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EMSO: European Multidisciplinary Seafloor Observatory

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Abstract

EMSO has been identified by the ESFRI Report 2006 as one of the Research Infrastructures that European members and associated states are asked to develop in the next decades. It will be based on a European-scale network of multidisciplinary seafloor observatories from the Arctic to the Black Sea with the aim of long-term real-time monitoring of processes related to geosphere/biosphere/hydrosphere interactions. EMSO will enhance our understanding of processes, providing long time series data for the different phenomenon scales which constitute the new frontier for study of Earth interior, deep-sea biology and chemistry, and ocean processes. The development of an underwater network is based on past EU projects and is supported by several EU initiatives, such as the on-going ESONET-NoE, aimed at strengthening the ocean observatories' scientific and technological community. The EMSO development relies on the synergy between the scientific community and industry to improve European competitiveness with respect to countries such as USA, Canada and Japan. Within the FP7 Programme launched in 2006, a call for Preparatory Phase (PP) was issued in order to support the foundation of the legal and organisational entity in charge of building up and managing the infrastructure, and coordinating the financial effort among the countries. The EMSO-PP project, coordinated by the Italian INGV with participation by 11 institutions from as many European countries, started in April 2008 and will last 4 years.

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1. Introduction

A fully comprehensive definition of the term "seafloor observatories" was given for the first time by the National Research Council report "Illuminating the Hidden Planet. The future of Seafloor Observatory Science", where we could read: *"…an unmanned system, at a fixed site, of instruments, sensors, and command modules connected to land either acoustically or via a seafloor junction box to a surface buoy or a fibre-optic cable…"* [1]. These observatories will have power and communication capabilities and will provide support for spatially distributed sensing systems and mobile platforms. Sensors and instruments will collect data from the sea surface, along the water column to below the seafloor. These complex systems have been developed to overcome the limitations of the stand-alone modules with respect to multidisciplinary monitoring and (near)-real-time communications and integration (e.g., [2]).

The establishment of a global network of seafloor observatories will provide powerful means to understand the ocean and the complex physical, biological, chemical, and geological systems operating within; - an important goal for the next decades. Much of seafloor observatory research is indeed interdisciplinary in nature and has the potential to greatly advance relevant scientific sectors, such as: 1) the role of the Ocean in climate; 2) dynamics of oceanic lithosphere and imaging the Earth's interior; 3) fluids and life in the Ocean crust; 4) coastal ocean processes; 5) turbulent mixing and biophysical interactions; and 6) ecosystem dynamics and biodiversity [3]. Seafloor observatories could thus offer Earth and Ocean scientists new opportunities to study multiple, interrelated scientific processes over time scales ranging from seconds to decades, such as: a) episodic processes; b) processes with periods from months to several years; c) global and long-term processes.

As a consequence of the adoption of this new approach, a new science, the "Seafloor Observatory Science", has progressively gained ground dealing with: a) studies of the Earth as an integrated system, looking at the interactions among geosphere, biosphere and hydrosphere; b) investigation of the links among phenomena traditionally studied separately; and c) uses of complex underwater observation systems [1].

2. Technology

Manifold scientific and practical advantages can be achieved with the use of seafloor observatories as they allow: a) to overcome limitations of traditional ship-based expeditions for data and sample gathering; b) to fulfil both near-real-time and real-time communication of data; c) to advance research in the Ocean, Earth and climate sciences, thus addressing important socio-economic issues. In this respect seafloor observatories represent the most recent technological advancement upon which Earth science can now rely.

The seafloor observatories are characterised by the following basic elements: a) multiple payload; b) long autonomy; c) capability to communicate; d) possibility to be remotely reconfigured; e) accurate positioning; f) data acquisition procedures compatible with those of land networks.

Different configurations can be adopted for the observatories according to the environmental conditions and monitoring scopes [3]:

1) **Autonomous:** Observatory in stand-alone configuration powered using battery packs, and with limited capacity connection, using, for instance, capsules, releasable by command or at programmed time, or an acoustic link from the surface, which can transfer either status parameters or a very limited quantity of data.
2) **Acoustically linked:** Observatory able to communicate by acoustics to an infrastructure, such as a moored buoy or another observatory.
3) **Cabled:** Observatory having as infrastructure a submarine cable (retired cables, dedicated cables or shared cables devoted to other scientific activities, such as neutrino experiments).

Support infrastructures can be considered as part of the observatories as they provide power and/or communications capacity to an observatory (e.g., a submarine cable, a moored buoy, another observatory). An infrastructure may also be the support to other instrumented packages that are sensor- or instrument-devoted to a specific observation task. Sensor packages may be hosted inside the observatory, operated autonomously, directly connected to an infrastructure or placed near an observatory, acting as its infrastructure, and interfaced to it.

3. The European experience

The European experience on seafloor monitoring was started in early '90s with the European Commission (EC) MArine Science and Technology (MAST) Programme. Feasibility studies were commissioned by EC to identify the scientific requirements [4] and to establish the possible technological solutions for the development of seafloor observatories (ABEL, [5]). In parallel, other studies and activities, such as DESIBEL [6], were carried out at EC level, aimed at defining needs and expectations for long-term investigations at abyssal depths.

Following these feasibility studies from 1995 to 2001 the EC supported the GEOSTAR and GEOSTAR-2 projects devoted to develop and test, in actual deep-sea conditions, a single-frame seafloor autonomous observatory for long-term (over one year) multidisciplinary monitoring at abyssal depths (down to 4000 m). The concept is shown in Fig. 1 [7, 8].

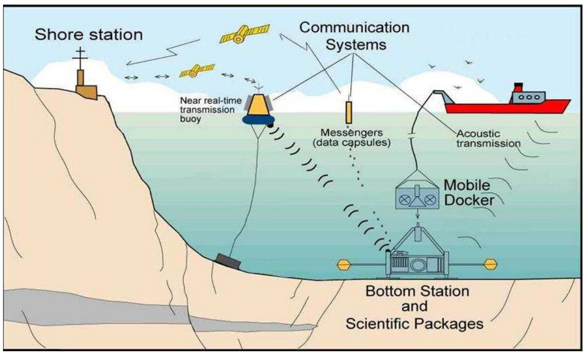

Fig. 1. GEOSTAR Conceptual scheme: the seafloor observatory (Bottom Station) is managed by the dedicated vehicle Mobile Docker (now called MODUS) and communicates through an underwater acoustic link with a ship of opportunity, through data capsules (Messengers), or a surface buoy, and then through satellite links to the shore.

The whole system is based on three main sub-systems: a) the seafloor platform, i.e. the Bottom Station hosting all the sensors, the primary lithium battery pack for power, the DACS (Data Acquisition and Control System), and the underwater part of the communications (Fig. 2a, bottom); b) the communications, mainly based on an acoustic link to a surface buoy and then satellite link (Fig. 2b); c) the special vehicle for deployment and recovery (MODUS, MObile Docker for Underwater Sciences) (Fig. 2a, top) [2, 3, 7, 8].

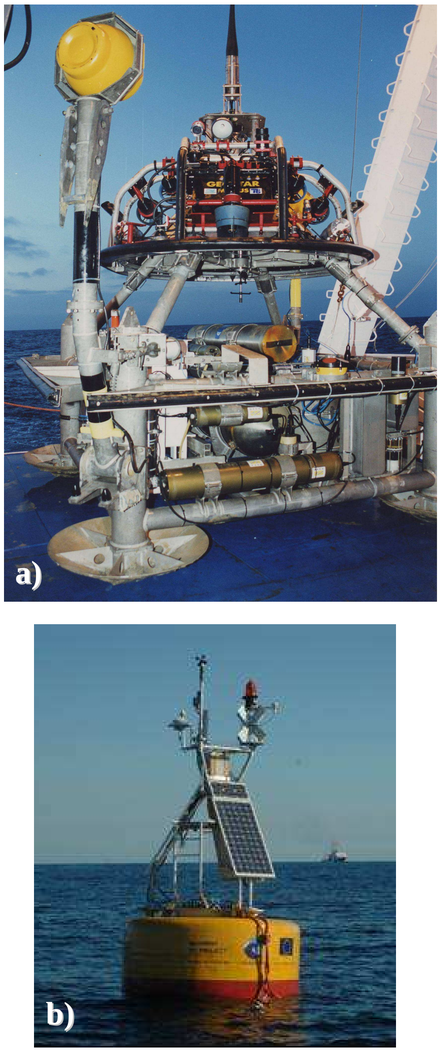

Fig. 2. Images of: a) GEOSTAR seafloor observatory (bottom) and MODUS (top); b) relay surface buoy for the communications.

The two GEOSTAR projects were the starting point of a set of European and Italian initiatives, which have led, in a timeframe of about 10 years to the development of other GEOSTAR-class observatories (Table 1).

All the instruments have a unique time reference, given by the use of a single high precision clock (stability $10^{-9} \div 10^{-11}$). From 1998 to 2008, many experiments have been performed using the following sensors [e.g., 9, 10, 11, 12, 13, 14, 15, 16, 17]:

- Broad-band 3-C seismometer;
- Magnetometers (vectorial and scalar);
- Gravity meter;
- Hydrophones (for geophysics and bioacoustics);
- Tsunami sensors (high resolution pressure);
- Differential pressure gauge (DPG);
- Acoustic Doppler current profiler (ADCP);
- Single point 3-C current meter ;
- Conductivity, temperature and depth (CTD);
- Transmissometer;
- Turbidity meter;
- Gas sensors (e.g., H_2S, CH_4, O_2);
- Automatic chemical analyser (pH, eH);
- Radiometer/Nuclear spectrometer;
- Automatic water sampler (48 bottles, off-line).

The total amount of data has exceeded 100 Gbytes (binary data), that are equivalent to more than 2000 operative days.

In a period of 4 years (2002-2005) the EC supported a further step from a single benthic observatory to seafloor observatory networking, in relatively shallow water with the ASSEM project [18, 19] and in deep water with the ORION-GEOSTAR-3 project [2, 3].

Table 1.

List of the GEOSTAR-class observatories

Platform	Dimensions (m) (L x W x H)	Weight (kN) (in: air-water)	Depth rated (m)
GEOSTAR	3.5 x 3.5 x 3.3	25.4-14.2	4000
SN-1	2.9 x 2.9 x 2.9	14.0-8.5	4000
SN-2 (MABEL)	2.9 x 2.9 x 2.9	14.0-8.5	4000
SN-3	2.9 x 2.9 x 2.9	14.0-8.5	4000
SN-4	2.0 x 2.0 x 2.0	6.6-3.4	1000
GMM	1.5 x 1.5 x 1.5	1.5-0.7	1000

4. International initiatives on seafloor observatory networks

Many large-scale projects have been planning to establish permanent seafloor networks at International level. Canada, Europe, Japan and the USA are the major actors in these projects.

In the USA the most prominent initiative in the field is the Ocean Observatories Initiative (OOI), sponsored by the National Science Foundation (NSF). The OOI infrastructure is an integrated observatory with three elements: 1) a regional cabled network consisting of interconnected sites on the seafloor spanning several geological and oceanographic features and processes, such as NEPTUNE; 2) relocatable deep-sea buoys that could also be deployed in harsh environments, such as the Southern Ocean; 3) new construction or enhancements of existing facilities leading to an expanded network of coastal observatories. One major component of this planning effort is NEPTUNE (North East Pacific Time-series Undersea Networked Experiment), a project that aims to establish a lithospheric-plate-scale multidisciplinary observatory network on the Juan de Fuca Plate, located off the American west coast, and connected to two land-based research laboratories with submarine cables (located in Victoria University, Canada and Monterey Bay Aquarium, USA) [20, 21, 22]. The planned lifetime is 30 years. In 2002-2003 the two cabled-observatory test beds, VENUS (Victoria Experimental Network Under the Sea) in the Strait of Georgia, the Strait of Juan de Fuca and Saanich Inlet, British Columbia, Canada (3 different cables) [23], and MARS (Monterey Accelerated Research System) in Monterey Bay, California, USA (a 62-km cable down to 1220 m w.d.) [24] were funded and activities are running in both test sites.

Japan started in 1978 to manage cabled seafloor observatories for scientific use, and particularly for real-time monitoring for seismic and tsunami warning. At present, eight cabled experiments are running in Japan and all these experiments should be part of a larger omni-comprehensive project based on cable technology [3]. One of the most recent Japanese projects is the 4-year DONET (Dense Ocean floor Network system for Earthquakes and Tsunamis), managed by JAMSTEC (Japan Agency for Marine-earth Science and TEChnology), with the aim to realize a seafloor cabled “antenna” with observing points including seismometers and pressure gauges [25].

At the European level, the creation of a multidisciplinary network of seafloor observatories is being supported by the EC through several initiatives.

In 2002-2004 the EC sponsored the ESONET-CA project (European Seafloor Observatory NETwork-Concerted Action). This project promoted activities to develop the multidisciplinary "seafloor segment" of the European Space Agency-European Commission (ESA-EC) "Global Monitoring for Environment and Security (GMES)" Programme, particularly aimed at contributing to research into geo-hazards, global change and biodiversity. ESONET-CA has produced guidelines for the establishment of a European seafloor network of observatories from the Baltic Sea to the Black Sea. In this context one of the most important outcomes has been the definition of "key-sites" at which cabled multidisciplinary observatories should be deployed [26].

This phase has been followed by the on-going project (2007-2011) ESONET-NoE (European Seas Observatory NETwork-Network of Excellence), coordinated by the French institute IFREMER, that involves 50 partners from 14 countries. ESONET-NoE intends to promote the European underwater ocean observatory system with focus from the margins to the deep sea. Its major aim is the integration of the scientific and technological community interested in multidisciplinary ocean observatories, mainly with regards to: a) global change and physical oceanography; b) Earth sciences, geo-hazards and seafloor interfaces; c) Marine ecosystems; and d) non-living resources [27]. ESONET-NoE has confirmed the "key-sites" already defined in the previous concerted action, adding other crucial sites like Marmara Sea, another area where there are strong scientific motivations to develop nodes of an underwater permanent network. All these sites have been confirmed by EMSO (European Multidisciplinary Seafloor Observatory) and are shown in Fig. 3.

Several scientific activities have been running for a long time at different sites to prepare the cabled observatories. Among these sites, the one in Eastern Sicily has been already operative in real-time since January 2005 having connected the SN-1 observatory to an electro-optical cable and acquired data at the shore station These activities were performed under an agreement between two major Italian scientific institutions, INGV and INFN (Istituto Nazionale di Fisica Nucleare) [13]. Fig. 4 shows some recent earthquakes recorded by the SN-1 real-time seafloor observatory.

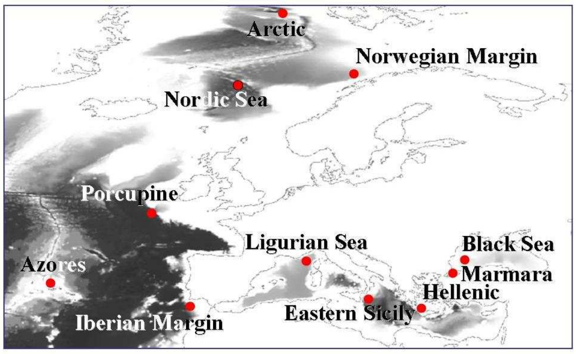

Fig. 3. European margin "key-sites" indicated by ESONET-CA and -NoE, candidates as nodes of the EMSO underwater permanent network

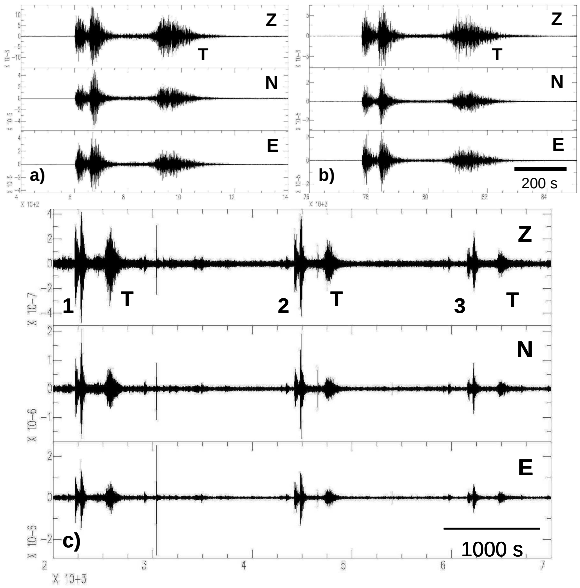

Fig. 4. Earthquakes occurred off-shore Peloponnesus (Greece) on February 14, 2008 and recorded by the real-time SN-1 seafloor observatory. A bandpass filter 4-12 Hz has been applied. The plots are ground velocity vs time: a) the most energetic (10:09 GMT, M_W=6.9); b) the main aftershock (12:08 GMT, M_W=6.2); c) some relevant shocks occurred between the 2 main ones (1-10:36 GMT M_L=3.9, 2-11:12 GMT M_L=3.7, 3-11:41 GMT M_L=3.3). All the earthquakes are followed by clear tertiary waves, that propagate in the water (T in the figures)

At the end of April 2008, SN-1 has been recovered after 3 years and 3 months. The observatory will be refurbished, adding sensors and functionalities, particularly taking into account geo-hazards and bio-acoustics. It is planned to be redeployed and reconnected to the cable in late Spring 2009. These activities have been performed in the frame of the PEGASO project (funded by "Regione Siciliana") and the LIDO (LIstening to the Deep Ocean) demonstration mission (activity funded by ESONET-NoE).

5. European strategy towards a permanent seafloor network

The "European Strategy Forum on Research Infrastructures (ESFRI)", launched by EC in April 2002, brings together representatives of EU Member States and Associated States, appointed by Ministers in charge of research, and one representative of the European Commission, and has as its main objective to facilitate coherent support for large Research Infrastructures (RIs) at the European level. The forum periodically issues a roadmap with a list and description of strategically-important Research Infrastructures to be supported by the European Union. In September 2006 the ESFRI report was published containing a list of 35 large-scale RIs belonging to different fields [28]. Within the environmental sector, one of the most important infrastructure listed is EMSO. It will be based on a European-scale network of seafloor observatories and platforms with the basic scientific objective of long-term monitoring, mainly in real-time, of environmental processes related to the interaction between the geosphere, biosphere, and hydrosphere, including natural hazards. It will be a geographically distributed infrastructure composed of several deep-seafloor observatories, that will be deployed on specific sites around European waters, from the Arctic to the Black Sea, passing through the Mediterranean Sea - thus forming a widely distributed pan-European infrastructure.

The rationale for EMSO infrastructure is based on the following issues:

- **Scientific**: the sea as key element to understand the dynamics and evolution of the Earth components (geosphere, hydrosphere, biosphere);
- **Technological**: maturity of methodology and approaches for deep-sea observations (i.e., long-term time series);
- **Strategic**: environmental control for preservation (habitat, biodiversity), mitigation of hazards, new resources exploitation;
- **Cultural:** strengthening the European Research Area (ERA) in competition with USA, Canada and Japan.

The European GMES programme has identified a need for a seafloor segment of a proposed surveillance system as a complementary instrument to land- and space-borne systems. EMSO observatories will allow permanent real-time environmental monitoring for geo-hazard impact mitigation, security, and deep-ocean circulation. EMSO observatory sites (both existing and planned sites) will be cabled from the shore in order to constitute a "star-shape" network of data and image collecting systems. The data from this segment will be integrated with those of the land-based networks and also with the observational data of satellites. The EMSO development is based on the synergy between the scientific community and industry with the aim of significantly improving marine technologies and developing strategies to strengthen the European competitiveness with respect to other countries like USA, Canada and Japan.

The EMSO infrastructure will enhance our understanding of processes that require long time series data appropriate to the scale of the phenomena. The new frontier of multidisciplinary understanding of ocean interior, deep-sea biology and chemistry and ocean margin processes will be addressed by permanent monitoring of key areas. This could lead to a concerted networked infrastructure in Japan, the North American Pacific Coast and Europe. Fig. 5 shows the geographical distribution of the different International efforts in developing seafloor permanent networks. It is worth pointing out that all the seafloor network initiatives under development take place in the northern hemisphere while the southern hemisphere, where the oceanic coverage is wider and the ocean role could in principle more deeply influence the Earth processes, is presently out of the scope of any ongoing initiative of seafloor permanent monitoring.

The EC, under the Research Infrastructures sub-section of the Capacities Programme within the 7^{th} Framework Programme (FP7), launched at the end of 2006, a call for proposals for Preparatory Phase (PP) projects for each of the RIs listed in the ESFRI

Report. These projects will provide the necessary European support to create the entities in charge of managing the RIs, thus creating the legal and organisational structure to coordinate the financial effort among the countries.

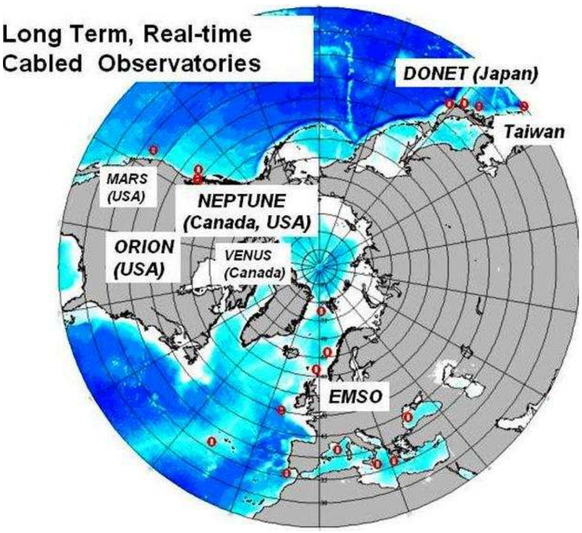

Fig. 5. Geographical distribution of the International projects devoted to develop long-term, real-time cabled observatories

EMSO-PP, a 4-year project, was approved in November 2007 and has just started (April 2008) It is coordinated by Italy, represented by INGV, with eleven other Institutions, each representing its country (see the "Acknowledgments" section for the details on the EMSO-PP Partnership).

The EMSO-PP main objectives are: 1) to establish the governance entity for the EMSO infrastructure serving scientists and stakeholders in and outside Europe for long-term deep-water observations and investigations; 2) to enable the deployment of the infrastructure and its long-term management, including the solution of technical bottlenecks; 3) to promote the catalytic process and synergic effort at EC and national levels, coordinating and harmonising all available resources.

The ultimate output of EMSO-PP is the creation and integration of regional entities, each managing sub-sea observatory sites (RLEs-Regional Legal Entities) with a single coordination entity (CLE-Core Legal Entity), as illustrated in the scheme of Fig. 6.

The scientific and technological community will greatly benefit from the availability of these new powerful research tools, able to generate datasets of capital importance for the understanding of our Planet.

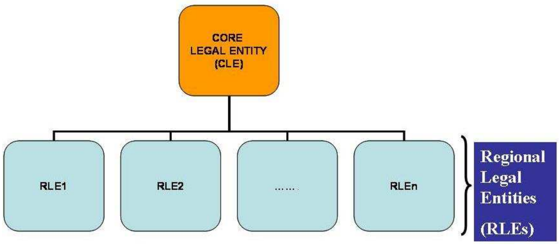

Fig. 6. EMSO infrastructure: the mutual relationship between the CLE (Core Legal Entity), the coordination entity, and the RLEs (Regional Legal Entities), each one managing a network node

6. Conclusions

The establishment of the EMSO network of seafloor observatories will represent a change of direction in Ocean science research, and will require a major investment of human and economic resources over many decades. Many potential benefits of this huge effort are envisaged and include:

- establishment of a basis for new discoveries and major advances in the ocean sciences;
- advances in relevant areas of research, such as marine biotechnology, the Ocean's role in climate change, and the assessment and mitigation of natural hazards (including earthquakes and tsunamis);
- improved access to oceanographic and geophysical data, enabling researchers to study the ocean and Earth in real-time or near-real-time by providing multidisciplinary observatory infrastructures;
- establishment of permanent underwater observation sites - considering that over the 70% of Earth's surface covered by oceans - to provide truly global geophysical and oceanographic coverage;
- enhancement of interdisciplinary research for improving the understanding of interactions between physical, chemical and biological processes in the oceans;
- increased public awareness of the oceans, by proving new educational opportunities for students at all levels, using seafloor observatories

as a platform for public participation in real-time experiments.

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