatch type buoys have a composite single line mooring of 14mm diameter compi wire rope without a releaser. (the anchoring weight is recovered and redeployed) Wavescan type buoys have a composite single line mooring of 16mm jacketed wire rope (inductive cable) with 18mm of nylon rope and 16mm polypropylene rope. The buoys are using a 2.5 or 5 tons acoustic releaser.	Y	Seawatch and Wavescan use train wheels for anchoring weight, 900 kg and 1200 kg respectively.	Buoy Annually/Cabled Platform every two years	Seawatch buoys, wavescan buoys and the autonomous platform are serviced with R/V Aegaeo The cabled seabed observatory was installed by the Italian cable ship Meuchi, but plan to do maintenance with R/V Aegaeo

Table 5: Servicing frequencies and vessel requirements for the EMSO observatories

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2.3.3 EMSO observatories, future developments

The current plans for future developments for the EMSO observatories are summarised in Table 6. The short-term plans are reasonably well developed, for the longer term and especially the 5+ year timescale, plans are relatively vague and give little more detail than mentioning that the intent is to develop, deploy and test new sensors, oceanographic instrumentation and marine technologies. The EMSO Azores observatory sets a concrete goal by expressing the intent to decrease the maintenance period to 2 years, with the option to look at specific questions on energy consumption or availability. As said before, it is important that development plans for these observatories are aligned with ongoing technical developments and strategies for vessels, ROVs and AUVs.

The new generation of ROVs will be designed to carry, deploy and recover light physical, chemical or biological sensor acquisition packages and will provide functionalities to dock to observatories for servicing of instruments and databases. Future trends for ROVs will also include the availability of high-voltage electric power (greater than several tens of kW) for scientific equipment. The additional capacity of deploying heavy

packages directly using the ROV will allow complex installation or maintenance operations such as the installation of interconnected cables over long distances with the use of specific tools.

In future, AUVs accomplishing intelligent missions will be able to connect to ROVs in specific rendezvous manoeuvres through high bandwidth acoustic and optical links or transfer datasets collected during the dive to the observatories. Autonomous surface vehicles (ASV) will function as communication relays for AUVs, with over-the-horizon connection to the research vessel for transmitting AUV monitoring data. Reconfiguration of AUV missions will be possible remotely without recovery and without the AUV surfacing. There is also an increasing trend towards swarming AUVs, i.e. the ability to operate several AUVs together in a coordinated fleet.

AUVs will combine advanced sensor data with generic high-resolution mapping (including using simultaneous localization and mapping (SLAM) navigation technologies), geochemical sensor suites, spectroscopy, chemical analysers working with filtering devices, and automated sampling. The next generation of 6000m AUV e.g. CORAL (Ifremer), coming into operation in 2021, will provide these features. It will have manoeuvring capabilities that will allow precise targeting of measurement locations such as underwater observatories.

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Name	Future/Planned Equipment_2018	Future Plans 2-3 Years	Future Plans 5 +Years
Porcupine Abyssal Plain	Use of optical and photographic tools to address biological and ecological EOV maturity is a priority for future development. Development of the data hub and telemetry systems on PAP-1, to take advantage of EGIM developments. Addition of marine autonomous systems to the observatory data collection. This may include gliders visiting the site for cross-comparison with mooring sensor data and long-range AUV water column and benthic data collection.	Moving toward a Mobilis MO buoy and glider deployments 2021	Increased use of gliders in the area, and samplers on the buoy
SMARTBAY	This Pilot autonomous mooring deployment complements a long-standing annual survey to the site since 2004, the original driver was the collection of physical oceanographic data by CTD. The survey has evolved over the years, with chemistry added from 2008 and biological elements such as plankton hauls have also been added more recently. The annual survey - led by the Marine Institute, seeks to gather high quality oceanographic data along a targeted section of the Atlantic Ocean starting in Galway Bay along the 53N line and heading out to the South Rockall Trough.	Pilot Deployment in 2018-2019 Current deployment 2020-2021 Not yet established as a long term operational programme	Expand observatory with the deployment of additional sensors. Secure long term financial sustainability
EMSO-AZORES	Hydroctopus (hydrophone micro-array for studies of near surface micro-seismicity): upgrading the existing electronics in order to reduce energy consumption, allow yet higher frequency sampling (from 250 to 1000 samples/s), connect the instrument to COSTOF and send near real-time detections of subsurface micro-seismic events. DEAFS (on-demand remote sampling of vent fluids for later onshore analyses): prototype.The first prototype was deployed in 2017. It should be connected to SEAMON	technological objectives: 1. to decrease the maintenance period to 2 years, with perhaps specific questions on energy consumption or availability, 2. concerns the ability to deploy and recover parcels on the seafloor with the help of an ROV or HOV, without leaving ballast on the seafloor. This would decrease the maintenance duration by optimising the underwater operations.	To decrease the maintenance period to 2 years, with perhaps specific questions on energy consumption or availability,
ESTOC	Acoustic communication between midwater frame and surface buoy for real-time communication of observations. Identify and test new technologies. Identify opportunities and establish means to use European research vessels to reduce uncertainties in the availability of vessels for the maintenance of observatories.	Acoustic communication between midwater frame and surface buoy for real-time communication of observations (pending). Working on agreement with national agencies/institutes IEO and AEMET for sustained vessel support. Incorporation of carbon variables in ICOS OTC.	Test of new oceanographic instrumentation and marine technologies for scientific research. Increase ecosystem observation capacities. Improve passive acoustic monitoring. Revise mooring configuration for greater reliability and midwater data quality.

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LIGURIAN SEA	Biogeochemical sensors technology. The technology of MUG-OBS (long term deployment with periodic data request) could be used for marine observation at the sea floor level. It could provide an opportunity to record reference oceanographic data on the DYFAMED site, complementary to the geophysical observation.	EMSO-Ligure Cabled Scientific Jonction Box (SJB) Deployment of the updated scientific junction box (SJB) and 4 scientific equipment connected to the site of the Km3Net observatory (French fleet EMSO scientific campaign	Development and test of new oceanographic instrumentation and marine technologies for scientific research. Performance of bio-ecological experiments with the acoustic tracking systems.
WESTERN IONIAN	The extension of the spatial coverage with a new seafloor electro-optical cable deployed by INFN from the southernmost tip of Sicily for 100 km down to the Ionian abyssal plane offshore Capo Passero. Two new junction boxes already realized will be deployed: the first connected to the Catania site. The second will be connected to the cable deployed offshore Capo Passero site. EGIM module in cabled configuration will be installed and connected using the new junction box to submarine cable and to Catania shore laboratory	Replacement of Catania frame and ODI female connectors due to lack of connection during 2019 cruise. JB, SN1 and EGIM will be deployed after the replacement	
HELLENIC ARC	A multi parametric multi-platform observing system monitoring; automated sensors capable of delivering near real-time high frequency data.	Short-term plans are towards the simplification of the system. Thus, the sensors from the autonomous seabed platform will be incorporated in the cabled platform. The final configuration will be the open sea surface buoy with multiple sensors from surface down to 1000m and the cabled platform at 1600m also with multiple sensors.	Long term plans are the integration of mobile platforms such as Argo floats and endurance Glider lines.

Table 6 Future plans for the EMSO observatories, with an outlook for 2-3 and 5+ years

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EMSO ERIC: www.emso.eu The European Multidisciplinary Seafloor and water column Observatory (EMSO)

OOI: www.oceanobservatories.gov

Ocean Networks Canada: https://www.oceannetworks.ca/

Adrian Round Director of Observatory Operations Sea Operations for Ocean Observatories Installation and Maintenance of Cable Observatories: Right tools for the right job

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