The European Multidisciplinary Seafloor and water-column Observatory: The development and utilisation of largescale distributed European cabled marine research infrastructure.

Paul Gaughan (MI) Ireland, Laura Beranzoli, Paola Materia (INGV & EMSO Interim Office), John B. Picard, Mairi M.R. Best (EMSO Interim Office), Italy; Jean-Francois Rolin (IFREMER), Mathilde Cannat (IPGP), France; Christoph Waldmann (KDM), Germany; Michael Gillooly, Fiona Grant (MI), Ireland; Per O.J. Hall (UGOT), Sweden; Vasilios Lykousis (HCMR),Greece; Henry A. Ruhl (NOCS), UK; Benedicte Ferré, Jürgen Mienert (UIT), Norway; Jorge Miguel Alberto de Miranda (IPMA), Portugal; M. Namik Çağatay (ITU), Turkey; Henko De Stigter (NIOZ), The Netherlands; Juan José Dañobeitia,(CSIC), Eric Delory (PLOCAN), Spain; George Oaie, Vlad Radulescu (GeoEcoMar), Romania.

Abstract:
EMSO (European Multidisciplinary Seafloor and water-column Observatory; http://www.emso-eu.org) is a large-scale European Research Infrastructure (RI) composed of fixed-point, seafloor and water-column subsea networks and observatories with the scientific objective of near- and real-time, long-term monitoring of environmental processes related to the interaction between the geosphere, biosphere, and hydrosphere. EMSO infrastructure is distributed in European waters, from the **Arctic**, through **the Atlantic** and **Mediterranean Sea** to the **Black Sea**. EMSO will be the sub-sea segment of the COPERNICUS initiative and will significantly enhance the observational capabilities of European Member States. The EMSO User Strategy is closely aligned with Blue Growth -the long term strategy of the European Union to support sustainable growth in the marine and maritime sectors. The strategy includes a vision of the EMSO infrastructure as the heart of a powerful, new European high-tech marine science and technology Innovation Platform.

1. Introduction to EMSO

EMSO is one of the environmental Research Infrastructures included on the roadmap of ESFRI (European Strategic Forum for Research Infrastructures) since 2006. It provides a new kind of large-scale infrastructure able to spur multidisciplinary and inter-disciplinary investigation of deep ocean processes related to Marine Ecosystems, Climate Change and Marine Geo-hazards. Such fixed-point open ocean observations significantly enhance the marine environmental research capabilities of European member states and increase the potential for adequately responding to the major challenges related to environmental changes. EMSO contributes to the *in situ* observations of the Global Monitoring for Environment and Security initiative (formerly GMES, now renamed COPERNICUS programme. [1]

In 2013, the ESFRI Assessment Expert Group (AEG) established by the EC provided the assessment of EMSO RI maturity and accordingly the RI's statutes and plans were improved such that they are fully in line with AEG recommendations. Later in 2013, these improvements were further checked and approved by the ESFRI Environmental Working Group.

The global ocean covers 95% of the living space of our planet, and is the core momentum of our planet's physical, chemical, and biological cycles. In order to have a hope of understanding and navigating the changes predicted for the coming decades, we must have a continuous, interactive, and comprehensive observing presence in the oceans. Long-term fixed-point observatories provide continuity, vigilance and high time-resolution data in time (milli-seconds to minutes). This makes them uniquely able to resolve sudden, hourly, daily, tidal, monthly and annual cycles as well as decadal environmental trends. Continuous observation allows the detection of unpredictable events such as earthquakes, tsunamis, dense water cascades, plankton blooms, water mass movements, and influence of eddies, which cannot be detected by infrequent, short-term ship expeditions. Furthermore by monitoring the water column from the surface to the sea floor, phenomena can be investigated that are beyond the reach of remote sensing. Spanning a range of temporal and vertical spatial dimensions at fixed (Eulerian) points, across a regional scale, the EMSO observatory nodes are complementary to remote sensing, gliders, ship-borne and mobile (Lagrangian) methodologies.

2. Global Ocean Observations - the Vision

As underlined in recent policy documents such as the **Galway Statement** [2] **and Belmont Challenge**[3], in order to understand the changes predicted in the coming decades, EMSO aims to have a continuous presence in the oceans; and in order to understand both the slow moving and rapid catastrophes, EMSO seeks to have continuous real-time data from which to learn and to derive adaptation and early warning systems. Ocean observatories provide power and communications to allow a sustained interactive presence in the ocean. This challenge can only be addressed as part of an international cooperation between USA,[4] Canada, Japan, Australia, Europe and other interested countries where EMSO takes a role for the European side.

Oceans are under increasing pressure from human activities such as pollution and overfishing. Human-induced changes taking place in our seas and oceans include: rising temperatures, melting of polar ice, ocean acidification, extreme weather events, marine invasive species, changes in biodiversity and species distribution, and depletion of fisheries stocks; these changes are already having a profound impact on our societies, increasingly so in the medium-term. Oceans produce the vast majority of our planet's biomass, and regulate oxygen, heat flux, greenhouse gases, and climate.

Understanding processes in the marine environment is of paramount importance for any prediction of short-, intermediate- and long-term global change. The oceans are complex dynamic systems across scales of time and space, including processes from episodic catastrophic events to slow trends difficult to discern from the overlying variability of short-term processes. The high resolution, long-time-series collection of multiple variables across a breadth of environments represents the only approach capable of shedding light on the complexity of these systems.

EMSO was set up in 2006 to provide the interactive monitoring capacity to track these critical changes and ecosystem services. Research focused on the seas and oceans is central to addressing these challenges by delivering knowledge and tools to enable mankind to prepare for, and adapt to, these changes. To truly advance this knowledge, scientists across a broad range of disciplines and domains must make a quantum leap towards integrated research and innovation on a scale which will help us to much better understand, protect, manage, and sustainably exploit the seas and oceans that surround us.

3. Scientific Challenges

Over the past few decades, research has revealed the enormous complexity of processes that operate in the largest habitat on Earth: the oceans. The importance of these processes lies in the mechanistic link to functions that directly affect human societies, including climate regulation, carbon dioxide uptake, oxygen production, and the provision of natural resources, all of which are essential to the well-being of human populations. Over the last century, global climate change, the worldwide degradation of ecosystems, rapid population growth, and the depletion of resources have led governments and international organizations to acknowledge the imminent need to better understand the causes and consequences of these changes. The Intergovernmental Panel on Climate Change (IPCC) estimates that global warming will continue for centuries and will have pervasive impacts on society[5,6].

As a result of this growing awareness, European researchers have been focusing on programs that address urgent earth and ocean science related questions of international priority such as the impacts of climate change or threats posed by geo-hazards (e.g., earthquakes and tsunamis).

In order to provide meaningful answers to such questions, patterns and processes that range over many time and spatial scales have to be resolved. *In situ* observations of key ocean variables over long timescales and with adequate temporal resolution are an essential part of addressing these issues.

To provide an integrated approach, consecutive EU Framework Programs have invested in the integration of the geosciences, physical oceanography, bio-geochemistry and marine ecology communities with long-term, fixed point nodes in the deep ocean representing a key contribution (Table 1). These distributed infrastructures augment traditional research projects with standardized and integrated

in situ observations by addressing interdisciplinary objectives simultaneously across temporal and spatial scales.
The processes that occur in the oceans have a direct impact on human societies, therefore it is crucial to improve our understanding of how they function and interact. To encompass the breadth of these major processes, sustained and integrated observations are required that appreciate the interconnectedness of atmospheric, surface ocean, water column, deep-sea, and solid-Earth dynamics. Maintaining observations of key ocean variables - at different observatory locations, over long timescales, with adequate temporal resolution - has been challenging. However, multi-parameter datasets enable more multidisciplinary methods, giving strong benefits to many disciplines[8]. Seafloor observatories are a powerful tool for long-term multidisciplinary data collection[9]. Major international science priorities in the multidisciplinary fields of geosciences, physical oceanography, biogeochemistry, marine ecology, and geo-hazards are being advanced through observatory development and networking (Table 1).

Geosciences	Interactions of geosphere with hydrosphere and biosphere, fluid flow and gas seepage through sediments and vents, gas hydrate dynamics, non-living resources, sediment transfer to the deep-sea, elemental cycling and links to climate change
Geo-hazards	earthquake and tsunami hazards, volcanic hazards, slope instability and failure, gas hydrate release
Physical oceanography	water mass characterization, currents and mixing, thermodynamics, ice cover, climatology, and links to climate change
Biogeochemistry	global carbon cycle and elemental cycling within the ocean through both physical and biological processes, and climate feedbacks
Marine ecology	distribution and abundance of sea life, ocean productivity, biodiversity, ecosystem function, living resources, carbon cycling and climate feedbacks

Table 1 Scientific multidisciplinary fields related to fixed ocean observatories *[10]*

4. Map of EMSO nodes (yellow circles) and shallow-water test sites (white triangles)

5. EMSO ERIC Multidisciplinary User Community

In order to appreciate the variety and extent of the EMSO ERIC wide potential user base, it is useful to review again the numerous components that make up the EMSO ERIC Research Infrastructure system. This overview reflects the users' perspective in terms of services to which they have access. These include:

- ***Cabled Infrastructure*** - permanent infrastructures including measuring instruments deployed on the seabed and water column, continuously acquiring time series of oceanographic and geophysical data; through electro-optic cables extending across the seafloor, instruments are powered and interactive communication allows transmission in real time the acquired measurements;
- ***Stand-alone observatories*** - infrastructure composed of mono-and multi-parametric modules for marine monitoring, which can be relocated and used for experiments in specific areas of interest. Real-time data connection can be provided through buoys with satellite links. Bandwidth and power are balanced against flexibility of placement, including in remote locations;
- ***Supporting Infrastructure*** - includes equipment needed for optimal management and maintenance of cabled and non-cabled observatories, including ROVs, and execution of research and services;
- ***Laboratories for the Analysis of the Marine Environment*** - laboratories with multidisciplinary research capabilities for the analysis of water samples, sediment and biota;
- ***Laboratories for Development of new Sensors and Technologies*** - laboratories and test sites dedicated to marine monitoring systems and research and testing of new technologies (e.g., components, sensors, materials, techniques).
- ***Data Centres*** - centres dedicated to data collection, management, discovery, access, transmission, storage, analysis/products, modelling,

sharing and, together with private partners, commercialization of data products.

6. EMSO Governance and Governing Bodies

EMSO ERIC will be the legal entity responsible for coordinating and facilitating access to open ocean infrastructure of fixed-point observatories in Europe [11]. Italy is the host country for the EMSO ERIC. The procedure to create EMSO ERIC started in December 2013 (submission to EC of the step 1 by the Permanent Italian Representative in Brussels) and was completed in spring 2016.

The EMSO ERIC organisation is designed to enable the long term functioning of a geographically distributed and remotely located array of fixed-point ocean observatories as a single research infrastructure. The statutory governance structure of EMSO ERIC is schematically illustrated in Figure 1 and comprises the following bodies:

- Assembly of Members (AoM)
- Director-General (DG);
- Executive Board (EB);
- Scientific, Technical and Ethical Advisory Committee (STEAC).

Moreover, the operation of EMSO Research Infrastructure is enabled by:

- *Central Management Office (CMO)*, located within the Statutory seat, supporting the DG in day-to-day management and service provision;
- *Regional Teams*, in charge of managing EMSO facilities at regional level;
- *Service Groups* in charge of delivering services to users.

The Regional Teams and Service Groups will be represented on the Executive Board of EMSO ERIC.

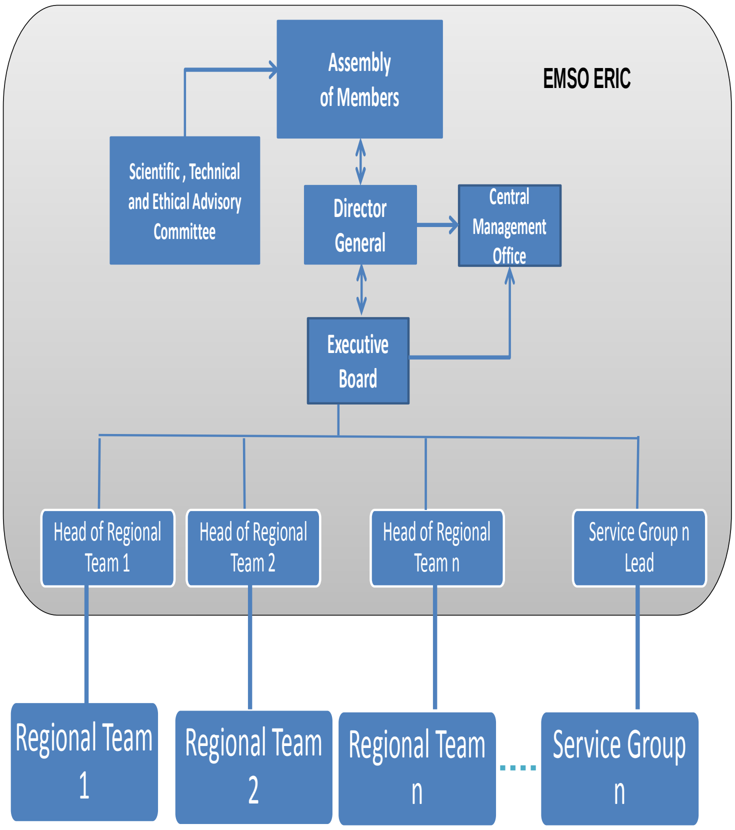

Figure 1: Emso governance Structure

On January 21st 2016 the ERIC (European Research Infrastructure Consortium) Committee approved the Step 2 of EMSO's application process to the ERIC. The positive opinion by the ERIC Committee will give the European Commission the green light to publish the

EMSO Statutes in the Official Journal of the European Union, final step of the approval process.

Full members of EMSO-ERIC, at this time, are: **France, Greece, Italy and the UK**. Other countries are undergoing internal procedures to join as full members: **Ireland, Portugal, Romania, Spain**, and as observer: **The Netherlands.**

7. How is EMSO relevant to the subsea cable industry?

Elements of the EMSO initiative relevant to **industry** include:

[1] a value proposition centered on the collection, validation, and dissemination of key, long time-series, marine scientific data.
[2] an innovation hub which provides a rich environment for an ecosystem in which EMSO's "core product" - quality scientific data - are continuously enriched by innovations from partners and third-party suppliers and developers across diverse disciplines.
[3] a multidisciplinary community of users, suppliers, developers, value-added providers, advocates and sponsors; all drawn from scientists, policy-makers, business people, educators, media and citizens.
[4] user engagement and retention tools - an open access data policy and data standardization across a distributed infrastructure.
[5] market analysis - where Industry is most likely to benefit from cooperation with EMSO such as subsea sensors and networks, offshore oil & gas, unmanned vehicles, deep-sea mining, and tidal, wave and wind energy;
[6] value-added services such as Trans National Access (TNA).

8. Why the subsea cable industry should be interested in EMSO?

The emergence of these government-funded subsea scientific observation platform will prove to be a powerful resource for the Tele-communications industry, with public-sector investments having already solved many of the questions and challenges required for the scientific monitoring of the ocean floor. The sensor specifications and real-time data management issues have been defined and addressed. Interoperability between different platforms is a key new feature of the EMSO Platform. The opportunity now exists to develop Public-Private partnerships for testing sensors and prototypes in situ, without the need to develop new test facilities.

A convincing scientific and societal case for the integration of environmental sensors into new submarine telecommunication cables was presented in white paper by Butler et. al. (2014)[12]

The paper suggests that the status of submarine cables as critical infrastructure necessitates the incorporation of basic sensors to monitor that infrastructure. Without this basic data, the design of cable systems remains uninformed with regard to the natural and manmade hazards that must be mitigated.

The scientific and societal reasons for the sensor incorporation into subsea cable infrastructure are compelling. A relatively straightforward complement of instrumentation - accelerometers, high-resolution pressure gauges, thermometers - will answer many of the basic science and societal needs as well as provide for the monitoring of the physical state-of-health of the cable system itself. Technological advances have made it possible to integrate basic sensors with repeaters on submarine telecommunication cables at intervals of about 50-70 km, at an estimated installation cost of 5-10% of the total cost of system deployment.

9. Conclusions

An innovation platform like EMSO will provide an effective testing environment and supporting infrastructure to develop and enhance these improved sensing technologies and ensure their effective integration into existing cabled observatories for long term monitoring.

The ongoing progression in ICT developments, increased use of Internet and advances in subsea technology will contribute to the need to upgrade or replace the existing subsea cable infrastructures over the next 20 years offering an opportunity to deploy more sophisticated sensing equipment to monitor ocean processes as well as the health and performance of the cable systems themselves. The EMSO platform will be at the cutting edge of this interface between industry technological requirements and publically funded infrastructures.

We need to find the right models for funding and operating hybrid cable systems such that the ultra-high reliability demanded by submarine cable owners is maintained. This needs to be supported by a commitment by future users – including academia, governments, NGOs and disaster response agencies – to subscribe to the new environmental data services in light of the huge benefits they will bring. The EMSO ERIC and its governance structure is a major step towards linking the key stakeholders to achieve this goal.

Other stakeholders involved in installation of subsea cable networks as part of their operations include The Offshore Oil and Gas Sector, Marine Renewable Energy sectors and the emerging Deep Sea mining industry. These sectors have a requirement for multi-purpose cables where the installation of environmental monitoring sensors is an increasingly important consideration when considering installation of cabling.

Cable companies need environmental information to perform due diligence on protection of their assets to prepare and mitigate for the risks - both man made

events and natural hazards of their cable installations.
That the global Under-sea communications cable infrastructure does not monitor its ocean environment is itself extraordinary. As a matter of both scientific prudence and societal necessity, addressing this flaw is a matter of satisfying the due diligence requirements associated with the mitigation of future outages in global Internet traffic.[12]

The EMSO ERIC is a new powerful coalescence of multiple national ocean observatory infrastructures across Europe and will provide the interactive monitoring capacity to track critical changes in our oceans. EMSO ERIC will also promote private-public partnerships with industry to foster innovation in the marine domain.

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