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# Open-Sea Observatories: A New Technology to Bring the Pulse of the Sea to Human Awareness

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## 1. Introduction

Historically, observation in Marine Science was mainly based on *in situ* measurements made mainly over ship surveys and shore measurements. Unfortunately, ship surveys can only be episodic, and are constrained by weather and by the constant rise of ship-time cost. As the data provided by non-communicating moorings are stored in the measurement system, a ship intervention is needed to recover both the mooring and the data after several acquisition months. Further to the rather successful medium- and short-term deployment of these traditional devices, scientists have expected the development of long-term observations and permanent marine system-monitoring tools so as to gain more insight into the observed processes. By providing additional information, satellite technology can partly solve this gap between the reality and expectations. However, even though satellite images provide information over a large time frame (from minutes to years) and a wide range of spatial resolutions (from metres to thousands of kilometres), they only cover the upper layer of the sea. An Open-Sea Observatory is a complementary tool that allows one to make, in the water column and on the seafloor, long-term measurements of many environmental parameters and to acquire them in real-time, or near real-time. In addition to this real-time data transmission, these systems permit remote intervention by humans when needed, and thus can be considered as 2-way communicating devices. Because of these two characteristics, observatories are innovative systems that bring internet to the ocean and make the ocean reality visible to the human eye. According to our definition of an Open-Sea observatory, other very useful observation tools such as gliders, floats, repeated profiler transects, etc. will not be considered in this chapter to only focus on such ocean observatories.

Observatory initiatives have been spreading worldwide since the 1990s. In Europe, several initiatives started twenty years ago so as to upgrade free-fall systems from the sea surface (the so-called "landers") to make them 2-way communicating and to develop bottom

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stations linked to a ground station by acoustic or cable connection. The development of observatory expertise in different ways and places has led scientists to federate their efforts around common projects, amongst which the most recent ones in Europe are EUROSITES, ESONET and EMSO (see next section). Worldwide, the most advanced network of cabled multidisciplinary observatories is the Neptune Canada infrastructure led by the University of Victoria; its 800-km-long cable was installed by Alcatel Submarine Networks in autumn 2007. Five nodes with their associated instruments were deployed in 2009. The infrastructure is currently running and the data are available on the main website http://www.neptunecanada.ca/. In the USA, the Ocean Observatory Initiative (OOI), driven by the National Science Foundation (NSF), is currently developing observatories in three steps: coastal observatories, cabled region observatories (the Neptune US observatory) and global observatories. In 2006 Taiwan decided to develop and implement a submarine observatory off the western part of the island (MACHO project). Japan chose to install a 20-node submarine network, devoted to seismic monitoring and tsunami alerts, DONET (http://www.jamstec.go.jp/jamstec-e/maritec/donet/). China recently implemented an observatory network off its eastern coasts (http://www.bulletins-electroniques.com/actualites/66736.htm); it is dedicated to research in oceanography and geosciences by scientists from the partner universities (Tongji university Jiaotong Shanghai University, Huadong Normal University and Zhejiang University). In Europe, several initiatives started about twenty years ago. Clearly, deep-sea observatories are a new technological approach that has become accepted and is being implemented worldwide. Why is this?

This is due to scientific and societal needs. Indeed, only long-term observatories allow continuous observations over long-timescales (at least 10 years) of very numerous parameters collected through power intensive sensors. This capability is crucial in observations of natural processes that are either very episodic or hidden by higher-frequency noise, and thus only detected through acquisition of long data time-series. These long-term observatories are also an opportunity for society to monitor the sea in “real-time”, and thus to prevent geo-hazards such as earthquakes and tsunamis. It also allows monitoring of long-term phenomena such as those caused by the global warming. The open-access policy for collected data makes them more accessible to the general public, stakeholders and socio-economic users. Furthermore, through support to those research areas where access to high-quality data is relatively rare, it widens the community that gets access to deep-sea research and attracts worldwide research cooperation. Long-term observatories are crucial for the scientific community so as to maintain the high-level reached in the research developed under the scope of past and present framework programmes.

In the following pages, we will show how observatories (i) can serve various marine research fields, in a broad sense, such as oceanography, biogeochemistry, volcanology, seismology, and geosciences and (ii) help to enlarge the vision and the understanding of marine sciences at the crossroads of these disciplines throughout Europe. The history of observatory development in Europe will be reminded in Section 2 to explain the current status, the available infrastructures and equipment. Their deployment and associated feedback as well as the expected further steps will be illustrated from on-site deployment case-studies in Section 3.

## 2. History of open-sea observatories in Europe

The first fixed platforms dedicated to quite long-term measurement were traditional moorings initially deployed at sea for time-span of a few months to one year according to the system autonomy in terms of energy and data storage capacity. Mooring provided unprecedented long multi-parameter time-series for oceanographic research. Nevertheless, deployment and sustainability for periods over, at least, one year imply that one has to come back to the field site, at least twice a year, for data recovery, power supply check up and eventually sensor cleaning. Under these conditions, a mooring can be maintained for several years, but a major difficulty is to get ship time at both the right periods of time and good weather conditions, which turns out to be costly. In addition, the lack of communication system during the acquisition months makes impossible to know whether the system is working correctly or not prior to data retrieval. This raised the need for development of more energy-autonomous systems able to communicate and transfer data to a ground station. These new systems should include an onboard electronic unit including, at least, a centralised 2-way communication system with a data logger. These considerations are at the origin of the observatory concept: an infrastructure equipped with several sensors and an onboard communicating electronic unit. Several types of observatory systems have, thus, been developed and deployed: let us cite upgraded landers and single acoustically-linked bottom stations further upgraded to multi-node stations, cable infrastructures and finally the observatories in use today. Two complementary review articles were published in 2006 (Person et al. 2006; Favali and Beranzoli, 2006); it appeared to us worth writing the update presented in this paper.

### 2.1 Equipment and infrastructure evolution until now

Several initiatives were precursors to observatory systems; let us cite the so-called "landers", which are dropped from the sea surface to free-fall to the sea bottom. The reader will find an interesting list of these systems in the final activity report of the ESONET CA project (http://www.oceanlab.abdn.ac.uk/esonet/ESONET_fullrep.pdf). Amongst the systems presented in this review paper, we will consider only those able to communicate with a ground station further to a dedicated upgrade permitting the addition of a 2-way communication unit.

#### 2.1.1 Upgraded landers

The BOBO lander developed by the NIOZ (Van Weering et al., 2000) consists of a frame with 3 legs (2-m-high). At their foot, the lander is 4-m-wide (figure 1). As its frame was specially designed to endure stays of one year at least on the seabed, it was, thus, built with dedicated material. To prevent attacks by corrosion or electrolysis, the construction parts and connections were very carefully isolated. The instrumentation is attached to both the hexagonal frame and the lander legs. Electrical power is supplied to the instrument by a built-in battery pack housed in a glass sphere.

In Sweden, the Göteborg University (Hall et al.) has developed and operated autonomous landers since the early 1990s. Then, research institutes from France, Denmark and the USA have developed and used 5 different lander systems. Considerable efforts have also been made in the development of new sensor technology (dedicated, for example, to oxygen

sensing). Later, within the framework of the EU-ALIPOR project, the consortium interconnected all sensors and systems into a modern network (a CAN network, *Controller Area Network*), which allows high-speed and high-security communication between instruments and sensors. The advantage of such a network is that new instruments and sensors can be hooked up in "plug and play" mode to the existing network and all data can be collected by a control unit and transmitted to the users network which is in wireless 2-way communication (acoustic) with the surface.

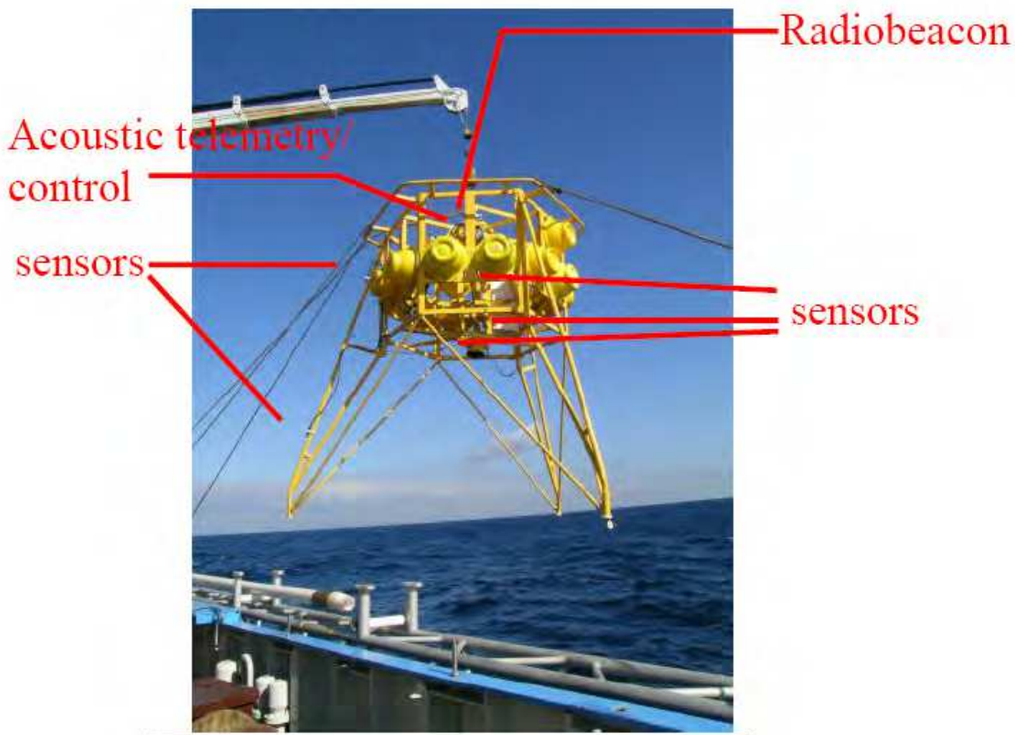



Fig. 1. BOBO lander in previous version (source: http://mars-srv.oceanlab.iu-bremen.de/infra_obser_bobo.html)

IFM-GEOMAR has operated a series of 8 landers of modular design for investigations of the deep-sea benthic boundary layer. A special launching device is used for their deployment, either in conventional free-fall mode or in targeted mode, on hybrid optical fibre or coaxial cables. The lander is accurately positioned by the launcher, and then softly deployed and quickly disconnected through activation of an electric release. The bi-directional video and data telemetry provide online video transmission as well as the power supply (< 1 kV) and surface control of various relay functions. Autonomous lander clusters connected by optical cable and ensuring data transmission to the surface, and in the future by satellite link to the shore, are envisioned as an important contribution to the sea observatories of the future. A lander cluster (figure 2) consists of various types of scientific observation-dedicated landers, power supplies and garages for small autonomous vehicles (AUV, crawler) and tethered ones (ROVs).



Fig. 2. Lander cluster developed by IFM-GEOMAR (source IFM- GEOMAR: http://www.ifm-geomar.de)

### 2.1.2 Acoustically linked bottom stations

The first steps towards long-term and multi-sensor bottom stations deployed in Europe by remotely controlled vehicles such as ROVs took place in the 1980s. Let us cite, for example, NADIA, SAMO and GEOSTAR systems that worked as single node platforms. Later, engineers developed multi-node platforms such as those used in the ORION and ASSEM projects.

#### 2.1.2.1 NADIA and SAMO systems

In France, Ifremer undertook several early initiatives such as NADIA developed in 1985 and SAMO (Person et al., 2006). The former (figure 3) was an autonomous structure, moved and controlled by the Nautile submersible, and designed for deployment into Ocean Drilling Program (ODP) holes (Montagner et al., 1994). Then, the SAMO 1 & 2 stations (Abyssal Station for Oceanographic Measurements) were designed from this technology so as to continuously monitor hydrothermal vents. SAMO was a communicating infrastructure equipped with a camera for acoustic and real-time transmission of images as well as temperature and turbidity data to the surface. The first deployment took place in 1991 during the HERO campaign. Later, in 1993, the HYDROGEO structure was deployed within the framework of an Ocean Drilling Programme (ODP) to characterise temperature and pressure fields and their variations associated to the fluid dynamics in drilling holes. It consisted of 20 thermistance chains, and 3 pressure sensors. It was deployed in 1994 (June-July) in Hole 948 (15° 31'N; 56° 43'W) at a depth of 4 938 m, for more than one year, and recovered on Nadire R/V with the Nautile submarine in 1995 (November and December).



Fig. 3. NADIA observatory developed by Ifremer in 1985, © Ifremer

**2.1.2.2 GEOSTAR class observatories**

The Geophysical and Oceanographic Station for Abyssal Research, GEOSTAR, is a prototype of bottom stations developed under the leadership of INGV (National Italian Institute of Geophysics and Volcanology). This observatory prototype comprises a set of geophysical and oceanographic sensors for continuous, time-referenced and synchronised measurements and it is deployed from the sea surface through a dedicated and remotely controlled tethered vehicle, MODUS. GEOSTAR has been submitted to a set of pilot experiments in the Mediterranean Sea and the Atlantic Ocean prior to the development of additional seafloor observatories of different sizes and pieces of equipment. The observatory is a 4-leg marine aluminium frame of slightly less than 10 $m^3$, which holds all of the devices constituting the scientific and operative payload (figure 4). The first phase of the project was completed in late 1998 with the 2-week deployment of a prototype in shallow waters (40 m) of the Adriatic Sea.
The success of GEOSTAR led to the subsequent development of a class of observatories designed for different applications, but which shared common solutions and infrastructures (EC ORION project, Italian projects SN-1 and MABEL). Two GEOSTAR-class observatories and associated instruments with telemetry were linked together into a submarine network known as ORION (Ocean Research by Integrated Observatory Networks, 2002-2005). Between 2003 and 2005, this network operated in the Tyrrhenian Sea at the base of the Marsili Volcano seamount (3 320 mwd), with acoustic communications of data and commands between the observatories. One of these observatories, GEOSTAR, could also communicate with a surface buoy. The system provided important results and represented significant advances in communication systems. However, it is worth noting the existence of limitations on the data rate imposed by the current performances of the acoustic telemetry. In order to increase data

flow to a ground station for application addressing geo-hazards (e.g., earthquakes), INGV had the opportunity to upgrade one of the observatories to a cable configuration (Favali et al., 2006a). More information can be found in Favali et al. (2006b) and on the website: http://roma2.rm.ingv.it/en/facilities/seafloor_multidisciplinary_observatories/1/geostar.

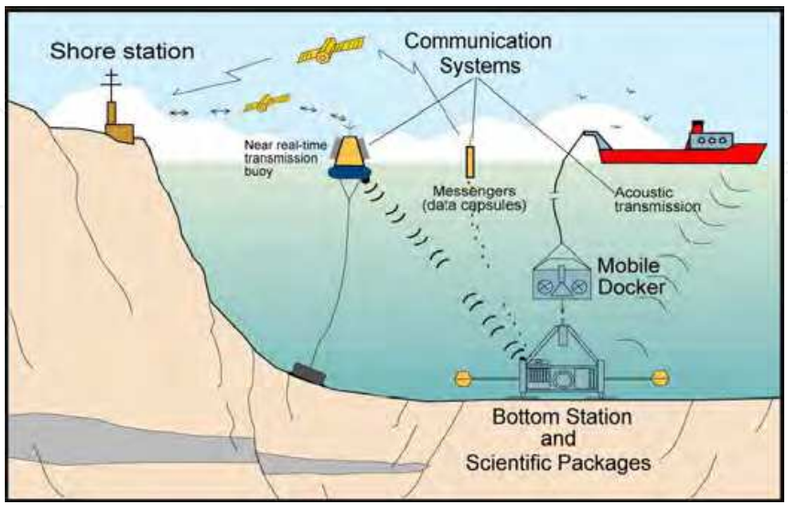



Fig. 4. GEOSTAR bottom station (from Favali and Beranzoli, 2009)

#### 2.1.2.3 ASSEM multi-node technology: Array of Sensors for long-term Seabed Monitoring of Geohazards

ASSEM was the first application of a new observatory concept dedicated to the long-term monitoring of a limited area (some km²) and based on a network of interconnected measurement nodes. This FP5 European project was coordinated by Ifremer in 2001-2004. Its design was based on a cost-effective and light platform with a standardised layout of sensors sharing a common data and communication infrastructure. The ASSEM project enhanced some marine technologies dedicated to the real-time monitoring of the seafloor. The system main component was the COmmunication and STOrage Front end (COSTOF) permitting a local storage of data and data transmission as well as exchanges between the whole set of sensors and the external world through an underwater network. ASSEM consisted in an array of several nodes to be deployed in water and sediment by a submersible or a ROV (figure 5). Their design and sensor package (pore pressure, methane, geodesy, tiltmeter, CTD, turbidity, currents) were alike. Data were exchanged between the nodes through networked acoustic modems. One of the nodes was connected to either a surface buoy and then to the shore by satellite communication or to a ground station with a cable. ASSEM was designed as a light (less than 250 kg) and deep (4 000 m water depth-rated) platform. The first prototype was produced at Ifremer, Brest, in January 2004. Its dual objectives were: i) monitoring of a set of geotechnical, geodesic and chemical parameters distributed on a specific seafloor area in order to gain more insight into the slope instability phenomena and ii) assessment with anticipation, whenever possible, of the associated risks (Blandin et al., 2002, 2003, 2005). Two test sites were selected for validation of the basic concepts: they were located in Norway and in the Gulf of Corinth, respectively. Its use in a set of new targets, in particular within the framework of ESONET Demonstration Missions, has been fostered by the success of these field experiments. For further information refer to the ESONET NoE newsletter, ESONEWS (spring 2008).

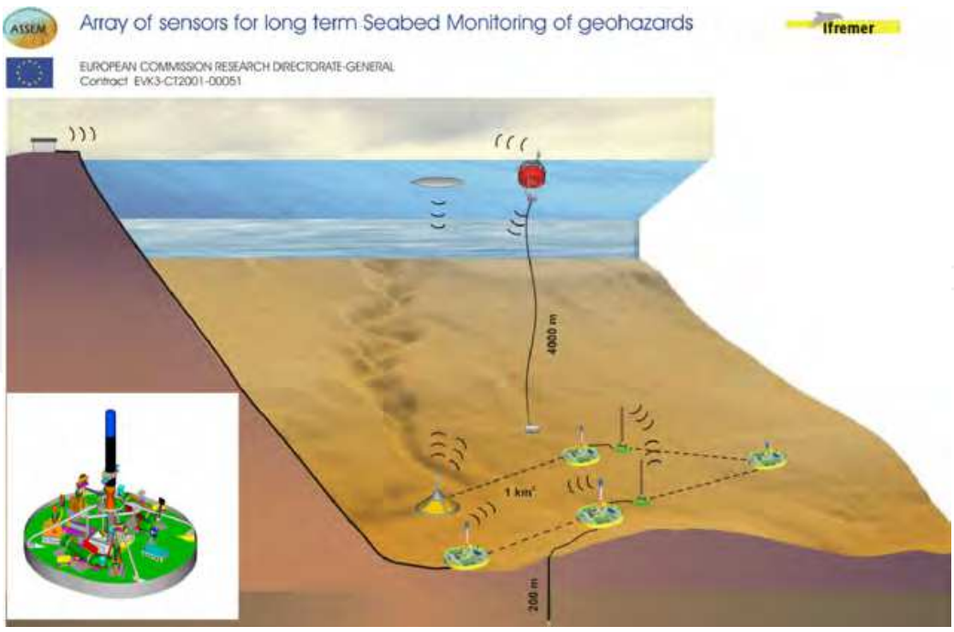



Fig. 5. An ASSEM node and a sketch of multi ASSEM node system ©Ifremer

### 2.1.3 Communicating moorings

The first important experiment led to the implementation, around Europe, of a network of communicating moorings managed within the framework of the ANIMATE project. ANIMATE ("Atlantic Network of Interdisciplinary Moorings And Time-series for Europe") was funded by the EU in 2002-2004 under the scope of the 5th Framework Programme and then was continued, in part, by the EU-funded projects Mersea IP and Carbo-Ocean. The project was launched in 2002 so as to develop a European carbon cycle time-series infrastructure at 4 key sites in the north-east Atlantic Ocean (figure 6a). It was based on the implementation of real-time telemetry of subsets of the prime data to be collected for immediate dissemination to the scientific community through satellite link, and via the Internet for the general public.

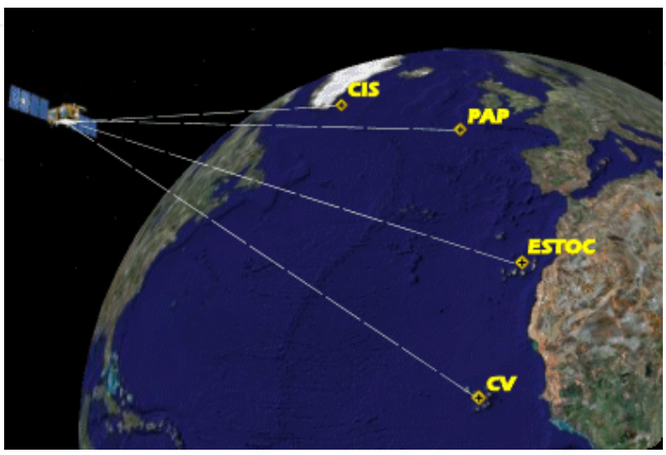



Fig. 6a. Four deep ocean mooring sites managed within the framework of ANIMATE and then EuroSITES (source: http://www.noc.soton.ac.uk/animate)



Fig. 6b. Concept of an Animate mooring (source: http://www.noc.soton.ac.uk/animate)

The 3 deep ocean mooring sites denoted as CIS, ESTOC and PAP have collected data for three years under the ANIMATE banner. Further to the validation of the original ANIMATE mooring concept (figure 6b), additional funding enabled one to enhance and refine the systems for provision of a set of long-term time-series to be included in the general effort dedicated to climate change monitoring. In 2006 a fourth mooring was developed at the Cape Verde Islands. In April 2008 the ANIMATE network became part of the EuroSITES European Ocean Observatory Network aimed at becoming a permanent infrastructure.

### 2.1.4 Cabled observatories

**General Concept**

Several layouts have been proposed for the development of cabled observatories connecting undersea sites of scientific experiments:

- Single line of Sensors or Nodes
- Sensor Rings
- Sensor Meshes

An illustration of the general concept is presented below (figure 7).

The scientific systems deployed to date have predominantly consisted in a single cable routed from the landing point to the sea, where a single sensor or several ones are connected to the cable. Power is supplied to the cable from the shore station; the return path is either a second conductor in the cable or via a seawater return that employs a seawater ground anode at the end of the cable and a ground bed on the beach. The fundamental drawback of a single cable is its susceptibility to damage (electrical shortage or cable cut).

The design of one of the very first sensor systems by Neptune Canada (University of Victoria) is based on a ring configuration (figure 8) with 2 cables routed to the same landing point via physically different routes. In the event of accidental damage to one leg, the other one should be still able to supply power to the ring and to transmit data to and from the field site.

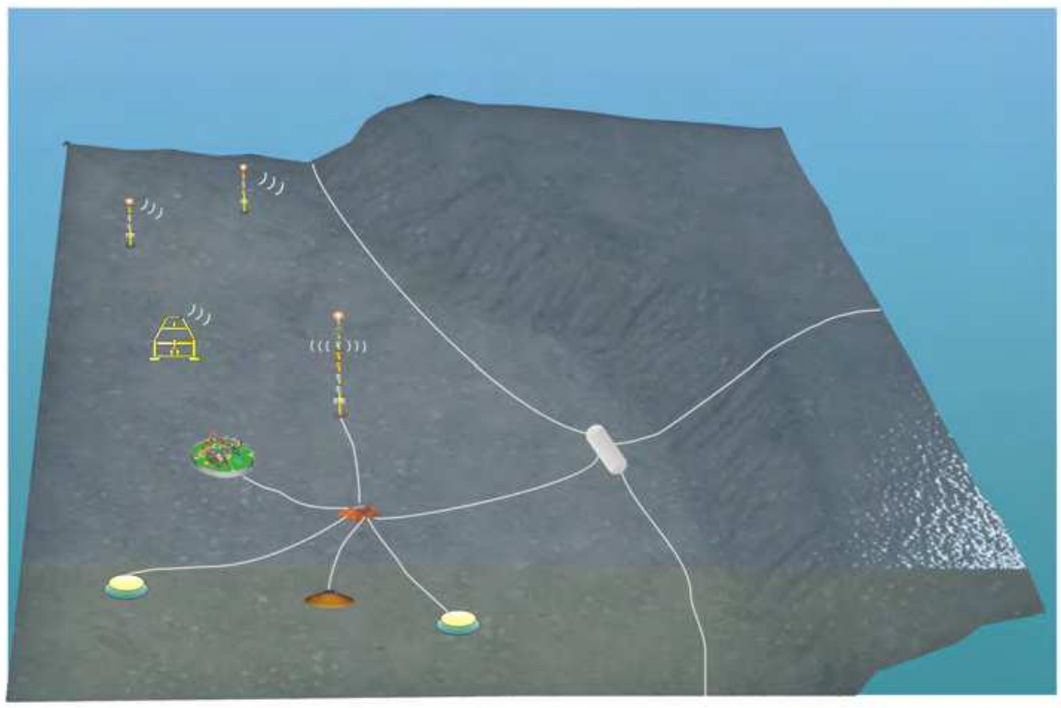


Fig. 7. Deep-Ocean observatory concept showing cabled and local wireless access from fixed and sensor systems. ©Ifremer/M. Chapon-Ashaine

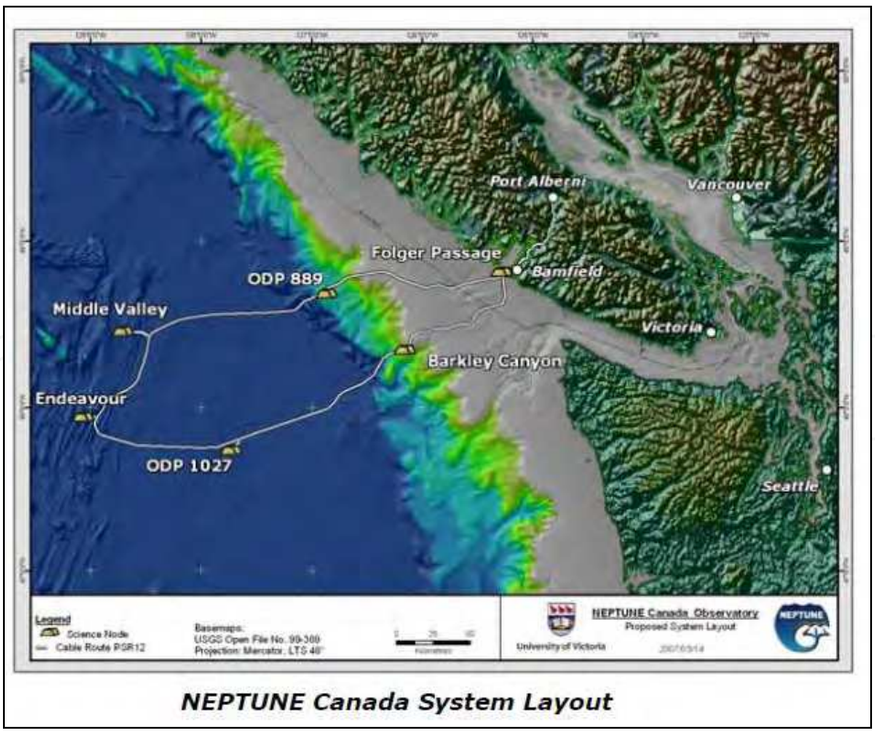



Fig. 8. Route of Neptune Canada cable infrastructure (source: http://www.neptunecanada.ca/)

Whatever the concept, the main components of a cabled observatory are concerning cables and nodes, junction boxes, permanent cabled instrumentation, short-term scientific packages, eventually associated with moored buoys with or without an electro-opto-mechanical cable. More generally, construction and maintenance of the observatory shall cover:

- Field site surveys
- Module lifting and lowering to seabed
- Cable laying and underwater connections
- Inspection and maintenance works

A common feeling is that that the main backbone of cable and cable fittings (branching unit, spur cable, main node) will be likely deployed by a fleet specialised cable installation and maintenance. However, after the initial deployment by a specialised vessel, the next interventions over the observatory operational life may be achieved by multi-purpose oceanographic vessels. This operation life includes generic operations such as those described below in the example of the ANTARES telescope about the secondary junction box and the connected permanent instrumentation.

**Example of ANTARES cabled observatory**

The aim of the international ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) collaboration is to detect and to study the production of high-energy neutrinos in the Universe. The ANTARES infrastructure is also a permanent marine observatory providing high-bandwidth real-time data transmission from the deep-sea for geosciences and marine environmental sciences.

The main cable lands near Toulon, a south-eastern coastal site in France, and runs along ~40 km offshore and down to2 500 m in depth, where the primary junction box is connected to the mooring network for power supply and data transfer (see figure 9). The first mooring line equipped with particle detectors was moored in early March 2006. The network was completed on the night of May 30, 2008, when the final 2 ANTARES lines were powered on, which thus brought the total number of detection lines to 12 and marked the completion of the largest undersea neutrino telescope available to date. A 13$^{th}$ line has been instrumented specifically for marine science research. The reader can get an overview of the system building and deployment at http://antares.in2p3.fr/News/index.html. Because of the need to extend the network, it was decided to plug a Secondary Junction Box (BJS) with an additional infrastructure.

This additional infrastructure installed on the ANTARES site was developed by Ifremer Toulon. The BJS was deployed 2 500 m deep in the Mediterranean Sea in November 2010 over a scientific cruise on the Research Vessel, "*PourquoiPas*", and the connections were made via the Ifremer ROV, Victor6000. This upgraded network is now fully operational, with scientific modules already connected and data provided in real-time.

The BJS connected to the main *ANTARES* junction box provides Internet communication interfaces between the scientific equipment and the shore. Its 7 wet mateable ports for users allow data transmission at a rate of 100 Mb/s and supply power to the connected pieces of scientific equipment. In this way, every scientist can get access, in real-time, to the whole set of sea sensor data from the ground laboratory. Users can get access to the system from anywhere in the world and can interact with their own instruments as if they were on their workbench. The target requirements in the design of the whole BJS were high-reliability and 20-year life expectancy. Though the concept is simple, one should be aware that the physical system is much more complex.

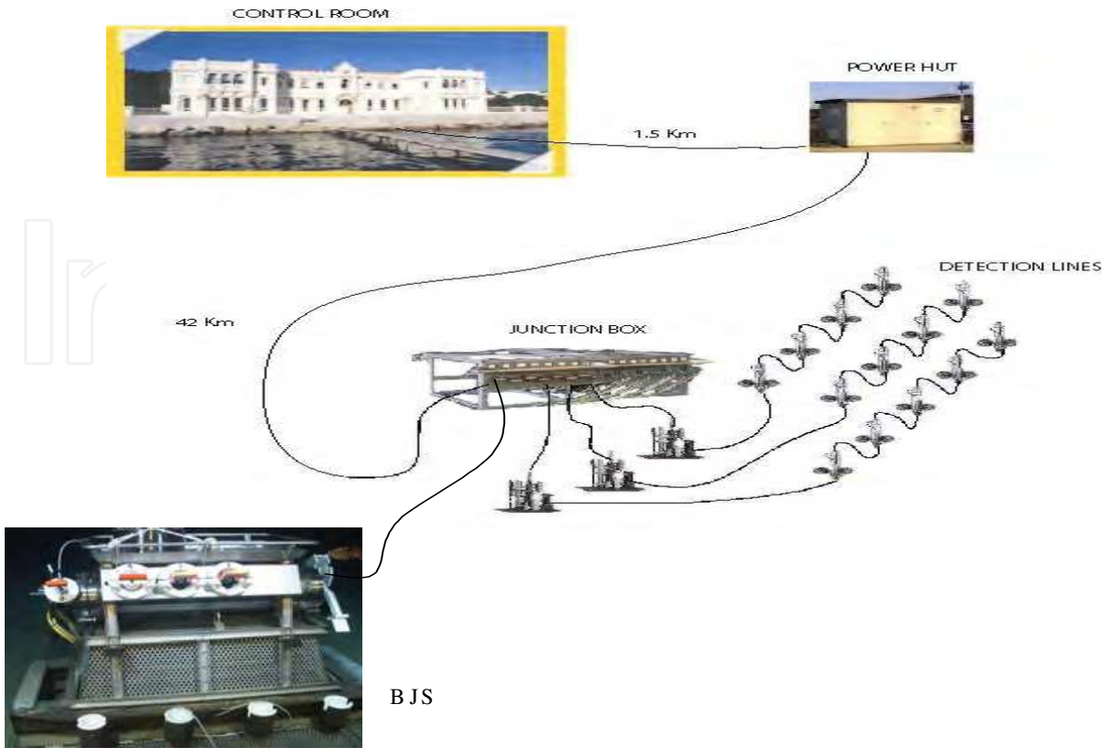



Fig. 9. Scheme of the ANTARES cable network (source: Ifremer and CNRS/CPPM)

The main design features of BJS power systems are to provide 400 V (DC) with 1 kW full power and to ensure a total protection of the power supply input, even in case of electrical fault at the output. This requirement calls for a highly accurate monitoring of the delivered current as well as detection of leakage and ground fault at the outputs. The entire system is monitored by a fully autonomous controller: the system is thus always powered and can restart the switch and the power generation in case of alarm signal. Prior to the deployment of the BJS electronic titanium housing, a heavy sled was built and laid down on the seafloor. This sled is equipped with two platforms mounted on either side so as to keep the ROV (Victor 6000) stable during the connexion operations achieved with the 2 manipulating arms.
Different scientific modules have been connected to the BJS on the 2 500 m-deep seabed, and are now delivering real-time data. Generic oceanographic sensors developed by CNRS/DT-INSU have been deployed for the real-time monitoring of key oceanographic parameters, e.g. temperature, salinity, current-velocity and -direction, pressure and oxygen concentration. Moreover, biolumiscence data have been recorded on the site with a camera. A multi-parameter seismometer module for seafloor motion observation proposed by the *Geosciences Azur* laboratory has also been connected to the BJS to meet both operational and scientific goals. A few days after the connection, the instrument recorded a rare seismic event of magnitude 4 that took place between Toulon and Corsica. The available data contributed to a better location of this event. This new infrastructure presents all the capabilities for a European demonstration mission with real-time data acquisition, in order to test recently-developed instruments and observatory technologies, e.g. a novel concept of deep-sea sensor network, or a new design of economic wet mateable connector, or a highly accurate synchronisation system. By nature open-sea observatory research is mainly

interdisciplinary and has the potential to open the way for very significant advances in the field of science of concern.**Other cable observatories in Europe**

The ANTARES initiative is not isolated in Europe; a neutrino telescope has also been implemented off Sicily under the leadership of the Italian National Institute of Nuclear Physics (INFN). Similarly, in October 2002, INGV team deployed an updated version of the GEOSTAR system for long-term measurements: the SN-1 observatory, which is currently in operation offshore Eastern Sicily in about 2 100-m-deep waters and in a cabled configuration thanks to an agreement with INFN, which has made accessible a 25-km-long electro-optical cable. The GEOSTAR-class observatories have so far provided a huge amount of long-term time-series of seismological-, gravity-, magnetic-, geochemical- and oceanographic-measurements that constitute an unprecedented resource to gain more insight into the complex and maybe inter-related processes that take place in the deep sea. A cabled observatory concept is currently under development in coastal zones as shown by the MeDON initiative (Marine e-Data Observatory Network:http://www.medon.info/). Today the sensor packages are tested in Plymouth (UK) littoral zone waters, and a complete demonstrator will be deployed off Brest (France).

### 2.2 Toward a shared observatory infrastructure

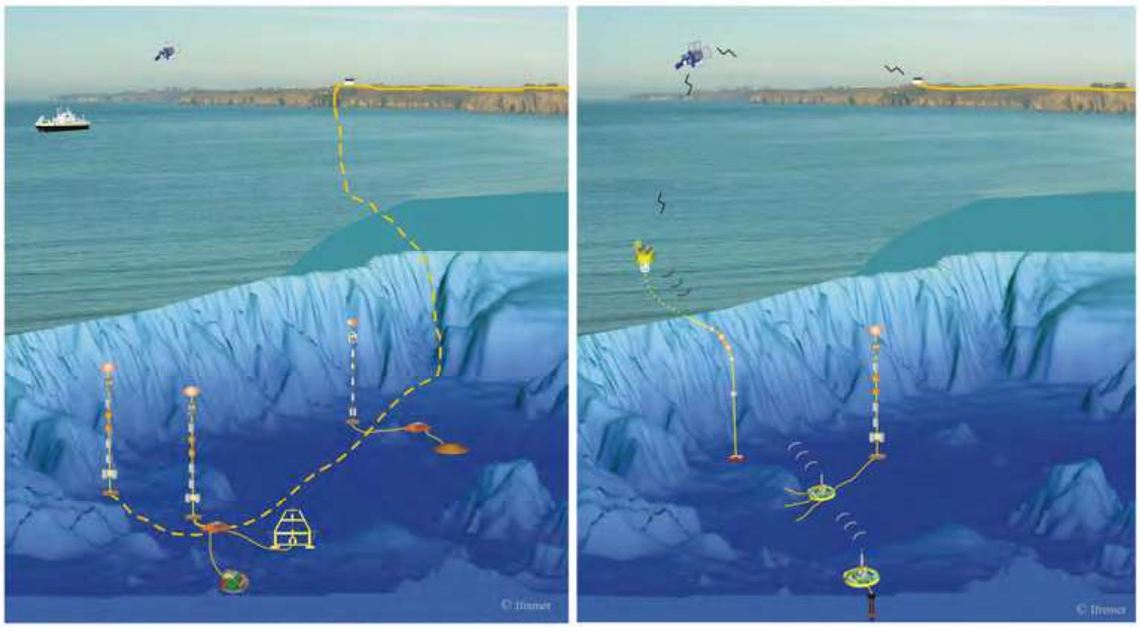
Given that most of the most recent infrastructures are still in operation, capabilities of long-term sea observation are currently available, and it is more than likely that it will be alike in the near future. This is the case of both cabled observatories with and their modules such as GEOSTAR and ASSEM nodes, communicating moorings and communicating landers. Nevertheless, strong synergy and common governance are essential prerequisites for sustainability over decades, money- and time-saving and securing the technical know-how. This implies firstly the preparation of a state-of-the-art on existing capabilities with the assessment of their possibilities for the future, then a convergence of common procedures and pieces of equipment. This would allow the development of a European infrastructure involving joint participation at every step of the way.

An initial review of open-ocean observatory capabilities in Europe was completed in the ESONET-CA "Concerted Action" project co-funded by the EC (2002-2006) and led by Aberdeen University. Then ESONIM, a European Specific Support Action (SSA), led by the Irish Marine Institute (IMI), took the ESONET-CA plan a step further by producing a practical and flexible business plan to establish a seafloor observatory based on the ESONET Celtnet Porcupine site. In June 2007, the European Marine and Maritime Science and Technology Community defined a strategy for the community through the Aberdeen Declaration: this was the actual beginnings of the ESONET Network of Excellence (ESONET-NoE) and of the upcoming projects, EMSO and EuroSITES.

The European Seas Observatory NETwork of Excellence (ESONET-NoE, http://www.esonet-emso.org) (2007-2011) was coordinated by Ifremer (France) and co-funded by the European Commission. ESONET-NoE aimed to promote the implementation and management of a dedicated network of long-term multidisciplinary ocean observatories in the deep waters around Europe. One of its objectives was to overcome research fragmentation in Europe through unification of the various European initiatives of ocean observatory implementation in Europe. It involved 14 European countries, more than 50 institutions and SMEs, and about 300 scientists, engineers and technicians. ESONET-NoE consolidated the deep-sea-observatory community at the regional and European levels at

around 11 sites across Europe. The two-step process of the ESONET-NoE submission was the occasion to strengthen the core partnership and to enlarge it to major countries such as Spain, Turkey and Norway as well as to key partners such as NOCS (UK). ESONET-NoE has been working closely on an infrastructure project entitled EMSO (European Multidisciplinary Seafloor Observatory). Its Preparatory Phase (EMSO-PP) has been co-funded by the European Commission since April 2008 (www.esonet-emso.org). The success of the EMSO proposal in getting funds was an objective of ESONET-NoE over the first year of ESONET-NoE (2007-2008). EMSO-PP project officially started one year after ESONET so as to prepare the infrastructure implementation according to ESONET initiative. While ESONET federated the community of partners to write the common technical specifications of ESONET-EMSO observatories, EMSO was working at implementing them, preparing the legal context of the infrastructure and related legal bodies and looking for funding at the national and international levels.

Throughout this collaborative work, a consensus was reached about the definition of an open-sea observatory which is an open-sea fixed station (or a network of stations), docked or moored on the seafloor *plus eventually* a set of marine sensors in communication with the shore by a 2-way system via acoustic-, satellite-, or cable- connection in real-time or near-real time. These observatories enable coherent acquisition of data relating to oceanographic, geosciences and climatic phenomena, at relative high frequency over long timescales of, at least, ten years. The two kinds of observatories that have been acknowledged are: i) "Stand-alone observatories" and ii) "Cabled observatories" (figure 10). It is worth noting that another mobile observatory has, also, been defined; it is dedicated to the monitoring of the marine environment under very particular conditions whenever it is needed but, in this chapter, focus will be only on the two previous types.



Cable observatory Stand alone observatory

Fig. 10. The two observatory types according to the definition by ESONET EMSO and EuroSITES consortiums.© Ifremer/M. Chapon-Ashaine

Stand-alone and cabled observatories both communicate to a shore station, but through different methods. The stand-alone observatories are autonomous as regards energy, and transfer their data from a surface buoy to a data centre by satellite link. Communication below the water level is supported by acoustic link or by a cable set in-between the sensors and the surface buoy (figure 10). Cabled observatories both transfer their data to a shore station and are supplied with power via a telecommunication cable. Both kinds of observatories communicate in real-time or near real-time, but with the latter, the amount of data transmitted by satellite is restricted.

In parallel with the ESONET-NoE and EMSO-PP projects, the EC also co-funded the EuroSITES Collaborative Project (2008-2011). EuroSITES formed an integrated European network of 9 deep-ocean observatories and 3 associated sites positioned across European seas in waters off the continental shelf and at more than 1 000 m-deep in order to permit measurements of various parameters from the sea surface to the seafloor (figure 11). EuroSITES was coordinated by the National Oceanography Centre of Southampton, (NOCS, UK) and involved 13 partners across Europe and the Cape Verde Islands. This project jointly with ESONET and EMSO has contributed in a better integration across European countries of European open ocean observatories. EuroSITES project has resulted in enhancement of observatory infrastructure, from the moorings to the sensors and telecommunication facilities. Nowadays EuroSITES observatories are monitoring more atmospheric and ocean parameters (essential climate and ocean physical, biogeochemical and biological variables) than ever before. The higher rate of near real-time transmission of datasets has led to a greater use of *in situ* data in the validation of climate models.




Fig. 11. A conceptual design of a EuroSITES open ocean observatory. (Source: EuroSITES)

EuroSITES observatory infrastructure includes:

- i) a **surface buoy** used to locate the observatory and to transmit, in near real-time, data to scientists ashore via satellite. It is equipped with a platform for the attachment of the meteorological sensors in use for simultaneous monitoring of atmospheric conditions and ocean variables;
- ii) a **mooring line** from the sea surface down to the seafloor to which instruments and sensors are fixed for monitoring the ocean environment, along with buoyancy aids and weights to preserve the mooring integrity;
- iii) a suite of **devices** including:
  - the **sensor frame** equipped with sensors for measurements of various ocean parameters including temperature, salinity, chlorophyll-a, nutrients, oxygen and carbon dioxide;
  - the **sediment trap** to catch all the sinking particles from the surface (shells, animal molts, detritus and aeolian dust);
  - a time-lapse camera system such as the **bathysnap camera**, which is deployed on a lander system on the seafloor and takes photographs every 8 hours to record the benthic activity for over a year at a time.
- iv) an **anchor** to maintain the observatory in the same position.

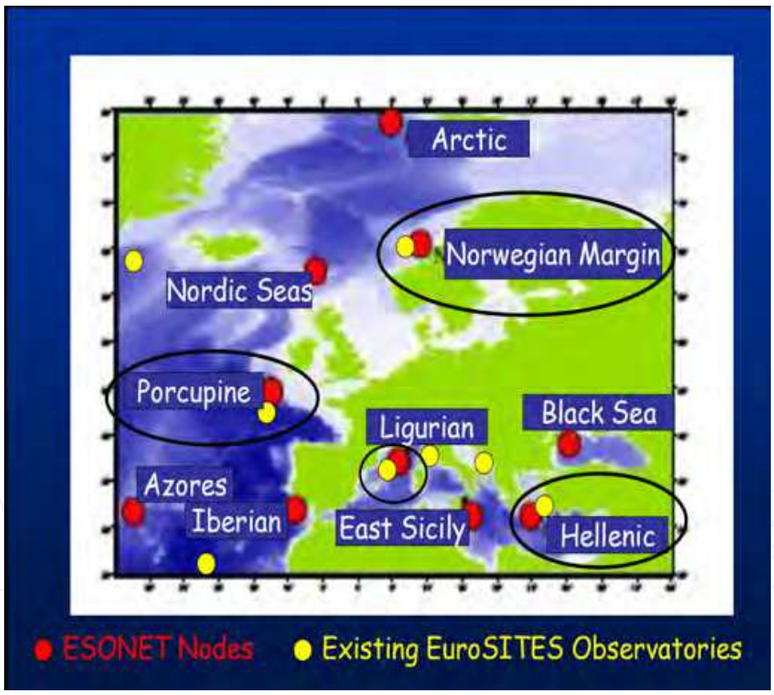



Fig. 12. Map of some European open-sea observatories, including some key sites of the European projects EuroSITES, ESONET and EMSO. This map does not include the EuroSITES Cape Verde observatory (subtropical Atlantic region), nor the Plocan observatory (Canaries islands). EMSO sites are included in ESONET ones.

Figure 12 presents an updated map of the European open sea observatory sites falling under the scope of the EuroSITES, ESONET-NoE and EMSO-PP projects developed in strong collaboration. It shows that the existing infrastructures are located in many common

geographical regions of interest. The consortia of these 3 projects are moving towards a common future vision for open-/deep-ocean observatories. In the next section, 3 examples of open-sea observatories deployed around Europe in the north Atlantic Ocean (Azores sites, Porcupine Abyssal Plain) and the Mediterranean Sea (Marmara Sea) will be presented to exemplify applications in several marine science fields: e.g. ecosystems monitoring, seismology and geosciences, oceanography and biogeo-chemistry.

## 3. Current observatories: Examples of infrastructures in Europe and their possible future

Observatories networked at the seafloor- and water column-levels offers to earth- and ocean-scientists new opportunities for studies of multiple and interrelated processes over timescales from a few seconds to decades. These include i) episodic processes, ii) processes with time-spans from weeks to several years, and iii) global and long-term processes. Episodic processes include, for instance, eruptions at mid-ocean ridges and volcanic seamounts, deep-ocean convection at high latitudes, earthquakes, and biological, chemical and physical impacts of storm events. The second category includes processes such as hydrothermal activity and biomass variability in vent communities. The establishment of an observatory network is essential to investigate global processes such as the dynamics of the oceanic lithosphere and the thermohaline circulation in the Ocean. Any increase in sampling capability results in major advances across a range of scientific disciplines:

- Global change, physical oceanography, marine biochemistry,
- Earth sciences, geohazards and seafloor interface,
- Ecology
- And non-Living resources.

A key work was carried out by H. Ruhl et al. (2011) within the framework of the ESONET NoE project. It was aimed at reviewing the science areas in relation to ocean observatory research and introducing some of the scientific issues that observatories will help to address. The reader can refer to this article to get an overview per scientific discipline; here, focus will be only on topics relevant to the following applications.

### 3.1 An observatory dedicated to marine ecosystem monitoring on MOMAR site

Marine organisms are sensitive to their physical and biochemical environment. Consequently, due to the increase of anthropogenic modifications in the environment, one among the challenges of the 21st century is to evaluate the sensitivity of the ecosystem to anthropogenic changes. Indeed, given the short- and long-term impacts of climate and global changes upon the primary production, the entire trophic chain is likely to be affected in a complex way (see the review in H. Ruhl et al. (2011), section 2.4). This implies to accurately monitor the biochemical cycles and to gain more insight into the ecological functions of organisms at several levels of the trophic network according to the environment conditions and its evolutions. This should be done in several water layers, including the bottom one and the benthic one. A special focus should be made on the deepest ocean, which is scarily explored and so "well unknown". Indeed, the conduct of long-term explorations of the deep areas is difficult because this environment is hostile. The benthic zone is influenced by the processes at play within the upper water layers and by those from the seabed such as hydrothermal vents, gas hydrates, and more generally by geophysical processes. Fluid flow within and through the seabed transfers substantial amounts of mass,

heat and chemical energy in relation to geophysical, biogeochemical and ecological processes. Estimation of fluxes is, thus, essential to the calculation of ocean global budgets and to enhancement in the modelling of global changes. Many of these processes are developing on relatively short timescales and can be unpredictable. Deep-sea observatories are suitable tools to monitor the changes induced by both such short-term events and long-term global changes. In addition, the interactive communication between observatories and scientists allows the latter to modify the sampling strategy whenever an episodic, and maybe unpredictable, event is detected.

### 3.1.1 A case study site: MoMAR Site

The MoMAR (Monitoring the Mid Atlantic Ridge) initiative is aimed at providing multidisciplinary time-series datasets about hydrothermal systems in the Azores region of the Mid-Atlantic Ridge, where 4 hydrothermal fields are currently studied (figure 13). The goal is to get some feedback of the links between volcanism, deformation, seismicity and hydrothermalism in order to gain more insight into the coupling between hydrothermal ecosystems and these sub-surface processes and into its effect upon exchanges with the ocean. The Lucky Strike hydrothermal system (figure 13) is located on the summit of a volcano and consists of a hundred of hydrothermal sources that surround a lava lake. In the close vicinity of the vent sources the environment is hostile with temperature varying from 4 to 330°C. The chemical properties of the fluid have evidenced a complex hydrothermal system. On smokers the biological communities include bivalves, often colonised by micro-organisms, and host many faunal species. In the warmest zones shrimps are the main habitants. The food network is mainly based on chemosynthesis. As hydrothermal vents are very dynamic systems, their variations induce, in the ecosystem, complex changes that need to be better understood. In the past, field-observations were organised through ship surveys conducted at nearly the same seasons and under similar or very similar conditions, and thus the temporal variations were not taken into account. Consequently it was also difficult to capture a seismologic event and to observe the associated changes in the ecosystem.

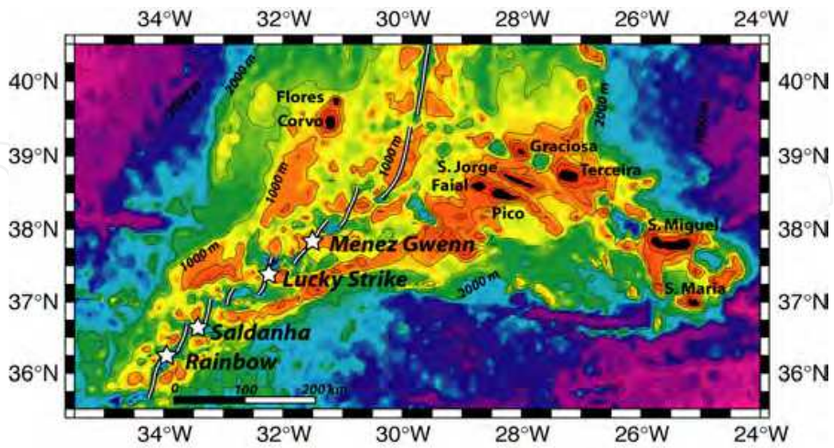



Fig. 13. Bathymetric map around the Azores islands. The Lucky Strike site is one among the 4 hydrothermal sites (white star). ©Ifremer

To fill this gap, the implementation of a permanent observatory on Lucky Strike started, in 2008, with the deployment of autonomous temperature probes at vents selected so as to

build on previous experiments dedicated to ecology, geodesy and seismology. Under the scope of the ESONET Network, the MoMAR-D demonstration mission has maintained and reinforced these experiments through a stronger participation of colleagues from other European countries. The system operates 200 miles off the closest island, at a depth of nearly 1 700 m on two field sites: a geophysical node is moored in the Lucky Strike lava lake, and a geochemical/ecological node at the Eiffel Tower vent site.

### 3.1.2 Strategy and technology on the MoMAR site

A prerequisite to the monitoring of the effects induced by the above mentioned geophysical phenomenon is the detection and monitoring of this rather unpredictable geophysical activity, which usually takes place in short lapses. An observatory will help to capture the event and to update the sampling strategy according to the phenomenon features. This observatory must include facilities dedicated to the monitoring of the life evolution around the hydrothermal site and measurement of the impacting environmental parameters such as key physico-chemical properties associated with the geophysical activity. The system allows one to directly observe the ambient life with a camera and to measure parameters with dedicated sensors. The first part of the project was dedicated to the development and adaptation of the interfaces between the various sensors and the monitoring nodes. It was followed by an on-shore trial period that took place a few weeks before the cruise. The whole system was finally deployed during the MoMARSAT cruise with the RV "*Pourquoi Pas?*". The website, http://www.ifremer.fr/momarsat2010/, was created to daily track the operations at sea. In the summer of 2011 a second cruise was organised for infrastructure maintenance and equipment upgrade.

**The required infrastructure and pieces of equipment**

The observatory infrastructure (figure 14) is composed of 2 SEA MOnitoring Nodes (SEAMON) acoustically linked to a surface relay buoy (BOREL) to ensure satellite communication to the land base station in Brest (France). These SEAMON nodes are based on a technology developed during the ASSEM project. For instance, they were upgraded for deployment from a ROV instead of being free-falling devices. One of the challenges was to prepare a system reliable for long-term deployment (several years) in the vicinity of an active hydrothermal vent (*i.e.* at less than 2 m from the hydrothermal spring) where life conditions mean important biofouling and hostile environment for sensor. In addition the system had to be ROV-operable, deployed and maintained far away from the coast. This implied that any subsystem component had to be tested and qualified prior to the final deployment.

The first SEAMON node (SEAMON Est) dedicated to large-scale geophysical studies was moored in the centre of the large lava lake present in the Lucky Strike vent field. This node hosts an Ocean Bottom Sismometer (OBS) and a Permanent Pressure Gauge (PPG).

The second SEAMON node (SEAMON West) was deployed at the base of the Eiffel Tower active edifice to study the links between faunal dynamics and variations of physico-chemical factors. This node is composed of two sensor modules (figure 15). The former is a chemical *in situ* analyser developed by NOCS for measurements of iron concentrations in diffuse hydrothermal fluids. The latter is an ecological module (TEMPO) developed by Ifremer and described hereafter. Both sensor modules were connected to SEAMON onboard and moored once attached to the SEAMON West structure.

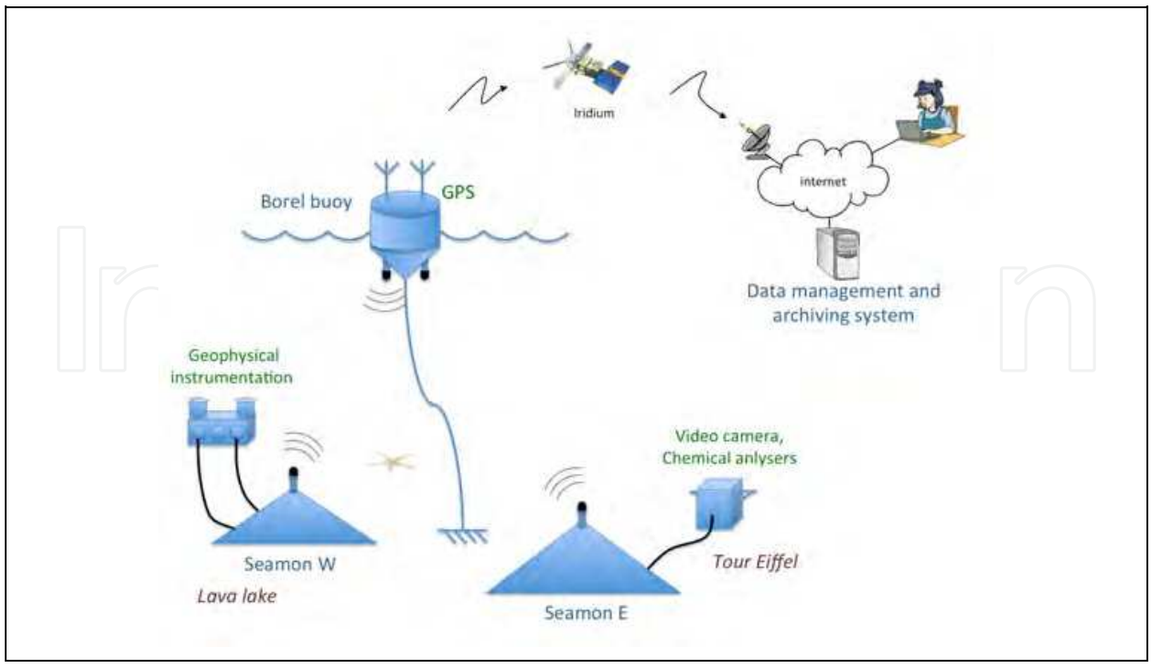



Fig. 14. MOMAR observatory concept



The TEMPO ecological module



The IronMan chemical analyser deployed on small cracks.

Fig. 15. Modules deployed on SEAMON west site (Eiffel Tower) © Ifremer/Victor 6000

TEMPO is an upgraded version of TEMPO Mini, which is an instrument package created by Ifremer for real-time monitoring of ecosystems (Auffret et al., 2009). Firstly Tempo mini integrated a 2 Megapixel streaming video camera with embedded event detection, 4 LED lights, an oxygen sensor and a temperature sensor. An efficient and innovative biofouling protection procedure was applied to the camera, lights and optical oxygen sensor (Delauney et al., 2010). TEMPO was tested and deployed on the coastal cable demonstrator, VENUS, of Neptune Canada from September 2008 to February 2009. Further to the proven evidence of its robustness, it was updated to include a chemical analyser, CHEMINI-Fe developed within Ifremer (Vuillemin et al., 2009) for measurements of total dissolved iron concentrations in the deep-sea waters. In this new version the High Definition (HD) video camera was coupled with 6 LED lights, an oxygen and temperature probe. This new version, named TEMPO, was deployed on the MoMAR site, and one photo was sent everyday to the ground station over one-year period (other video images were stored in the system).

**Deployment**

SEAMON nodes and the sensor modules were moored by the ROV, Victor 6000, from the RV "*Pourquoi pas?*". On Lava Lake, the sensor module was deployed near the SEAMON East and was connected underwater with wet mateable connectors by Victor6000 (figure 16).




Fig. 16. Deployment and connection of the SEAMON East node, (lave Lake) © Ifremer/Victor 6000

On Eiffel tower active edifice, the SEAMON West-linked sensor modules were precisely deployed on the sea-bottom by the ROV: TEMPO was located in front of a mussel bed, and the chemical analyser was positioned on a small crack (figure 17). The deployment of TEMPO was controlled *in situ* by using a prototype of underwater WiFi link. Using this link, the first video sequences acquired by the camera during on-board deployment were helpful in the validation of the exact position of the system and in the tuning of the recorded image quality.

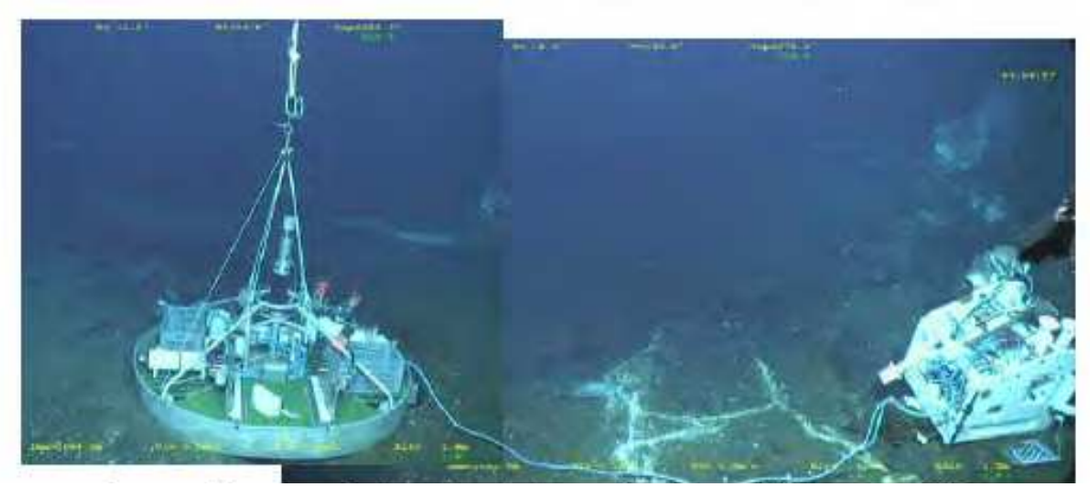


Fig. 17. SEAMON West and TEMPO after deployment and in operation on Eiffel Tower site © Ifremer/Victor 6000

The TEMPO ecological module and the IronMan chemical analyser were deployed on small cracks. The technique in use for exchanges between the two nodes and a BOREL buoy moored on the ocean surface within the acoustic range of the SEAMON stations is underwater acoustic communication. This buoy is equipped with two identical and redundant data transmission channels to ensure uninterrupted data flow. The acoustic

modems were chosen further to ESONET trials and are provided by EVOLOGICS GmbH (Berlin). Scientific and technical data (including a low-resolution photo) are transmitted daily to the data centre in Brest via IRIDIUM satellite transmission. Energy is supplied to the buoy by lead batteries recharged by solar panels. SEAMON West was deployed at the base of the Eiffel Tower active edifice.




Fig. 18. Autonomous surface buoy communicating with the moored system and satellite (a). © Ifremer/ J. Blandin

The 2 SEAMON nodes and the geophysics module were moored by using the vessel cable. On the bottom, Victor 6000 ROV performed the precise deployment and connection operations. The connection of the sensors to the nodes was validated by two methods tested over the cruise. A wet mateable connector was used for *in situ* connection of the geophysics-dedicated module to SEAMON West, whereas the sensors were on-board connected to SEAMON East. The Borel buoy was deployed within the acoustic range of the 2 nodes. In addition to real-time communication sensors, autonomous instruments (OBS, ocean bottom tiltmeter, current meters, particle trap, colonisation modules and temperature probes, see Table 1 below) were also deployed in the Lucky Strike vent field. They were equipped with 1-year data storage facilities.

### 3.1.3 Results and next steps

This observatory infrastructure has acquired a synchronised multidisciplinary data set and has enabled the development of solutions for sensor interoperability, shore-sensor interactive communication, data-management and –dissemination as well as public outreach. The first result was the validation of the procedure in use in the on-site deployment of the different components of the observatory. The two nodes were deployed on October 4 and 5, 2010. The Borel buoy was moored on October 12, 2010 and data transmission started immediately. The transmitted data are stored within Ifremer facilities. Some among the data can be viewed online at http://www.ifremer.fr/WC2en/allEulerianNetworks. The near real-time data have been used both as support for scientific

analysis and interpretation as well as indicator of the occurrence of an event. Volcanic-events or rapid degassing of the magma chamber, tectonic (displacement along axial faults) or hydrothermal ones have been recorded. In June and July 2011, a year after the deployment, the MoMAR team went back to the field site for system recovery and upload of non real-time data for further upgrade and redeployment. Nowadays, the system is still deployed. The analysis of the provided data is in progress; however, some results are already available. For instance the TEMPO module showed a smoker that was growing of 4 to 5 cm in height in two weeks (figure 19). It evidenced an increase of the local community as well as an extension of the area colonised by bivalves and several seismic events were recorded.



Fig. 19. The TEMPO observation module was deployed in the vicinity of an active hydrothermal site at the base of the 11-m-high Eiffel Tower edifice located on the Lucky Strike vent field on the Mid-Atlantic Ridge. It recorded photos for 5 months; they were to the sea surface via acoustic communication and to the in-land Ifremer data centre via satellite. The SMOOVE camera was looking at a Bathymodiolus azoricus mussel assemblage. On the above picture, one should note the presence of many predators, e.g. the crab, Segonzacia mesatlantica. Physico-chemical measurements were made in parallel to monitor the changes in environmental conditions and to evaluate their impacts on the dynamics of the vent fauna. Copyright J. Sarrazin/PM Sarradin, Ifremer.

Future steps include a cruise planned for 2012 and targeted to temporary recovery for maintenance of the system and redeployment. Despite the autonomy of the observatory, on-site operations are needed every year. Ideally, the cable system should allow a greater data flow in real-time, especially for video streaming, but the installation of such a long cable is not economically sustainable with the technology currently available.

### 3.2 A multiparameter, permanent observatory dedicated to Earth sciences, geo-hazards and seafloor interface in the Marmara Sea

The solid earth interacts with the ocean through many processes such as earthquakes, slope instability and sediment failures, fluid flow and seepage of gas through sediments and gas hydrates. Gas hydrates host large quantities of solid methane in marine sediments. Seismic activity and warming can make gas hydrate unstable and result in large releases of greenhouse gases that add positive feedback to global warming. Around Europe, this can

occur in the Black Sea, the Mediterranean Sea, the Gulf of Cadiz, the Nordic Sea and Arctic sites (Bohrmann et al. 2003, Woodside et al. 2006, Lykousis et al. 2009, Westbrook et al. 2009, Hustoft et al., 2009). The study of earthquake-related fluid-fault processes helps to gain more insight into gas emissions, seismic activity and oceanic warming (Etiope and Favali 2004). Earthquakes and landslides can both generate important tsunamis, phenomena that have recently become dramatically famous. These sad experiences highlight the need for, at least, enhancement and/or generalisation of early warning systems in sensitive zones. As a result, more geo-seismic deep-ocean observatories have been studied and implemented so as to improve prevention methods through a better understanding of earthquake- and tsunami-generating processes.

Cold seeps are often observed in association with active faults (e.g. Moore et al., 1990; Henry et al., 2002). This has led the scientific community to hypothesise that, at least, some of these fault channelled fluids come from deep levels within the sediments and, possibly, from the seismogenic zone in the crust. Furthermore, gas has been reported to expel from pockmarks and mud volcanoes in relation to the occurrence of earthquakes. Coupling between deformation, pore pressure transients and fluid flow may lead to post-seismic fluid release, earthquakes precursor signs and/or systematic variations in flow rates, fluid chemistry and pore pressure during inter-seismic phases. Numerous fluid vents and related features have been discovered along the North Anatolian Fault (NAF) system in the Marmara Sea.

### 3.2.1 A case study site: MARMARA Site

**Tectonic setting**

The Sea of Marmara hosts the submerged section of the highly active, 1 600-km-long, right lateral strike-slip North Anatolian Fault (NAF). According to historical evidence (Ambraseys and Jackson, 2000) a major earthquake happened in 1509 in the central part of the Marmara Sea. A series of earthquakes with estimated moment magnitudes close to, or greater than, 7 occurred in 1719, 1754, and in May and August of 1766 in the Marmara Sea region, but the distribution of damage was unable to give clues about the exact geometry of the associated segment fault ruptures (e.g. Ambraseys, 2002; Parson, 2004; Pondard et al., 2007). The next series of Mw ~ 7 events comprises 3 earthquakes in 1894, 1912 and 1999. The earthquake of the year 1894 affected the Cinarcik Basin and Izmit Gulf, but it is unclear which fault ruptured in the Cinarcik Basin. The earthquake of 1912 ruptured the Ganos fault on land and extended it further offshore (Armijo, 2005), but this distance may have been quite short (Ambraseys, 2002). Whatever the interpretations, a consensus has been reached within the scientific community about the fact that the Istanbul-Siliviri segment in the central part of the Marmara Sea is the most likely to rupture in the future. No break of this segment has been recorded since 1766.

**Relations with fluids and gas emissions**

In the Gulf of Izmit, repeated surveys have shown increase in the intensity of methane emissions after the earthquake of August 17, 1999 (Alpar, 1999; Kuscu et al., 2005). In the deepest parts, cold seeps with their associated manifestations, such as carbonate crusts, black patches and bacterial mats, were observed along the fault (Armijo et al., 2005). A systematic correlation was also found between active faulting and the acoustically detected gas escapes. Remarkably, the fault segment with the less acoustic anomalies found within the main fault trace corresponds to the Central High and Kumburgaz Basin area (see Fig. 1

in [Géli et al., 2008]). This segment is the most dangerous since it is the only one to have not undergone rupture since, at least, 1766. The identification of thermogenic hydrocarbons with the same geochemical signature as those found in the Thrace Basin at the top of anticline structures indicates that the North Anatolian Fault cross-cuts gas reservoirs from the southern continuation of the Thrace Basin gas field (Bourry et al., 2009). This finding opens new perspectives that were not even imaginable a few years ago. Moreover, it supports the need for monitoring gas emission activity along with seismicity: a major challenge is to determine whether gas can generate detectable signals related to the stress building process over the seismic cycle. To address this challenge, a continuous collection of geochemical and geophysical data in the immediate vicinity of the fault zone is a must. It can be done through implementation of permanent seafloor observatories in the Sea of Marmara and development of methods and tools for data processing, integration and analysis. A two-step strategy has been developed; it includes a prospecting phase aimed at getting a more accurate definition of the area prior to the implementation of a permanent system.

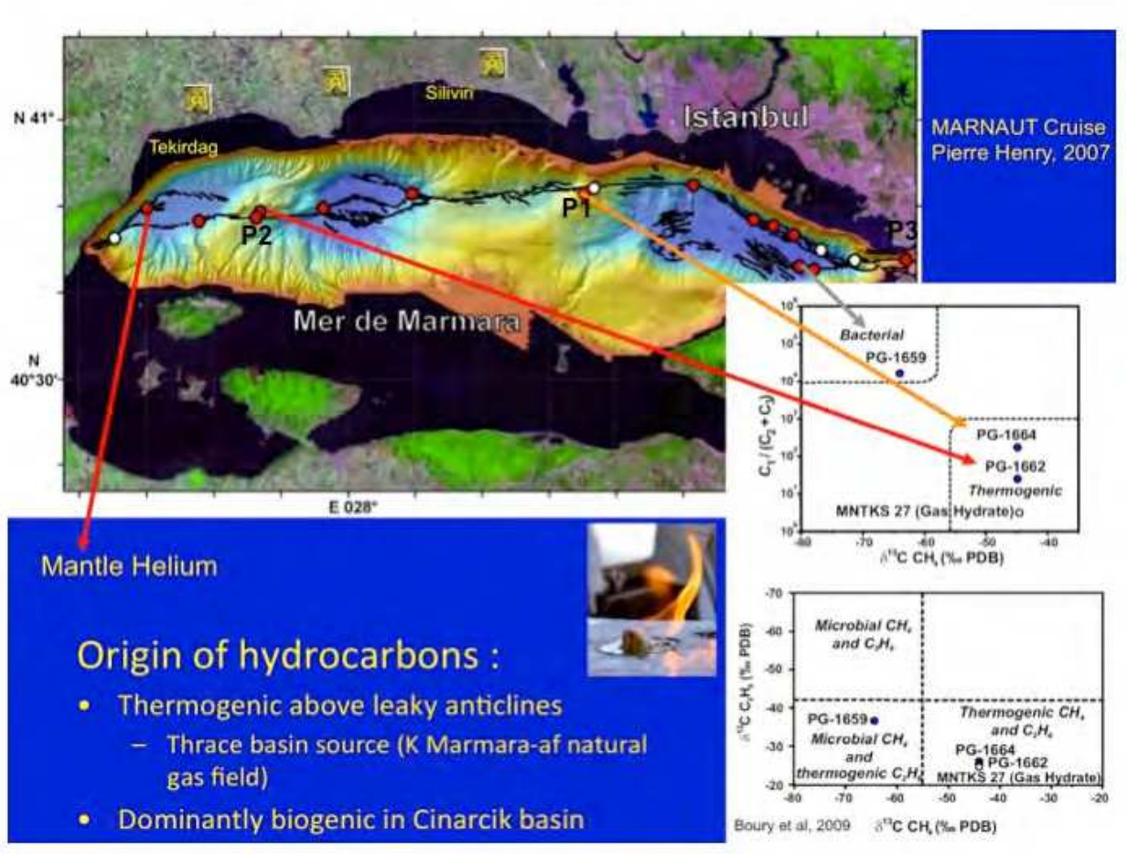



Fig. 20. Map showing the most active northern branch of the North Anatolian Fault (NAF; black line), gas emission sites (red dots). The inset diagrams show the composition plots of gases indicative of the thermogenic and deep origin (Géli et al., 2008; Bourry et al., 2009). P1, P2 and P3 indicate potential sites that were identified for multi-disciplinary seafloor observatories during the ESONET Marmara-DM Demonstration Mission.

### 3.2.2 Strategy on Marmara site: A prospecting step to prepare a permanent infrastructure

The Marmara Demonstration Mission (April 2008 to September 2010) was conducted within the EU-funded ESONET-NoE programme to: i) characterise the temporal and spatial relations between fluid expulsion, fluid chemistry and seismic activity in the SoM, ii) test the relevance of permanent seafloor observatories for an innovative monitoring of earthquake-related hazards, appropriate to the Marmara Sea specific environment, and iii) conduct a feasibility study for optimisation of the submarine infrastructure options (optical fibre cable, buoys with a wireless meshed network, and autonomous mobile stations with wireless messenger). The partners involved in the Marmara-DM Demonstration Mission were: Ifremer, CNRS/INSU, CNR/ISMAR, INGV, ITU and DEU (Dokuz Eylül University, Izmir).
A total of 6 cruises† conducted within the framework of the Marmara-DM were devoted to the area exploration, which included:

- an accurate mapping of the bottom by microbathymetry measurement,
- acoustic detection of gas emissions through deployment of an acoustic gas bubble detector (named BOB and hereafter described),
- 3D and 2D high-resolution seismic survey on the Western High site,
- deployment and recovery of the multi-parameter sea-bottom SN-4 observatory of INGV (a GEOSTAR type observatory) at the entrance of the Gulf of Izmit on the fault trace and at the end of the rupture of the 1999 earthquake.

**The required infrastructure and pieces of equipment**

During cruises at sea, a temporary infrastructure was deployed to test the equipment and to better assess the design and specifications of the infrastructure. Significant research efforts to the development of innovative sensors for monitoring variations in the geochemical and geophysical properties of gas emissions were made during Marmara-DM. They dealt with:

- *Pore-pressure sensors.* The piezometer is a free-fall device with a 15-m-long sediment-piercing lance equipped with sensors for measurement of the differential pore pressure at 5 different depths (< 15 m) below the seafloor. This device proved to be very powerful for detection and monitoring of free gas accumulation and release in superficial sediments.
- *Methane sensor*. Based on one-year-long tests performed by INGV and dedicated to the measurement of variations in methane concentrations in the Gulf of Izmit. It uses the methane sensor developed by the German CONTROS company (HydroC™/ CH4, Hydrocarbon & Methane Sensor), which has provided encouraging results.
- Arrays of Broadband *Ocean Bottom Seismometers* (BB-OBS)‡ working in the 0.03 – 30 Hz bandwidth
- *Gas-bubble monitoring system (BOB).* The BOB station is a bubble detection system designed from halieutic echo sonars used to detect echoes backscattered by gas bubbles. It relies on well known acoustic technology, such as high directivity single beam or multi-beam echo-sounders, used in mapping and quantification of gas bubble emissions

† Two Cruises with R/V Le Suroit (Ifremer, France) from November 4 to December 14, 2009, 2 other ones with R/V Urania (Italy) in September-October 2009 and September-October 2010, and the last 2 with Turkish vessels, respectively R/V Yunuz and R/V Piri Reis in March 2010.
‡ The two leading manufactures of the BB sensors in use in Ocean Bottom Seismology are: Guralp (www.guralp.com) and Kinemetrics (www.kinemetrics.com).

from the seafloor and monitoring of their temporal variability (Greinert, 2008). These echo-sounders are ideally combined with 70 to 300 kHz ADCPs systems so as to identify different seeps in the datasets and to determine the horizontal and vertical velocities of the bubbles. It can monitor an angular area of 360° in 7°steps. For each step it acquires and records acoustic data and other needed parameters such as compass of the station, temperature and pressure. The 2-m-high station frame has a surface base of 1.3 x 1.3 m² and a total weight of 635 kg (figure 21). The detection radius is 150 m and it can work at varying depth up to 1500 m deep.

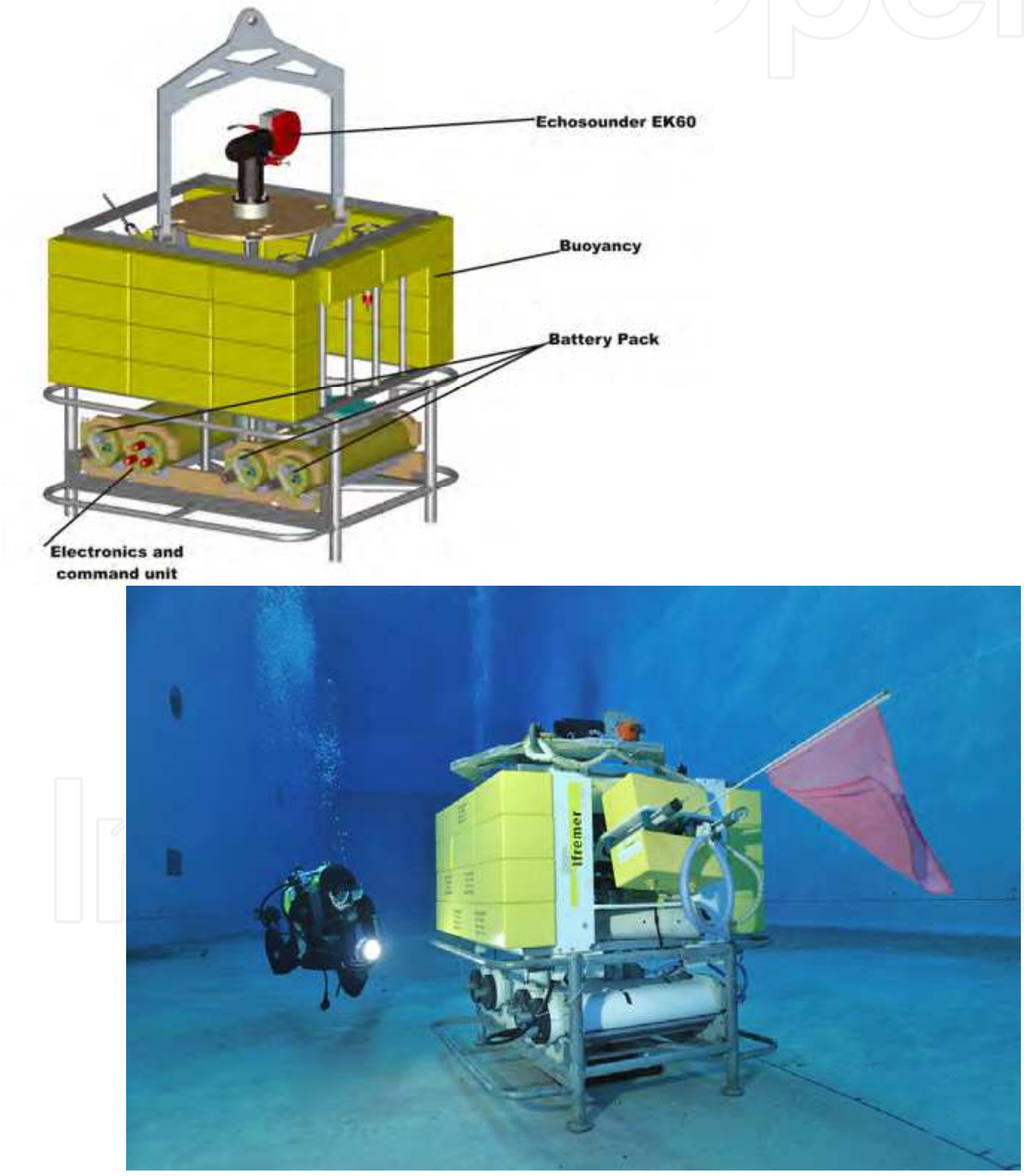



Fig. 21. Gas-bubble monitoring system (BOB module): conceptual design (left panel, ©Ifremer/RDT) and photo of the currently used BOB version (right panel, ©Ifremer/photo from M. Gouillou and O. Dugornay)

BOB was deployed by the Ifremer ROV, Victor6000, for the first time in December 2009 and off Istanbul to detect and quantify methane fluxes from the area. For its first try in deep waters, BOB recorded data over 4 days. This first *in situ* test evidenced important variations in gas flow. More recently, in summer 2011, BOB was also deployed in the Arctic area to detect and quantify methane releases under the scope of the ESONET demonstration mission AOEM (Arctic Ocean Esonet Mission) conducted between August 2 and 6, 2011. It proved to work well, and the collected data are currently analysed. BOB will be upgraded to extend the data recording duration so as to satisfy long-term observatory requirements.

### 3.2.3 Marmara DM results and next steps

**Results and next steps for the Mamara observatory**

The systematic mapping of fluid emission sites in the Marmara Sea over the Mamara-DM mission showed that, despite the association of many of them with active fault traces (Zitter et al., 2008; Géli et al., 2008), they are widespread and found in various contexts with no systematic relation to the activity of faults. The geochemistry of the fluids expelled also appears to be diverse, in particular the depth inferred for the fluid source (Bourry et al., 2009; Tryon et al., 2010). Instruments were deployed on the seafloor for durations from one month to one year. Some clusters of microseismic activity appeared to be spatially correlated with fluid migration through the crust (Tary et al., 2011). The flow-meters (Tryon et al., 2011) as well as the physical and chemical sensors, deployed with SN-4 system, measured temporal variations related to episodic fluid emissions through the seafloor.

The 6 cruises conducted in the Marmara Sea allowed the selection of the optimum sites for the future multi-parameters seafloor observatories (figure 22):

- Site P1, on the Istanbul-Silivri segment. This site is located in the seismic gap immediately south of Istanbul where intense bubbling is observed (1 km south of the main fault trace) despite the lack of evidence of fluid expulsion on the fault itself.
- Site P2, in the Western High area (also named Gas Hydrates area). The site is situated in the area where oil and gas seeps from the Thrace Basin were found and where the connections between the fluid migration conduits and the main fault system were imaged with a 3D, high-resolution seismic survey.
- Entrance of Izmit Gulf (Site P3). At this site, the principal deformation zone of the North Anatolian Fault is less than some tens of meters wide. In addition, the site is close to the western end of the surface rupture associated with the Izmit earthquake of 1999, where the next earthquake affecting the fault strand towards Istanbul may nucleate. It is a relatively accessible area, at shallow depth (200 m) and at less than 5 km from the coastline.

At sites P1 and P2, it has been proposed to install one cabled multi-disciplinary seafloor observatory on the Istanbul-Silivri fault segment that cuts an anticline characterised by the presence of numerous sites of gas emissions of thermogenic origin. The shore station will be cabled to one node, itself connected to, at least, 2 Junction Boxes (JBs) set respectively north and south of the fault (JBN and JBS). Each of them will be connected, at the most, to 10 instrument packages (Table 1). The devices deployed at each junction box will consist of: an array of 4 seismometers set at less than 500 m from the junction box, a piezometer, a bubble acoustic detector and a methane sensor. Clusters of seismometers will provide ultra-precise characterisation of earthquakes near the fault zone through use of array-based methods for hypocentre determination.

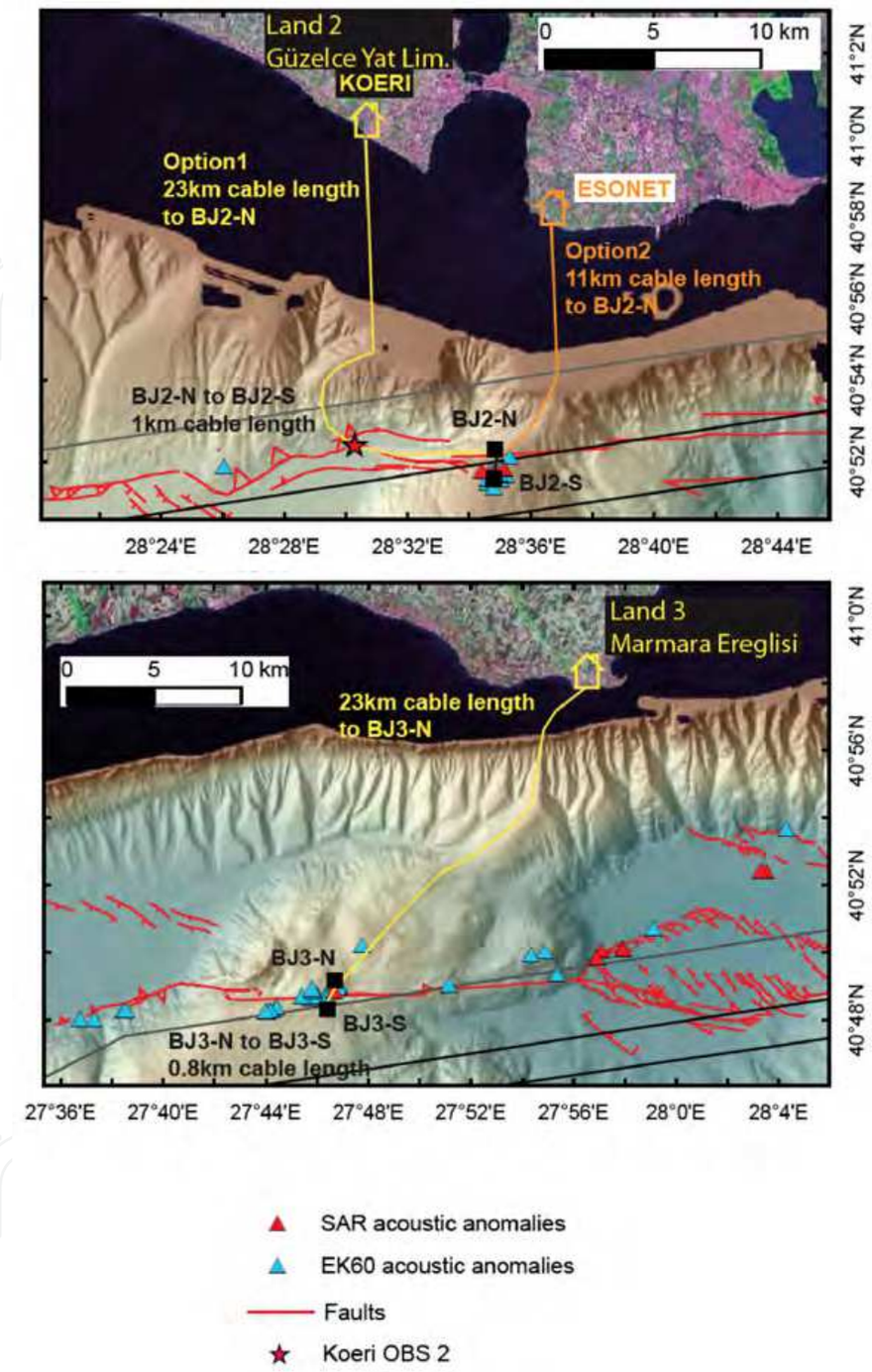



Fig. 22. View of the cable (yellow line) linking the observatory to the node at P1 (lower figure) and P2 (upper figure). The cable will be deeply buried all the way from shore to the main node. The area between the two SW-NE oriented, black lines is the separation zone between the upgoing and downgoing navigation corridor. The northern limit of the downgoing corridor is indicated as a thin grey line. The red star indicates the planned location of a cabled, permanent OBS to be deployed by KOERI in 2011.

| Connectors | Supplier | Availability of instrument/ Manufacturer | Interface | Power (Approx) |
|---|---|---|---|---|
| *1* | *OBS* | *Guralp* | *RS-232* | *< 10 W* |
| *2* | *Piezometer* | *NKE* | *RS-232* | *< 10 W* |
| *3* | *BOB (Bubble Observatory)* | *Ifremer* | *100BaseTX* | *< 10 W* |
| *4* | *Methane sensor* | *CONTROS* | *RS-232* | *< 10 W* |
| *5* | *Accelerometer* | *On-the-shelf* | *RS-232* | *< 10 W* |
| *6* | *Absolute Bottom Pressure Recorder* | *Paroscientific* | *RS-232* | *< 10 W* |
| *7* | *CTD/Oxygen/Turbidity* | *On-the-shelf* | *RS-232* | *< 10 W* |
| *8* | *Current meter / ADCP* | *On-the-shelf* | *RS-232* | *< 10 W* |
| *9* | *Time Lapse Camera* | *On-the-shelf* | *100BaseTX* | *< 10 W* |
| *10* | *Strong Motion Accelerometer* | | | |
| *11* | *Distance Meter* | *Sonardyne* | *RS-232* | *< 10 W* |

Table 1. List of the 11 sensor packages tested during previous EC-funded programmes, e.g.: the ESONET-NoE Programme (for slots 1 to 10) and ASSEM (for slot 11).

This infrastructure will contribute to enhance the knowledge and understanding of geophysical activity and will help scientists to make significant advances in this field. In parallel it will answer important societal needs such as seismic monitoring and prevention, which is a growing priority.

### 3.3 An observatory dedicated to biogeochemistry and physical oceanography on Porcupine site

Much of the transport of mass and energy from the upper ocean to the seafloor is controlled through the sinking of particles. It is, thus, essential to gain more insights into the functioning of this export. In particular the timescales of sinking and the origin and particle pathways are worth being investigated since these factors are crucial to determine the impact of a rapidly changing climate on a specific deep-sea ecosystem. The major source of particles is the photosynthetic production of phytoplankton in the euphotic zone. The matter, which finally sinks, can be either direct phytoplankton biomass or a conversion of it into certain aggregates. To investigate whether a region shows a strong vertical coupling between the surface ocean and the seafloor or whether it is dominated by lateral fluxes, the variables governing the particle export have to be analysed: this includes the characterisation of the particles themselves, the particle composition and form as well as the ability of the environment to re-suspend them, the role of ocean transport, and finally the local stratification of the water column. In regions with low stratification and deep mixing, such as the Arctic and Antarctic, a very close coupling between surface and the deep ocean has been found. It is this coupling and its variability which are the major scientific objectives of the Porcupine observatory site.

### 3.3.1 The Porcupine Abyssal Plain (PAP) case study

The Porcupine Abyssal Plain (PAP), 350 n.m. (nautic miles) off southwest Ireland (figure 23), is a key site for collaborative investigations within the framework of the EuroSITES and ESONET-NoE projects. The PAP site hosts the longest running multidisciplinary open-ocean time-series in Europe (http://www.noc.soton.ac.uk/pap). Over the past decade, the aim was the observation of changes in rate and state variables within the entire water column and the benthos for a wide range of biogeochemically significant features in the centre of the Porcupine Abyssal Plain. The site appears to meet many of the conditions required for analysis and interpretation of open ocean processes since it lies well away from coastal input; it is, indeed, situated in the middle of one of the biogeochemical provinces at a depth of 4 800 m where the abyssal plain is flat over large areas. Below the upper mixed layer, currents are in usually northerly and of low velocity. Winter mixing takes place at variable depth in the range 300-800 m, which facilitates investigations on the effects of the most important driving force on the upper ocean biogeochemistry: the nutrient supply.

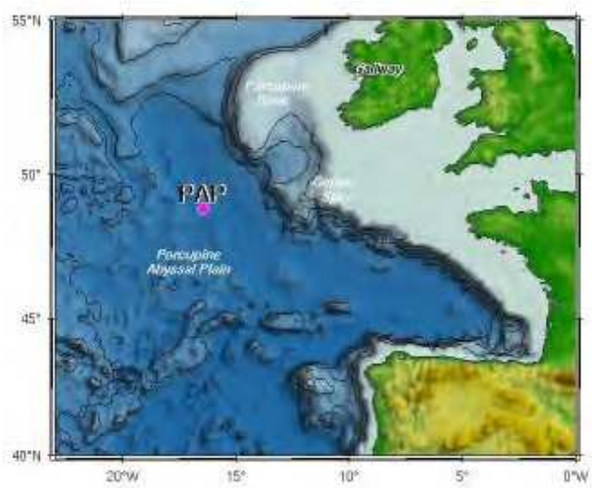



Fig. 23. Location map of the PAP Sustained Observatory (source: http://www.modoo.info/science).

The seasonal to interannual variability of downward particle flux that has been documented for the PAP site is of particular interest. Indeed, the variability has been attributed to changes in surface productivity, but longer time-series of particle fluxes have also shown a marked interannual variability, which can be related to climate modes such as the North Atlantic Oscillation (NAO). The scientific studies carried out on PAP site are targeted to an enhancement of our understanding of the complex oceanic processes from surface waters to the seafloor. They deal with the short-term variability of the oceans, including physical mixing, ecosystem dynamics and nutrient cycling. Longer-term trends in the Earth's climate are also addressed.

### 3.3.2 Strategy and technology on PAP site

The preliminary design for the PAP observatory was the CELTNET observatory. It involved a series of nodes linked together with sea-floor cables. However, for financial and technical reasons, it may be more appropriate that the nodes set in deeper waters work as stand-alone nodes with communication links and near real-time data transfer. Consequently, an

observatory prototype was designed to demonstrate the functioning of a re-locatable system with underwater acoustic telemetry as well as surface buoy telemetry of scientific and engineering data. This was achieved within the framework of the MOdular and mobile Deep Ocean Observatory (MODOO, http://www.modoo.info), *i.e.* an observatory with real-time data access by telemetry transmission.

The MODOO project (2009-2010) was organised to take profit from the existing water-column mooring infrastructure at PAP, which forms part of the EuroSITES ocean observatories and to develop it beyond the current state-of-the-art and within the objectives of ESONET-NoE. MODOO intended to integrate the both existing water column observatory with a benthic lander observatory into a single, real-time accessible observatory and to demonstrate the efficiency of one of the deepest acoustic links from the deep seafloor to the surface. The underlying concept in the MODOO project is to link and to operate existing stand-alone observatories so that to merge them into a single observatory. MODOO was mobile (or re-locatable) to be moved to regions of interest. Its modular architecture allowed connections to other stand-alone systems.

MODOO consisted of two observatory components (figure 24): a steel/plastic wire mooring and a benthic lander. The mooring was equipped with a bi-directional telemetry buoy connected, via the mooring wire, to inductively linked instruments. One of these "instruments" was a so-called "Data Collection and Dissemination" (DCD) node. This node acoustically linked the lander data with the surface buoy via the mooring wire. The lander also had a DCD node to which lander instruments were connected. The central components of DCD nodes, mooring, telemetry buoy and lander are described hereafter.

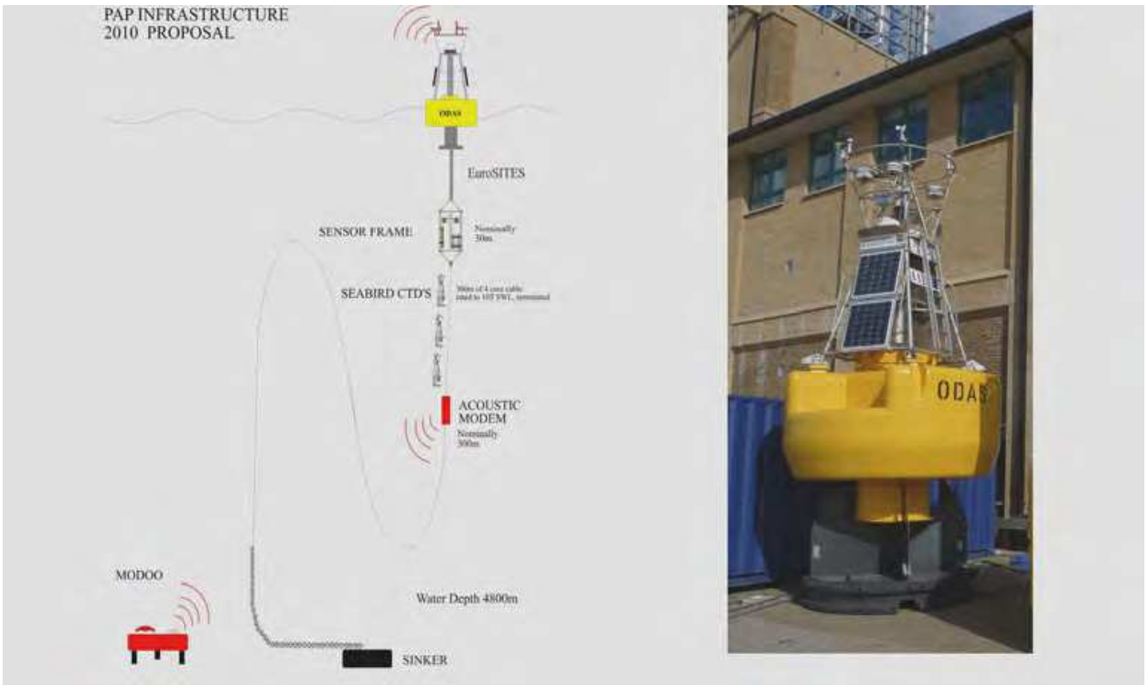



Fig. 24. Sketch of the PAP mooring as planned for the MODOO deployment (left). The PAP surface telemetry buoy at the NOCS'yard (right) (source: ESONET-NoE deliverable 45c, MODOO final report)

**Data Collection and Dissemination (DCD) node**

The central hardware linking the observatories components into one system was constructed around acoustic telemetry modems. These DCD nodes were expected to be used for communication between them, but also for sensor control, data storage, application of a precise time stamp to all data, data compression/uncompression for efficient transmission and checking of the transmitted data quality.

**The PAP mooring**

Two types of deep-sea mooring were deployed at the PAP site: they consisted of deep-water sediment trap moorings and, since 2002, a full water depth multidisciplinary mooring with surface telemetry devices. MODOO was expected to connect to the latter via an inductive coupled DCD node. The overall length of the PAP mooring is about 6 200 m; the deep sea part consists mainly in a Polyester/Polystell rope with the upper 1 300-m-long section made of Norselay® steel wire.

**Surface telemetry system**

The data logging and telemetry system on the PAP mooring was originally developed within the NERC-NOCS. The system is equipped with an Iridium 9522 modem, a Seabird inductive modem, a GPS receiver, a compass/pitch/roll unit and monitors for internal voltage/current/temperature. The buoy contains a solar charging controller and high-intensity LED recovery lamps that can be remotely switched on. The computer clock is regularly compared to the GPS clock and is adjusted so that it is +/- 1 second accurate. All of the data received from inductively coupled sensors are time-stamped with this clock as all the other data logged in the system. The Iridium modem is programmed to send regular position and engineering data reports by email, while scientific data are transferred through the dial-up mechanism. Commands can be sent to the unit by email according to a predefined command set for sensor control from the shore (event trigger). The system has successfully communicated with MicroCAT sensors at variable depths up to 4 960 m.

**The Benthic Boundary lander (BoBo)**

The BoBo lander (see §2) was developed as a stand-alone long-term monitoring system able, in its MODOO configuration, to carry a Seabird 16 CT (conductivity and temperature) probe (3 m above the bottom) with a Seapoint optical backscatter sensor (1 m above the bottom) and a new combined OBS-Fluorometer sensor (Wetlabs; 2m above the bottom) connected to it. A 1 200-kHz downward looking ADCP currentmeter is fixed to the frame 2 m above the sediment surface for measurements of bottom currents at high resolution (5 cm vertical bin size). At the same time the backscatter values of the 4 acoustic beams give additional 3D information about the amount of re-suspended material in case of correlation with the OBS sensors. In addition, a Technicap PPS 4/3 sediment trap with a rotating carousel of 12 bottles (250 ml) is mounted in the frame with the aperture (0.05 $m^2$) set at a height of 4 m above the bottom. A pan/tilt camera and 3 lights can be mounted in the frame at 2 m above the seabed. The camera can be programmed to record video images in 6 different settings and/or positions (these images are only accessible after retrieval). A power-unit supplies CT and ADCP probes with power and combines the RS232 connections of both sensors in a single underwater plug to

establish the link to the DCD node. The Lander was expected to be placed in 5 500 m deep water and at a maximum distance, along the horizontal, of about 3 000 m from the mooring anchor to secure ship operations.

### 3.3.3 MODOO results and next steps

The deployment mission started at the end of May 2010 on the James Clark Ross (JCR221) R/V. Soon after the deployment of the lander and of the DCD node mooring, trials evidenced communication problems between the 2 modules. The onboard team recovered the BOBO lander to fix the problem prior to a further deployment. The second deployment ended well, but a few hours later some devices from the system were found, by accident, drifting on the sea. The team concluded that the lander spheres encapsulating the power supply had imploded. The lander was lost despite the numerous and successful previous deployments in the past. The mooring was successfully deployed, and data are transmitted daily to the ESONET and EuroSITES data portals. In order to test the DCD communication, a second deployment of the DCD system was organised in August 2010 within the framework of the MOMAR demonstration mission. This second try was successful. The next step will be the inclusion of the MODOO system in a larger infrastructure consisting of 2 moorings and 7 landers, all able to communicate with the other ones and with the outside world via a surface telemetry system (German BMBF project Molab).

## 4. Conclusions

The experiments and research programmes achieved from the 1980s to the present time reflect the progressive enhancement of monitoring systems in the ocean basins. During this time span, marine researchers and engineers have been witness to the achievement and strengthening of the "open sea observatory" concept and to the technical evolution of earlier, quite simple, stand-alone mono-disciplinary instrumented modules into more complex multi-parameter platforms with extended lifetime and performances. This chapter was aimed at providing evidence of these evolutions at the European scale. Nevertheless, one should be aware that ocean observatories will never replace other observing systems; they should be considered as complementary tools that help scientists to make great advances in marine science. Indeed, marine science will always need traditional equipment for prospective actions, or to monitor either inaccessible sites where an observatory cannot be installed, or sites where the deployment of a less complex and cheaper system is sufficient.

Beyond these scientific focus restricted to topics discuss in this chapter, observatories are also pushing ahead the limits of other marine disciplines such as monitoring and study of Non-Living resources: energy (renewable resources and hydrocarbons, including $CO_2$ sequestration), mining/deposition, but also monitoring of fisheries, biochemistry, marine acoustics, marine forecasting for instance. Observatories can answer numerous scientific questions and can also satisfy societal and economical requirements like early warning systems for seismic prevention. The scientific and society pressure is increasing the need of observatory development but it is now clear that a coordinated research effort of long-term investigations and investment is required.

## 5. Acknowledgements

This article gives only a snapshot of the work done by the 54 ESONET-NoE partners. Ifremer, as coordinator of this project, greatly thanks all of the staff involved during this 4-year project (see partner list on www.esonet-emso.org). The authors also acknowledge the European Commission for co-funding of this project within the framework of the 6th Framework Programme under the contract GOCE-036851. They are also grateful to Kate Larkin (NOCS) and Laura Beranzoli (INGV) for their contributions and the BTU translation office of the Brest university (Bureau de Traduction de l'Université) for support.

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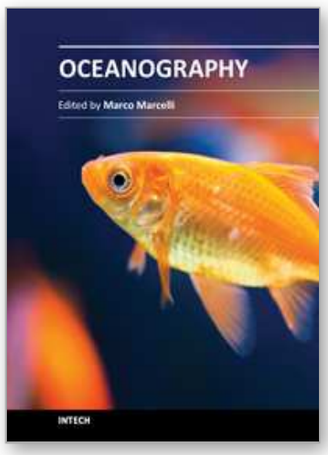
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**Oceanography**

Edited by Prof. Marco Marcelli

ISBN 978-953-51-0301-1
Hard cover, 348 pages
**Publisher** InTech
**Published online** 23, March, 2012
**Published in print edition** March, 2012

How inappropriate to call this planet Earth when it is quite clearly Ocean (Arthur C. Clarke). Life has been originated in the oceans, human health and activities depend from the oceans and the world life is modulated by marine and oceanic processes. From the micro-scale, like coastal processes, to macro-scale, the oceans, the seas and the marine life, play the main role to maintain the earth equilibrium, both from a physical and a chemical point of view. Since ancient times, the world's oceans discovery has brought to humanity development and wealth of knowledge, the metaphors of Ulysses and Jason, represent the cultural growth gained through the explorations and discoveries. The modern oceanographic research represents one of the last frontier of the knowledge of our planet, it depends on the oceans exploration and so it is strictly connected to the development of new technologies. Furthermore, other scientific and social disciplines can provide many fundamental inputs to complete the description of the entire ocean ecosystem. Such multidisciplinary approach will lead us to understand the better way to preserve our "Blue Planet": the Earth.

**How to reference**

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I. Puillat, N. Lanteri, J.F. Drogou, J. Blandin, L. Géli, J. Sarrazin, P.M. Sarradin, Y. Auffret, J.F. Rolin and P. Léon (2012). Open-Sea Observatories: A New Technology to Bring the Pulse of the Sea to Human Awareness, Oceanography, Prof. Marco Marcelli (Ed.), ISBN: 978-953-51-0301-1, InTech, Available from: http://www.intechopen.com/books/oceanography/open-sea-observatories-a-new-technology-to-take-the-pulse-of-the-sea-with-internet-in-the-ocean

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