EUROPEAN MONITORING SEAFLOOR AND WATER COLUMN OBSERVATORY (EMSO) IMPLEMENTS ITS EXTENSION PLAN STARTING FROM THE EXISTING DISTRIBUTED INFRASTRUCTURE.

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Abstract:
The Preparatory Phase of a large research infrastructure, dedicated to long term subsea scientific observatories called EMSO (European Monitoring of Seafloor and water column Observatory) has been performed by a consortium of scientific institutes representing their national funding agencies.
The experience in Europe includes cabled observatories for academic research in many disciplines: seismology, marine mammals monitoring, tsunami warning, global change studies, seafloor vents or seeps and associated biology, biogeochemistry of the water column, etc.
A data management policy is under implementation, it benefits from the latest issues of dedicated European projects and international standards on environment data.
The governance of EMSO will comply with the legal framework of a European Research Infrastructure Consortium (ERIC). It is planned to be operating during several decades after a 3 year integrating phase.

1. INTRODUCTION

Long term subsea scientific observatories have been promoted through a networking effort of European institutes during the ESONET project co-funded by the European Commission. The Preparatory Phase of a large research infrastructure called EMSO (European Monitoring of Seafloor and water column Observatory) has been performed by a consortium of scientific institutes representing their national funding agencies.

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2. SCIENTIFIC OBJECTIVES AND SENSOR TYPES

2.1 Objectives of the subsea network

Science objectives guide observatory design and dictate the ability to collect data without employing traditional means, such as research vessels. However, the latter are intended to complement the EMSO network, which will be serviced by a combination of research vessels and remotely operated vehicle (ROV) operations provided by EU Member States in a coordinated network established by EUROFLEETS. The most transformative facet of observatory design is its ability to address interdisciplinary objectives simultaneously across scales (Priede et al., 2003[3]; Favali et al., 2006 [2]; Barnes et al., 2008, [1]; Ruhl et al., 2011 [5]). Data will be collected from the surface ocean, through the water column, the benthos, and the sub-seafloor.

Depending on the application, *in situ* infrastructures will preferably be attached to a cable, which provides power and enables data transfer. Mobile systems, such as benthic rovers and autonomous underwater vehicles (AUVs), or link to additional subsea nodes by horizontal acoustic transmission or low cost cables can also be used to expand the spatial extend of a node. Cabled infrastructures provide important benefits including real-time data transfer and interaction with observatory activity as well as a rapid geo-hazard early warning system (Favali et al., 2006 [2]; Ruhl et al., 2011 [5]). Elements of observatory design and standardisation are addressed specifically in the development of the ESONET Label (Rolin et al. 2011 [4]).

2.2 Generic sensor module

While not all questions can be addressed by each individual infrastructure, it is feasible to include a specific set of variables that are measured at all sites and depths, including temperature, conductivity (salinity), pressure (depth), turbidity, dissolved oxygen, ocean currents, and passive acoustics. These variables are important in the context of climate system monitoring and are known as Essential Climate Variables (ECVs), which were defined to support the work of the UN Framework Convention on Climate Change (UNFCCC) and the IPCC. As sensor development progresses other variables can be added, such as the remaining ECV sensors (e.g. Chl-a, pH, CO_2, CH_4, H_2S, Eh, and hydrocarbons).

These generic sensors can be used to directly address a wide range of geo-hazard warning and scientific applications related to understanding natural and anthropogenic variation and the possible impacts of climate change. The system is able to detect tsunami waves, but also storm and tide wave loading, sedimentation dynamics that influence turbidity, such as resuspension and benthic boundary layer (BBL) dynamics. By linking tide, turbidity, and current meter readings, interaction strength and thresholds for resuspension and sediment transport can be further described.

Furthermore, the measurement of these parameters on the seabed and in the water column can help determine how seabed processes interact with ocean circulation, biogeochemistry, and ecological parameters. Combining generic sensors with specific sensors such as seismometers, geodesy, bubble flux observing systems, hydrothermal flow meters, and piezometers the remaining key questions outlined in Ruhl et al. (2011) [5] can be addressed such as how are seismic activity, fluid pore chemistry and pressure, gas-hydrate stability, and slope failure related? And what are the feedbacks between deformation, volcanism, seismic, and hydrothermal activity?

Generic sensors can also address questions related to physical oceanography. However, a generic sensor module at the surface, midwater and/or at the seafloor can only answer these questions partially. The use of salinity and conductivity sensors spaced regularly along strings and additional ADCP coverage can, however, capture the themes related to ocean physics. These include understanding wind-driven and deep-ocean circulation, planetary waves, and interactions between the BBL and the seabed. This fixed point infrastructure data is complementary of the ARGO floats and other mobile systems, such as gliders, as well as satellite data for the operational oceanography nowcast and forecast modeling ; this strongly augment the impact of generic sensors.

The oxygen sensor in the generic specification can address several aspects of biogeochemistry. Oxygen itself is important for aerobic life in the oceans which includes all metazoans (e.g. zooplankton, fish, and benthic invertebrates). Oxygen in the oceans is replenished primarily by inputs related to photosynthesis and equilibration at the air-sea interface. By making some crude assumptions one can estimate how much oxygen has been utilized by measuring how much remains compared to saturation levels (apparent oxygen utilisation [AOU]). So, variations in oxygen minimum zones (OMZs), as well as oxygen dynamics in the rest of the water column are of interest. Generic modules will also be able to make sensitive measurements of how oxygen concentration relates to turbidity and temperature, which have both connections to time variant respiration and/or re-mineralisation.

Carbon dioxide is an abundant greenhouse gas and is a key molecule in the oceans' biological pump. It is transferred from the atmosphere into the ocean and incorporated into phytoplankton production during photosynthesis. Some of this photosynthetic production is exported out of sunlit surface waters and sequestered for extended periods of time. There remains, however, much uncertainty in the transfer rates and dynamics of CO_2 uptake.

Measuring chlorophyll-a as an indication for the amount of primary production through the water column has many implications for biogeochemistry and marine ecology. These include sedimentation processes from the sea surface to the seabed, the input amount and seasonality of organic material, and the latter's role as food supply and the resulting implications for the existing fauna in different habitats. Chlorophyll-a also provides an insight into the importance of other parameters that trigger plankton blooms, as well as their seasonality/periodicity.

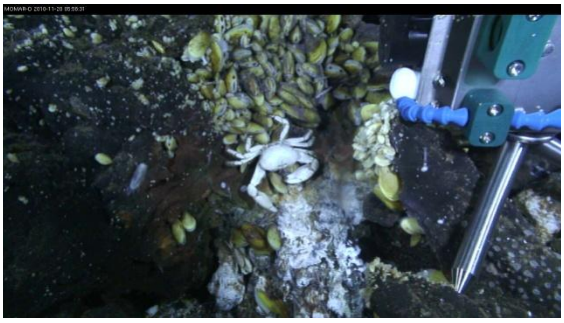

Figure 1 : Video images of hydrothermal vent biota.

As sensor technology develops biogeochemical sensors will likely transition from specialized to generic instruments in the coming months and years, including pCH_4 and pH sensors. EMSO partners are involved in the most advanced projects to provide reliable long term measurements.

With pictures taken hourly the activity of benthic vent communities and the growth of chimneys and fluid venting may be recorded on a time-series basis. Similarly, the behaviour, diversity, activity rates, and size distributions of many fauna can be determined for slope, canyon and abyssal plain habitats. Images are taken more often on some biodiversity hot spots such as hydrothermal vents (Figures 1 and 2).

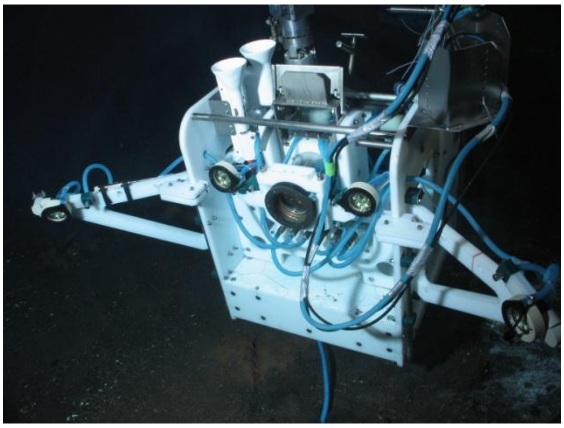

Figure 2: Instrument dedicated to imagery and physico-chemical data, used on EMSO Lucky Strike Azores site and Neptune Canada Endeavour site. (*copyright Ifremer*).

Another sensor with generic specification is the hydrophone, which is capable of detecting marine mammal sounds. Currently, there are hydrophone-based systems that can detect the position and identity of mammal sounds and thereby come up with estimates of density and distribution. Other sounds can also be detected, including anthropogenic sounds like those of passing ships, as well as rain, and the sounds of certain plankton and fish. Combining these systems with other ecological measurements will provide verification data that is needed to improve the detection of even more sounds. ADCP systems are sensitive to zooplankton and fish distributions, as well as currents. The addition of cameras and active acoustic systems like scanning sonar or synthetic aperture systems can greatly enhance the quantification of abundances.

Fluorometers, zooplankton samplers, and advanced microbial sensing systems also add to the impact of the generic observing system in order to address a diverse set of ecological questions.

2.3 Science specific modules

Each site has its characteristic features and can address science questions that are specific to a certain location. Science-specific sensor modules complement generic sensors and can be set up in varying combinations depending on site-specific objectives. For example, measuring seismic motion, gravity, magnetism, seafloor deformation, sedimentation, pore-water properties, gas hydrates, and fluid dynamics results in a much more comprehensive understanding and significantly increases geo-hazard early warning capability (Ruhl et al., 2011 [5]). Many physical and biological applications require instruments throughout the water column for recording high resolution time-series data over long periods. Depending on the specific application, these can be made up of profiling sensor arrays or sensors along mooring lines and even mooring arrays. Such systems can, for example detect variations in deep ocean currents and variations in the surface ocean or benthic boundary layers. And these specialized systems can include capability to synoptically measure physics, oxygen, nutrients, and other biogeochemical and ecological parameters. Other more specialized biogeochemical systems include sediment traps, pigment and hydrocarbon sensors and in the future, in situ mass spectrometry. Systems for marine ecological research include deepbiosphere monitoring time-lapse and video imaging, active acoustics, plankton sampling, associated chemical analysers, in situ respiration, and in a near future, in situ molecular and genetic analysis.

3. DATA MANAGEMENT

A data management policy is under implementation, it benefits from the latest issues of the ENVRI European project which develops common e-science operations between the most mature Research Infrastructures of the environment thematic in Europe. The convergence of this European orientation is expected with the other subsea Observatory initiatives such as Canadian (Neptune), US (OOI), Japanese (DONET), etc.

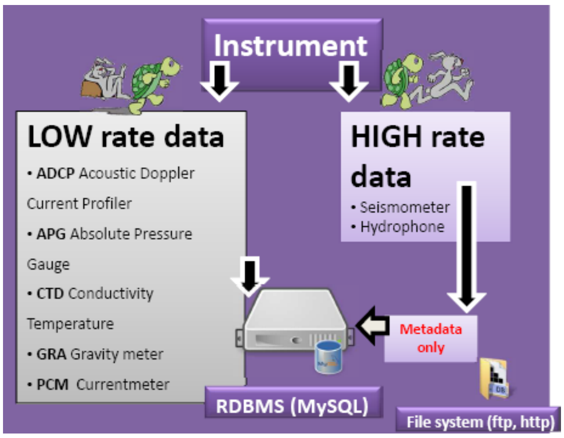

Figure 3: EMSO data flow.

The EMSO data infrastructure has been conceived to utilize the existing distributed network of data infrastructures in Europe and use the INSPIRE and GEOSS data sharing principles. A number of standards have been set forth that will allow for state-of-the-art transmission and archiving of data with the kinds of metadata recording and interoperability that allow for more straightforward use and communication of data (Figure 3). These standards include the Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) suite of standards, namely the OGC standards SensorML, Sensor Registry, Catalogue Service for Web (CS-W), Sensor Observation Service (SOS) and Observations and Measurements (O&M). OGC SensorML is an eXtensible Markup Language (XML) for describing sensor systems and processes. Following on progress from European funded project EuroSITES and others a SensorML profile is being created that can be stored in a so-called Sensor Registry that will act as a catalogue of each EMSO sensor. This dynamic framework can accommodate the diverse array of data and formats used in EMSO, including the addition of delayed mode data.

4. RESEARCH INFRASTRUCTURE

EMSO is a distributed infrastructure facing the difficulty of linking remote sites in extreme oceanic environments. Data transmission is the crucial function of a subsea observatory. It opens new perspectives to perform ocean scientific research. Indeed, real time or near real time transmission ensure that the data is collected under standardised conditions and will foster inter-comparison of time stamped series from generic and specific instruments of all disciplines.

The first generation of subsea observatories is now operating and they provide a foundation for EMSO implementation. Since beginning of EMSO Preparatory Phase in 2008, the capital and R&D investments of several Member States have been postponed due to the financial crisis. Depending of the availability of investment funds and the main focus of research, the infrastructure will consist either of:

- a cabled backbone providing internet connection to the shore or
- an acoustic stand alone station transmitting data to relay buoys which are able to provide a satellite link to the shore.

The power distribution and real time data will be the advantage of the cabled observatories. The branches of the cabled network will include nodes for high voltage to low voltage transformation and junction boxes (200 W, 1kW or 9kW) providing data and power branching of instruments.

The European infrastructures existing or under construction at the end of EMSO PP, although not sufficient to fulfil all scientific objectives, already demonstrate European expertise and capacity. Their management in a coordinated way is the first stage of EMSO.

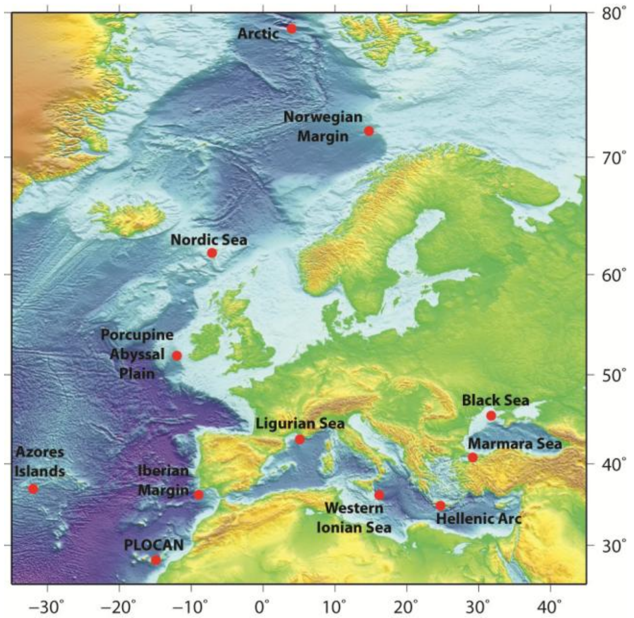

Figure 4: EMSO sites.

The operating EMSO sites are:

Arctic - Hausgarten

- Deep-sea observatory operated by AWI since 1999
- 15 permanent sampling sites
- Moorings and long-term lander systems since 2000
- Research: Evaluation of heat and mass transport through the Fram Strait; links between climate and surface ocean processes and deep-sea ecosystems; methane hydrate dynamics (with co-funding from Statoil-Hydro)
- Previous/recent activities: Arctic Ocean ESONET Mission (AOEM), HERMIONE and HYPOX research.

Prins Karls Foreland (PKF) - Seep Area: Since 2008 at least on cruise per yearly has been performed among UK, Norway, Germany and Dutch partners to study and monitor methane emissions offshore PKF.

- Next step: funding by Germany of a study of long term monitoring and possible cabled solutions

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Porcupine Abyssal Plain (PAP) Sustained Observatory.

- Active time-series station since 1980s
- Some data transmitted in near real-time by satellite
- Research: biogeochemical and physical measurements from upper 1000 m; seafloor video and photography; biogeochemical flux measurement systems

Azores - Lucky Strike hydrothermal vent field.

- Site active for more than a decade, observatory implemented and visited through a yearly maintenance since 2010.
- Research: geophysical movements of Earth (seismicity and vertical deformation); water, heat and mineral flow through vent system; behaviour of physical and chemical elements in vent fluid; variations in biogeochemistry and the ecological hotspots in vicinity of vents
- Next step: new subsea equipments under design for the monitoring from 2014 onwards.

Ligurian Sea

- **East Ligurian sea:** a) DYFAMED - DYnamics of Atmospheric Fluxes in the MEDiterranean Sea) b) Var canyon monitoring c) Nice slope monitoring of Geohazard

- **West Ligurian Sea – ANTARES** – Earth-Sea science extension of astrophysics underwater telescope (Astronomy with a Neutrino Telescope and Abyss environmental RESearch)
  Characterized by coastal upwelling, particle plumes, nutrient benthic exchange, bottom boundary layer processes, seismic monitoring.
- Research: sub-sea geophysics; slope stability; biogeochemical fluxes and marine ecology
- Next step: Cabled infrastructure in Nice airport area and participation to the new cabled infrastructure in West Ligurian Sea as MEUST project.

East Sicily - NEMO-SN1 seafloor observatory

- Cabled to laboratory in harbour of Catania by electro-optical cable
- Operating in real time since 2005
- Research: Geohazards, tsunami, climate change, bioacoustics and ambient noise.
- Integrated with land-based networks by transmitting real- time data to National Seismological Service Centre in Rome
- Next step: branches of the subsea cabled observatory dedicated to EMSO.

Hellenic Arc

- Series of four networks in the Hellenic study area
- Cabled system **NESTOR**, Stand alone **Poseidon Pylos and Poseidon E1-M3A** (35°66'N, 24°99'E).
- Research: Geohazards, tsunami, climate change, bioacoustics and ambient noise, biogeochemical fluxes, benthic-pelagic interactions; benthic respiration; biogeochemical fluxes; photography-based ecology; seabed methane fluxes; oil and gas industry activities
- Ongoing: tender on a new cabled observatory.

PLOCAN Canarias

- **ESTOC/PLOCAN** - European Station for time-series on the ocean
- Operating since 1994
- Research: ocean physics and biogeochemistry; decadal record of ocean acidification

Previous/recent activities: part of EuroSITES network and contributes to the Bermuda Atlantic Time-Series site (BATS)

- Next step: cabled observatory under construction.

The main projects under preparation for an implementation in 3 to 5 years : Marmara Sea, Black Sea, Iberian Margin, Norwegian Margin.

Three test sites, cabled to the shore with distance of a few kilometers are operating: Molènes island in France, built thanks to the European Interregional project MeDON, OBSEA observatory near Barcelona and Koljofjord in Sweden. Another observatory is funded in Ireland: Smart Bay.

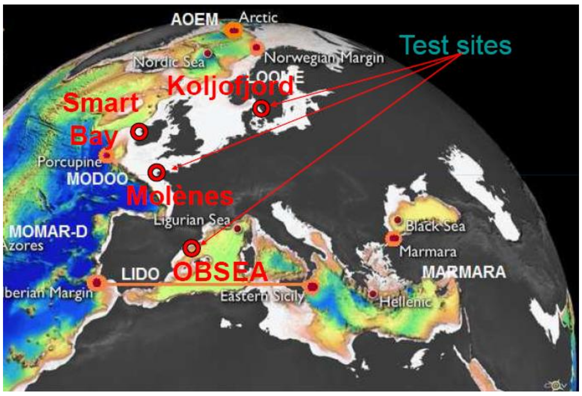

Figure 5: EMSO test sites are cabled to the shore and allow the evaluation of sensors.

5. EMSO AS A LEGAL ENTITY

The governance of EMSO will comply with the legal framework of a European Research Infrastructure Consortium (ERIC). The principal task of the new type of legal entity under European law called ERIC is to establish and operate a research infrastructure.

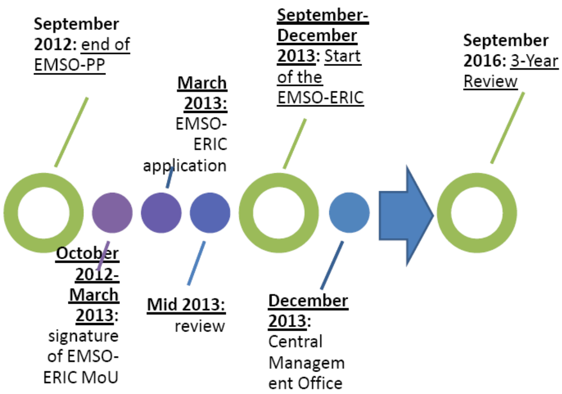

Figure 6: EMSO implementation planning.

It is planned to be operating during several decades after a 3 year integrating phase (Figure 6).

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