PAPER

The EMSO-ERIC Pan-European Consortium: Data Benefits and Lessons Learned as the Legal Entity Forms

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ABSTRACT

The European Multidisciplinary Seafloor and water-column Observatory (EMSO) European Research Infrastructure Consortium (ERIC) provides power, communications, sensors, and data infrastructure for continuous, high-resolution, (near-)real-time, interactive ocean observations across a multidisciplinary and interdisciplinary range of research areas including biology, geology, chemistry, physics, engineering, and computer science, from polar to subtropical environments, through the water column down to the abyss. Eleven deep-sea and four shallow nodes span from the Arctic through the Atlantic and Mediterranean, to the Black Sea. Coordination among the consortium nodes is being strengthened through the EMSOdev project (H2020), which will produce the EMSO Generic Instrument Module (EGIM). Early installations are now being upgraded, for example, at the Ligurian, Ionian, Azores, and Porcupine Abyssal Plain (PAP) nodes. Significant findings have been flowing in over the years; for example, high-frequency surface and subsurface water-column measurements of the PAP node show an increase in seawater pCO_2 (from 339 µatm in 2003 to 353 µatm in 2011) with little variability in the mean air-sea CO_2 flux. In the Central Eastern Atlantic, the Oceanic Platform of the

Introduction

The European Multidisciplinary Seafloor and water-column Observatory (EMSO, emso-eu.org) is a pan-European distributed research infrastructure, composed of fixed-point open ocean observatory nodes, whose aim is to provide coherent long-term data sets to study and monitor European seas. Changes relating to resource availability, climate change, habitat destruction, and geohazards have increased society's need for an improved understanding of the driving factors and the effects of such changes (e.g., Ruhl et al., 2011). EMSO includes polar to subtropical marine environments,

Canary Islands open-ocean canary node (aka ESTOC station) has a long-standing time series on water column physical, biogeochemical, and acidification processes that have contributed to the assessment efforts of the Intergovernmental Panel on Climate Change (IPCC). EMSO not only brings together countries and disciplines but also allows the pooling of resources and coordination to assemble harmonized data into a comprehensive regional ocean picture, which will then be made available to researchers and stakeholders worldwide on an open and interoperable access basis.
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from the surface down to the abyss. Eleven deep-sea and four shallow nodes span from the Arctic, through the Atlantic and Mediterranean, to the Black Sea (Figure 1).

EMSO observation data are collected from the ocean's surface, through the water column to subseafloor across geohazard, physical, biogeochemical, and ecological themes, with various emphases depending on location (Best et al., 2014; Favali et al., 2015b; Ruhl et al., 2011).

A New Type of Research Infrastructure

EMSO is forging ahead through the next challenge in earth-ocean science: how to coordinate ocean data acquisition, analysis, and response across provincial, national, regional, and global scales. When compared to other environmental infrastructures that have been established for decades (e.g., seismic and satellite systems), ocean observatories are a recent development (Favali et al., 2015b). EMSO represents the European effort, counterpart to similar large-scale systems around the world: Canada (Ocean Networks Canada [ONC], oceannetworks.ca), United States (Ocean Observatories Initiative [OOI], oceanobservatories.org), Japan (Dense Oceanfloor Network System for Earthquakes and Tsunamis [DONET], jamstec.go.jp/donet), China (East China Sea Seafloor Observation System [ECSSOS]), Australia (Integrated Marine Observing System [IMOS], imos.org.au), Taiwan (Marine Cable Hosted Observatory [MACHO], scweb.cwb.gov.tw/macho-web), India (Indian Ocean Observatory, www.theioo.com), and Cyprus (Offshore Communications Backbone [OCB]). Together, these will constitute a single powerful integrated global ocean observation network (Best et al., 2014). They are also inherently multidisciplinary and interdisciplinary and distributed geographically. While this can increase the challenge of harmonizing them at an international scale, it also means that there is the opportunity to do so before designs and protocols diverge too far.

FIGURE 1

Map of EMSO nodes. EMSO includes polar to subtropical environments, from the surface down to the abyss. Eleven deep-sea and four shallow nodes span from the Arctic, through the Atlantic and Mediterranean, to the Black Sea.

History and Linkages

It is important to appreciate that the various national initiatives that come together to form the distributed European Research Infrastructure Consortia (ERICs) have already experienced the challenges of any nationally supported infrastructure, including, in some cases, federated provinces and contributions of more than one institute (academic and/or governmental) and/or nation to an infrastructure. Potential ERICs that were placed on the European Strategy Forum on Research Infrastructures (ESFRI, esfri.eu) Roadmap met additional criteria—there was a demonstrated need for a pan-European infrastructure in the given domain. With EMSO on this roadmap, as an early example of a necessarily distributed infrastructure, the EMSO Preparatory Phase (FP7) project led to the Interim Phase (involving 13 countries) of forming the legal entity—the EMSO ERIC. Legally founded in 2016, the founding members of the EMSO ERIC include Italy (host nation), Greece, United Kingdom, France, Ireland, and Portugal; Spain, Romania, and Turkey continue to traverse their national membership processes; and Germany, Sweden, Norway, and the Netherlands continue to be part of the discussion. National membership is open to growth, and initial discussions have already started with other potentially interested countries, such as Malta, Croatia, Iceland, Cyprus, and Tunisia.

Marine science communities at national levels are also progressively joining together to network, share, and exploit their research infrastructures, efforts, and skills in support of EMSO. It is particularly important to have this national-level coordination as the ERIC structure is according to national membership. For example, Italian and French communities have established joint research groups, namely, EMSO Italia and EMSO France, gathering research institutions and universities under the leadership of Istituto Nazionale di Geofisica e Vulcanologia in Italy and Institut Français de Recherche Pour L'exploitation de la Mer and Centre National de la Recherche Scientifique in France. In the United Kingdom, the EMSO affiliation contributes to the national capability research framework of the Natural Environment Research Council. These research groups help to increase awareness of the EMSO opportunities and broaden the scientific user base. At the regional to global scale, the open user community is supported through European Seafloor Observatory NETwork–The Vision (ESONET-Vi, visobservatories.webs.com), following on the extensive scientific community planning contributions of the ESONET-NoE (FP6) project.

Along with EMSO ERIC and ESONET-Vi, the $FixO_3$ project (FP7) follows on the efforts of ESONET-NoE and EuroSITES FP6 projects to pull together the efforts of the European science community toward fixed-point ocean observatories. The $FixO_3$ project strengthens in particular the EMSO nodes and regional teams, operating at their national levels, and continues the development of the concept of a "label" for assessed technologies and services.

The broader target of coordination among environmental research infrastructures at the regional to global scale benefits from progress through the CoopEUS (coopeus.eu), COOP+ (coop-plus.eu), ENVRI, and ENVRIplus (envri.eu) Coordination and Support Action (CSA) EC projects. EMSO also represents a fundamental contribution to the long-term vision of the European Ocean Observing System (EOOS). It will contribute *in-situ* observations for the Global Monitoring for Environment and Security Initiative, COPERNICUS, and is aligned with the challenges and key priorities of Horizon 2020 and, in particular, with the Marine Strategy Framework Directive (MSFD). The data collected by EMSO already support policy and legislation of organizations such as the Intergovernmental Panel on Climate Change (IPCC), the United Nations Environment Programme (UNEP), and the Group on Earth Observation (GEO).

Infrastructure Evolution

EMSO open ocean observatory locations were identified according to the scientific priorities of the European marine science community, through multiple projects. These locations were selected because their ongoing key natural processes require long-term monitoring to understand their dynamics at the regional scale. EMSO spans from polar to subtropical climatic zones and from the open ocean (Atlantic) to closed basins (Mediterranean, Sea of Marmara, and Black Sea), thus offering a broad spectrum of study areas across diverse environments. Tests sites are also integral parts of the observatory network and are fundamental facilities for testing devices (software and hardware) to be incorporated into EMSO nodes.

The present operational modes of the nodes include both cabled and autonomous observatories, both with their benefits: while continuous data flow is provided by cabled nodes that receive power and communications directly from land, autonomous observatories are powered with long-lasting batteries, store the acquired data locally, and provide greater flexibility in placement. Some of the latter periodically transfer some data via acoustics or cable communications from the deep ocean to a surface buoy, which in turn sends them to land stations by satellite.

EMSO nodes have been developed in response to national to regional requirements. As such, they were designed and developed fit-to-purpose in a naturally distributed fashion. They have already experienced the support and growth challenges of any nationally supported infrastructure. The current challenge is the coordination of these distributed nodes, purpose built to address different societal concerns in the sea, to find the points of commonality where the whole may actually be greater than the sum of the parts.

EMSO Generic Instrument Module

Essential ocean variables (EOVs; ioc-goos-oopc.org/obs/ecv.php; Hayes et al., 2015) are being converged upon and are informing the development of standardized platforms. This process started in the surface ocean, as an extension of the "essential climate variables (ECVs)" concept, and therefore continues to require further input from the full water column and seafloor —over 90% of the living space of the planet. An example of addressing the need for this is the EMSOdev (H2020) project, which is developing the EMSO Generic Instrument Module (EGIM). Coordination among the consortium nodes through this project will produce standardized observations of temperature, pressure, salinity, dissolved oxygen, turbidity, chlorophyll fluorescence, currents, passive acoustics, pH, pCO_2, and nutrients. It also strengthens the consortium to operate as a whole greater than the sum of the parts, with each taking on different roles within the project; for example, the OBSEA Observatory (Aguzzi et al., 2011) at the Catalan-Balearic node will play its role as an important shallow-water test node within EMSO. This will create an innovative, standardized, and harmonized system of scientific measurements and time series. It will also strengthen Europe's role as a key player in the development of the International Oceanographic Commission–Global Ocean Observing System (GOOS). It is notable that the concept of working toward EOVs does not mean complete homogenization and standardization at a European level—for the foreseeable future, nodes will continue to have priority objectives such as ocean carbon research in one region or tsunami monitoring in another.

As the EGIM is open and modular, EMSO ERIC can also offer it as a service to industry for "client-specific" purposes. It can be used, for instance, for impact assessment of marine renewable energy concepts, for resource evaluation of marine turbines, for monitoring oil and gas spill accidents, for impact assessment of marine mineral resource extraction fields, for subsea monitoring of sediment debris flows (currents and turbidity), for geohazard monitoring of oil and gas production fields, and for monitoring fish behavior in key areas. Its compact and modular form marks a major advancement over larger and more complex approaches often needed in the past.

Node Upgrades

Early node installations are now being upgraded. For example, in October 2015, EMSO-France deployed a second cable and junction box serving the Ligurian Sea node in order to monitor slope stability offshore Nice. In 2016, the EMSO Azores node receives a major upgrade that will double its observing capacity. Also in 2016, the Western Ionian Sea Node's Capo Passero site will be installed (southernmost in the consortium), and the Catania site will be upgraded. Also in 2016, the Hellenic arc node in the Eastern Ionian Sea will be upgraded with a seafloor multidisciplinary cabled observatory.

Data Impact

Porcupine Abyssal Plain Node

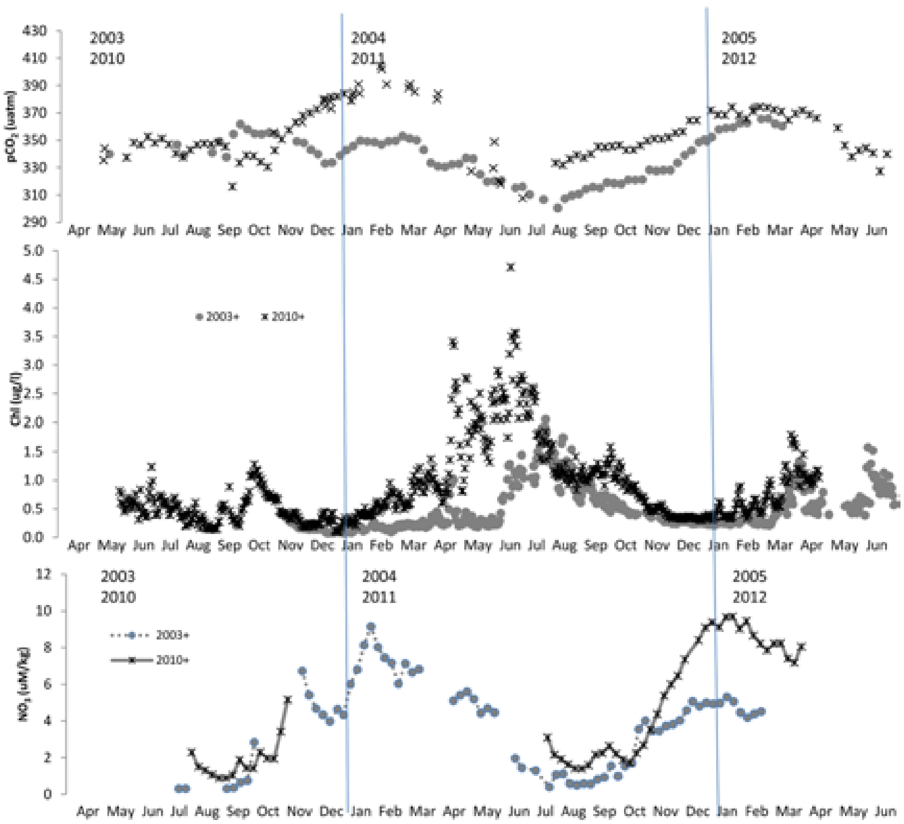
At the Porcupine Abyssal Plain (PAP) node in the northeast Atlantic (49°N, 16.5°W), we aim to understand the controls of biogeochemical fluxes in the open ocean to the deep seafloor and detect climate-driven trends from natural variability in the North Atlantic. Research includes quantification of the solubility and biological carbon pumps and their connection to changes in carbon sequestration as well as biomass and community structure over time. It is one of few locations globally where researchers can trace the effect of episodic events from climate and surface ocean variation to the deep seafloor, contributing *in-situ* data for understanding global change. High-frequency surface and subsurface water column measurements, using autonomously deployed instruments, show an increase in seawater pCO_2 (from 339 µatm in 2003 to 353 µatm in 2011) with little variability in the mean air-sea CO_2 flux. Year-to-year variations in the timing and intensity of the spring bloom occur despite similar winter physical conditions (temperature and mixed layer depth [MLD]) (Figure 2; Hartman et al., 2015). At the seafloor, sediment traps and time-lapse cameras have revealed how surface ocean variation can link to deep-sea food resource supply and reveal ecologically important animal functions and behaviors (e.g., Durden et al. 2015). Over 225 peer-reviewed papers have been published from the PAP time series since 1975 (noc.ac.uk/pap/publications).

Koljö Fjord Node

In this Swedish fjord, carbon cycling processes are tracked in high resolution in a coastal transition zone system rather than the deep sea of PAP. In this case, a cabled underwater observatory with more than 30 sensors delivering data in real time was used to study the dynamics of the upper pelagic carbonate

FIGURE 2

In-situ 30-m PAP-SO data from 2003 to 2005 (gray circles) and 2010 to 2012 (black stars) with vertical lines to represent the start of each year showing (a) p(CO_2), (b) chlorophyll a concentration, and (c) weekly averaged nitrate concentration (for further details, see Hartman et al., 2015).



system from September to April during 2 consecutive years (2011-2012 and 2012-2013). In the dynamic upper ca 15 m of the water column, salinity and temperature varied by up to 10 and 20°C throughout the recorded periods, respectively. Partial pressure of CO_2 (pCO_2), measured with newly developed optical sensors (optodes) at three water depths (5, 9.6, and 12.6 m), varied between 210 and 940 µatm, while O_2 varied between 80 and 470 µmol/L. Distinctive short-term variations of pCO_2 and O_2 were induced by either tidal oscillations, wind-driven water mass transport in the mixed layer, or occasional transport of deep basin water from below the thermo/halocline to the surface layer. Intensified air-sea gas exchange during short storm events was usually followed by stabilization of gas-related parameters in the water column, such as O_2 concentration and pCO_2, on longer time scales characteristic for each parameter. Biological processes including organic matter degradation in late summer/autumn and primary production in early spring were responsible for slower and gradual seasonal changes of pCO_2 and O_2. Net primary production (NPP) rates in the Koljö Fjord were quantified to be 1.79 and 2.10 g C m^{-2} during the spring bloom periods in 2012 and 2013, respectively, and ratios of O_2 production: dissolved inorganic carbon (DIC) consumption during the same periods were estimated to be −1.21 ± 0.02 (at 5-m depth in 2013), −1.51 ± 0.02 (at 12.6 m in 2012), and −1.95 ± 0.05 (at 9.6 m in 2013) (Atamanchuck et al., 2015).

Azores Node

The EMSO Azores fixed-point observatory aims to acquire, process, and model time series data to better understand water column and ecosystem dynamics at and above mid-ocean ridge hydrothermal vents. These ecosystems are controlled both by kilometer-scale hydrothermal circulations powered by magmatic heat and by smaller-scale near-seafloor surface fluid circulations and mixing between seawater and hydrothermal fluids. Currents in the water column near the seafloor also affect these fluxes. This fundamental knowledge is a prerequisite to assess faunal response to other potential sources of perturbation of the deep-sea environments, such as climate change, deep-sea mining, or hydrocarbon exploitation. Over the last few years, we have shown that the structure and composition of the dominant faunal assemblages at the Lucky Strike hydrothermal vent site are controlled by their position in the mixing gradient (Sarradin et al., 2009). Chemical processes in this gradient control the speciation of sulfide and metallic compounds (Aumond, 2013). Environmental conditions also influence not only the microbial production via the availability of energy sources (de Busserolles et al., 2009) and the proportion of endosymbionts in the mussel *Bathymodiolus azoricus* (Halary et al., 2008) but also the availability of toxic compounds and oxygen (Aumond, 2013; Sarradin et al., 2009). While the spatial distribution of the hydrothermal fauna is relatively well documented, only a few data are available on the temporal dynamics of hydrothermal ecosystems (Glover et al., 2010). Most studies concern recolonization processes on fast spreading ridges after catastrophic events (Shank et al., 1998) and rely on yearly cruises rather than on time series analyses (Sarrazin et al., 1997; Shank et al., 1998). The data quality procedure is now implemented and should stimulate the studies covering several years.

Oceanic Platform of the Canary Islands Node

In the Central Eastern Atlantic, the Oceanic Platform of the Canary Islands open-ocean node (aka ESTOC station) has a long-standing time series on surface and water-column variables, most notably on water-column physical, biogeochemical, and acidification processes. Acquired data have contributed to the assessment efforts of the IPCC and the characterization of oceanic processes in the North Atlantic subtropical gyre.

Western Ionian Sea and Hellenic Arc Nodes

The Western Ionian Sea (Favali et al., 2013) and Hellenic arc nodes are examples of systems that first and foremost feed into national and regional seismic, tsunami, and volcanic geohazard systems (Figure 3; Giovanetti et al., 2016). Like all fixed ocean observatories, they also provide power and communications and therefore have accommodated other instruments and applications of their data. For example, the high-resolution hydrophone data from the Ionian node are providing unparalleled information about marine mammals passing through these key marine straights (Figure 4; Sciacca et al., 2015).

Lessons Learned

- Ocean observatories are a recent development. They are also inherently

FIGURE 3

Examples of (top) regional earthquakes and (bottom) submarine landslides, both recorded by NEMO-SN1 cabled observatory (Western Ionian Sea EMSO node).

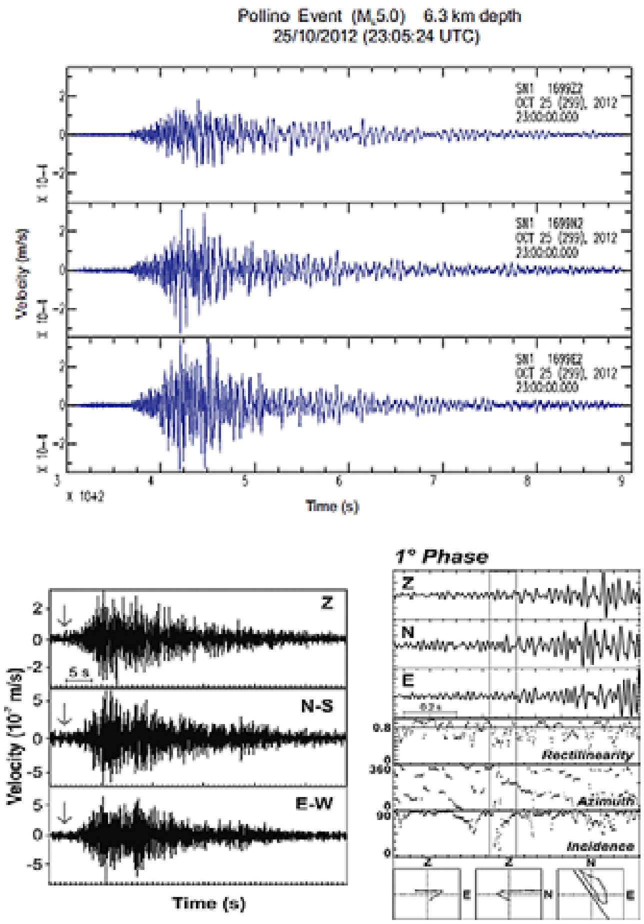
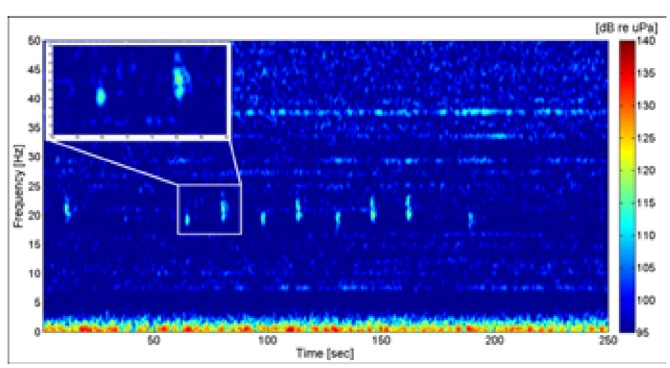


FIGURE 4

A typical detected sequence of fin whale calls, recorded by NEMO-SN1 cabled observatory (Western Ionian Sea EMSO node). The inset on the top right points out 18- to 20-Hz calls (for further details, see Sciacca et al., 2015). (Color version of figures are available online at: http://www.ingentaconnect.com/content/mts/mtsj/2016/00000050/00000003.)



multidisciplinary and interdisciplinary. While this can increase the challenge of harmonizing them at an international scale, it also means that there is the opportunity to do so before designs and protocols diverge too far (Favali et al., 2015a).

- In distributed environmental research infrastructures, the challenge is the coordination of distributed nodes, purpose built to address different societal concerns, to find points of commonality where the whole may actually be greater than the sum of the parts. This does not mean homogenization and standardization across the board, although they will be major assets, thanks to the engineering collaboration during EMSO preparation.
- It is important to appreciate that the various national initiatives that come together to form distributed ERICs have already experienced the challenges of any nationally supported infrastructure, including, in some cases, federated provinces, contributions of more than one institute (academic and/or governmental) and/or nation to an infrastructure, and so forth. Therefore, it is possible to move past national politics to form regional to global cooperation.

EMSO is forging ahead through the next challenge in earth-ocean science: how to coordinate ocean data acquisition, analysis, and response across provincial, national, regional, and global scales.

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