

# Seafloor observatories from experiments and projects to the European permanent underwater network EMSO

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**Abstract** - The establishment of a global network of seafloor observatories will help to provide the means to understand the ocean, and the complex physical, biological, chemical, and geological systems operating within it. This is a challenge for the opening decades of the 21<sup>st</sup> century. The EC experience on seafloor monitoring is outlined since the early stage (beginning of '90s). In particular, the attention is focused on the GEOSTAR experience, describing the technical characteristics and the sensors used in experiments. Some recent projects are detailed. Finally, the European effort towards permanent underwater network EMSO, one of the large-scale research infrastructures included in the ESFRI Roadmap, is also discussed. All the previous activities are framed in this context.

**Keywords** - multidisciplinary seafloor observatories, experiments and projects, European underwater permanent network (EMSO).

## 1. INTRODUCTION

The ocean exerts a pervasive influence on Earth's environment. It is therefore important that we learn how this system operates. Understanding the ocean, and the complex physical, biological, chemical, and geological systems operating within it, is a challenge for the opening decades of the 21<sup>st</sup> century. The establishment of a global network of seafloor observatories will help to provide the means to accomplish this goal. A fully comprehensive definition of the term "seafloor observatories" was given for the first time by the NRC 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]. The main technical characteristic of a seafloor observatory is a two-way communication between platforms and instruments and shore. Seafloor observatories can have as possible configurations: 1)

autonomous, 2) acoustically linked, and 3) cabled [2].

A global network of seafloor observatories will provide a powerful tool to understand the ocean and the complex physical, biological, chemical, and geological processes. 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 [2]. Seafloor observatories can thus offer Earth and Ocean scientists new opportunities to study multiple, interrelated natural phenomena 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. Episodic processes include, for instance, volcanic eruptions, deep-ocean convection at high latitudes, earthquakes, tsunamis, and biological, chemical and physical impacts of storm events.

The most technologically advanced countries, have launched a large number of projects and programmes addressed to long-term and multiparameter seafloor monitoring [2, 3]. Canada, USA, Japan, Taiwan and Europe are the major actors. In Canada the major component of this effort is NEPTUNE [4]. In USA the OOI a NSF Division of Ocean Sciences program [5] has launched the RSN [6]. One of the most recent Japanese projects is DONET [7]. In Taiwan the project MACHO to develop a submarine cabled observatory off-shore eastern part of the island [8].

## 2. THE EC GEOSTAR EXPERIENCE

The European experience on seafloor monitoring started in early '90s with the EC MAST Programme. Feasibility studies

commissioned by EC were addressed to identifying the scientific requirements [9] and to establishing the possible technological solutions for the development of seafloor observatories [10]. In parallel, other studies and activities, such as DESIBEL [11], were carried out at EC level, aimed at defining needs and expectations for long-term investigations at abyssal depths. Since 1995, INGV ran a scientific and technological programme for the development of deep-sea observation systems for geophysics, oceanography and environmental sciences. This programme was initially funded by the EC within the 4<sup>th</sup> and 5<sup>th</sup> FP through the two projects GEOSTAR (1995-1998) and GEOSTAR-2 (1999-2001) [12, 13, 14, 15, 16, 17]. Two paths were followed after the GEOSTAR experience: the development of other single-frame observatories devoted to specific applications and the enhancement of GEOSTAR as principal node of a network of seafloor observatories. These paths have led to the availability of other five GEOSTAR-class observatories and to the first European prototype of a deep seafloor observatory network. The information for all the developed single-frame observatories is shown in Table 1.

Platform	Overall dimensions (m) (L x W x H)	Weight (kN) (in air)	Weight (kN) (in water)	Depth rated (km)
GEOSTAR	3.5 x 3.5 x 3.3	25.4	14.2	4
SN1	2.9 x 2.9 x 2.9	14.0	8.5	4
SN2 (MABEL)	2.9 x 2.9 x 2.9	14.0	8.5	4
SN3	2.9 x 2.9 x 2.9	14.0	8.5	4
SN4	2.0 x 2.0 x 2.0	6.6	3.4	1
GMM	1.5 x 1.5 x 1.5	1.5	0.7	1

**Table 1** - Relevant information for the six observatories

SN1 is addressed to seismological, oceanographic and environmental measurements, and was initially developed between 2000 and 2002 within the GNDT Italian programme. In 2005 it has become part of the cabled underwater infrastructure off Eastern Sicily (NEMO-SN1) [18], first real-time node of the future permanent underwater network, EMSO [19]. GMM, built within the EC ASSEM project (2002-2004) [20], is devoted to seafloor gas monitoring [21, 22]. Another single-frame system, MABEL (now SN2), was developed for polar sea applications within the framework of the Italian PNRA [23]. It just finished the experiment in the Weddell Sea (Antarctica), where it was deployed late 2005 and recovered late 2008 using the R/V Polarstern of AWI.

Within the framework of the EC ORION-GEOSTAR-3 project (2002-2005) [2, 3, 17], GEOSTAR was implemented to act as the main node of an underwater network of deep-sea observatories of GEOSTAR-class with the capability of (near)-real-time communication. In addition to this main node, two more observatories, with the function of satellite nodes (SN3 and SN4), were built and equipped with geophysical and oceanographic sensors. The parallel running of the EC ORION-GEOSTAR-3 and ASSEM projects has given us the chance to integrate one of the ORION nodes (SN4) in the shallow water ASSEM system during the pilot experiment in Corinth Gulf. This integration was to demonstrate the compatibility of the two seafloor networks and the chance to operate a “coast-to-deep-sea” monitoring system in the near future.

### 3. TECHNICAL CHARACTERISTICS OF THE GEOSTAR SYSTEM

GEOSTAR system is designed as a stand-alone autonomous seafloor observatory, based on three main sub-systems [24]: A) the Bottom Station (BS), which is the frame equipped with sensors, power and Communication Systems (CS); B) the CS hosted by BS; C) MODUS, which was specifically designed to handle the BS from the sea surface during the deployment/recovery operations, and operates like a simplified ROV.

GEOSTAR is capable of long-term (more than one year in stand-alone mode) multidisciplinary monitoring at abyssal depths. At present, the maximum operative depth is 4,000 m.

#### A. Bottom Station

The BS, a four-leg marine aluminium frame (Fig. 1, bottom), hosts a wide range of sensors, able to collect multidisciplinary data on the same spot. It also contains the battery pack (primary lithium), electronics mounted inside titanium vessels, hard disks for data storage and the underwater part of the communication systems. The BS mission is driven and controlled by a central DACS unit to allow the management of a complete scientific mission with a wide set of data streams and tagging each measurement according to a unique reference time provided by a central high-precision clock [2, 3, 17, 25].

#### B. Communication Systems

Two independent CS were originally developed for GEOSTAR, based on different principles

[26]. The first one consists of buoyant data capsules, named Messengers (MES), releasable upon surface command or automatically, when filled of data or in case of emergency. Two types of MES are available: a) expendable (data storage capacity 64 Kbytes); b) storage (data storage capacity larger than the expendable, 40 Mbytes). The capsules can transmit via ARGOS satellites their position at sea surface and small quantities of data. The second CS is based on a bi-directional vertical acoustic link with a ship of opportunity or moored buoy. A surface relay buoy, equipped with a telemetry unit and radio/satellite transmitters, assures the (near)-real-time communication between a shore station and the observatory on the seafloor [2, 3, 16, 17, 26].

The most recent communication link implemented on the GEOSTAR-class observatories was through the cabling: a proper interface between platforms and electro-optical cables was implemented on the SN1 observatory. This determined the realisation of the first real-time seafloor observatory in Europe, NEMO-SN1 off Eastern Sicily [18]. This area was identified as one of the key-sites for the nodes foreseen in the previous ESONET-CA [27] and the on-going ESONET-NoE [28] EC projects and in the EC-FP7 Research Infrastructure project EMSO [19].

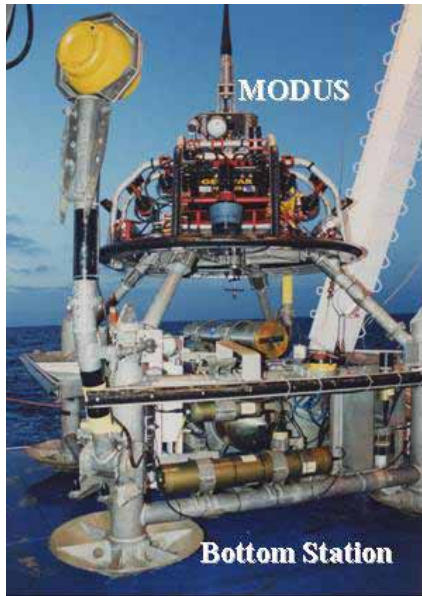


Fig. 1 - GEOSTAR BS (bottom) and MODUS (top)

### C. MODUS

Accurate and safe positioning at seafloor, re-entry and recovery capabilities of the BS are

ensured by the dedicated cable suspended module MODUS (Fig. 1, top), developed and built at TUB and TFH Berlin [29]. MODUS is a sub-sea intervention shuttle operating in deep seas while it is connected to a surface vessel with an umbilical, which provides power, bi-directional data-transfer via F/O telemetry and carries the load induced by the system during operation.

MODUS was conceived to be driven by a ship-board operator and initially could be moved only horizontally by means of two thrusters as needed during the BS recovery. For deep-sea missions the MODUS was enhanced with the inclusion of two additional thrusters to power the horizontal movements, one transponder and one altimeter to check MODUS location at depth from the sea surface, and sonar to identify the BS location during the recovery. The MODUS frame is also equipped with video cameras for visual seabed inspection. This system is able to carry up to 30 kN at abyssal depths.

### D. Sensors

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 sensors listed in Table 2. The total amount of data has exceeded 300 Gbytes (binary data), equivalent to greater than 3600 operative days (>10 years).

Sensors	Typical sampling rates
3-C broad-band seismometer	100 Hz
hydrophone (geophysics)	100 ÷ 2000 Hz
hydrophone (bio-acoustics)	96 kHz
gravity meter	0.1 ÷ 1 Hz
scalar magnetometer	1 sample/min
3-C fluxgate magnetometer	1 sample/s
APG	1 ÷ 15 s
DPG	1 ÷ 15 s
precision tilt meter (X, Y)	10 Hz
3-C single-point current meter	2 ÷ 20 Hz
ADCP	1 profile/h
transmissometer	1 sample/h
turbidity meter	1 sample/h
CTD	1 sample/10 min (or /h)
nuclear spectrometer	1 sample/4, 6, 8 h (stand-alone) 1 sample/30 s (real-time)
CH <sub>4</sub> sensor	1 Hz
H <sub>2</sub> S sensor	1 sample/10 min
O <sub>2</sub> sensor	1 sample/10 min (or /h)
chemical analyser (pH/eH)	1 sample/6 h
water sampler (off-line)	1 sample/500 s ÷ 1 week (48 bottles)

Table 2 – List of sensors used in seafloor experiments

#### 4. RECENT PROJECTS

##### A. Western Ionian Sea Observatory

SN1 was the first observatory based on the GEOSTAR technology. From October 2002 to May 2003 SN1 successfully completed the first long-term experiment off-shore Catania (Southern Italy, Eastern Sicily) at 2105-m depth in autonomous mode without any permanent acoustic or physical connection with the sea surface. SN1 was equipped with a vertical acoustic link to allow the remote request of the observatory data from a ship of opportunity and the retrieval of segments of acquired time series. During this experiment SN1 recorded about 15 Gbytes of data, mainly seismic. The high quality of the acquired data was demonstrated, definitively validating the procedure to deploy seismometer, de-coupling its housing from the frame coupling the instrument with the seabed [30]. The seismic events recorded only by SN1 opened new insights on the knowledge of the Ionian Basin seismicity [31].

After this experiment, SN1 was fitted with a fibre-optic telemetry interface so as to be compatible with the electro-optical cable owned and deployed off-shore from Catania by INFN and related with particle physics experiments. The cable layout is shown in Fig. 2.

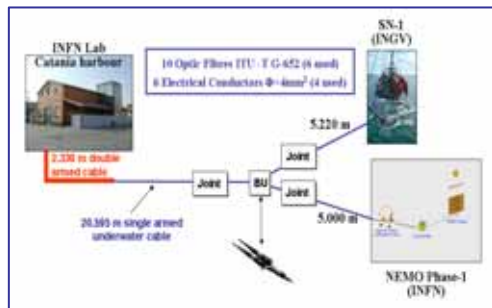


Fig. 2 - Cable layout deployed off-shore Eastern Sicily

In January 2005, the observatory was deployed by MODUS using the C/V *Pertinacia* of Elettra Tlc. in the same site of the first mission (about 25 km East of Catania at 2060 m w.d.) and connected to the submarine cable thus becoming part of the underwater infrastructure NEMO-SN1. These activities were performed under an agreement between two major Italian scientific institutions, INGV and INFN [18].

SN1 receives power from the shore, can communicate in real-time with the shore station inside Catania harbour, and is integrated in the INGV land based networks. NEMO-SN1 is the

first real-time seafloor observatory in Europe and one of the few in the world.

At the end of April 2008, SN1 was recovered after 3 years and 3 months by MODUS using the C/V *Certamen* of Elettra Tlc. The observatory will be refurbished, adding sensors and functionalities, particularly taking into account geo-hazards and bio-acoustics. It is planned to be re-deployed and re-connected to the cable within 2009. These activities are performed in the frame of the PEGASO project funded by “*Regione Siciliana*”, and the LIDO Demonstration Mission (LIDO-DM) funded by ESONET-NoE [28].

##### B. Iberian margin Observatory

The EC NEAREST project [32] proposes to place the sensors directly on the tectonic source to be able to monitoring the movements and to immediately recognise a tsunami. The area is the Gulf of Cadiz (Portugal) in which the destructive and tsunamigenic 1755 earthquake occurred destroying Lisbon [33]. During this project, GEOSTAR was installed in August 2007 south-west of Cape St. Vincent at over 3200 m w.d. and recovered in August 2008 always using R/V *Urania* of CNR. In this experiment, GEOSTAR was equipped with geophysical instruments and oceanographic instruments, and with a new prototype of “tsunameter”. This tool has been appositely designed to operate in areas that generate tsunami waves in order to send automated alert messages. The tsunameter is based on a double check of seismic and pressure signals and keeps into account the seafloor movements. It is planned to continue this experiment re-deploying GEOSTAR in the same site in Autumn 2009 using the new Spanish ship, R/V *Sarmiento de Gamboa*, thanks to the LIDO-DM. The Gulf of Cadiz is a key area defined by ESONET/EMSO as the future location of a permanent deep-sea observatory and NEAREST missions are considered a pilot implementation of this node.

##### D. Marmara Sea Observatory

The Marmara Sea developed along the highly active, right lateral strike-slip North Anatolian Fault, which produced devastating historical earthquakes along its 1600-km length [34]. The last destructive earthquake occurred at the eastern end of the Marmara Sea (1999  $M_w$  7.4 Izmit and  $M_w$  7.2 Duzce earthquakes). The major earthquakes, that seriously struck Istanbul and occurred on the segment of the North

Anatolian lying in the Marmara Sea, are since XVI century: 1509 ( $M_w$  7.2), 1566 ( $M_w$  7.3), 1754 ( $M_w$  6.8), 1766 ( $M_w$  7.2), 1894 ( $M_w$  6.8) and 1963 ( $M_w$  6.8) [35].

In 2008 the Marmara-DM was approved in the framework of ESONET-NoE [28]. This DM entitled “Multidisciplinary Seafloor Observatories for Seismogenic Hazards Monitoring in the Marmara Sea” aims at contributing to the establishment of optimized permanent seafloor observatory stations for earthquake monitoring in the Marmara Sea. Among the multiple activities planned in the Marmara-DM, a multidisciplinary seafloor observatory (SN4, Fig. 3) will be deployed in the eastern part of the sea at the westernmost end of the fault rupture caused by the 1999 Izmit earthquake using the oceanographic vessel R/V Urania of CNR. This experiment initially will last 1 year starting from autumn 2009 and we intend to continue over the time depending of the resources that will be available. Its major scientific goal is to contribute to the knowledge on the relationship between gas seepage and earthquake occurrence. It is well known that gas migration and surface gas anomalies, seepage and even eruptions of mud volcanoes, substantially increase in connection with earthquakes (e.g., [36], [37]).



**Fig. 2.** SN4 on the seafloor of the Gulf of Corinth (400 m w.d., April–November 2004) in the frame of ASSEM [20].

The Marmara-DM is a first step towards the realisation of a permanent long-term monitoring system fully integrated with the land-based stations, node of EMSO.

## 5. EMSO and ESONET-NoE

In Europe the effort for realising permanent underwater network is being supported by the EC through EMSO, an European-scale infrastructure of underwater observatories, constituting a widely distributed infrastructure for long-term monitoring of environmental processes related to ecosystem life and evolution, global changes and geo-hazards [19]. Parallely another relevant European initiative is running, ESONET-NoE project, that aims at boosting the integration of the European Ocean Sciences community interested in observatories and comprises more than 50 European universities, research institutes, companies involving 14 countries and about 300 scientist, engineers and technicians [28]. EMSO infrastructure is included in the ESFRI Roadmap [38] and will constitute the sub-sea segment of GMES [39] and GEOSS [40].

EMSO nodes are placed in specific marine sites on the European Continental Margin from the Arctic to the Black Sea through the Mediterranean Basin (Fig. 4). The design and development of the nodes depend upon the geographical location, the scientific and operational requirements. Two basic models can be envisaged for the nodes: stand-alone acoustically linked observatory and cabled observatory. However hybrid configurations could be adopted according to the site characteristics. The nodes will be equipped with a common set of sensors for basic measurements and further sensors for specific purposes.



**Fig. 4.** Map of the EMSO nodes

EMSO will be transformative by addressing interdisciplinary research priorities in:

- **Physical oceanography:** water mass characterisation, thermodynamics, ice cover, climatology, and impacts on climate change;
- **Geoscience:** transfer from Earth's interior to the crust, hydrosphere and biosphere, fluid flow and gas seepage through sediments and gas hydrate, non-living resources, sediment transfer to deep-sea and climate change;
- **Geo-hazards:** earthquake and tsunami hazard, volcanic hazard, slope stability;
- **Biogeochemistry:** global carbon cycle and elemental cycling within the ocean through both physical and biological processes;
- **Marine ecology:** distribution and abundance of sea life, ocean productivity, biodiversity, ecosystem function, living resources, and climate feedbacks.

EMSO will allow to understand:

- the environmental processes as the geo-, bio-, and hydro-sphere interactions;
- the temporal evolution (short-, medium- and long-term, periodic and episodic events) of the oceanic circulation, earth processes, deep-sea environment and ecosystems.

EMSO will take advantage of the synergies between the scientific community and the industry and will contribute to a significant improvement of marine technologies and the development of strategies for improving European capacities and competitiveness in ocean sciences and technologies.

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;
- **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 ERA.

EMSO is presently in the Preparatory Phase (EMSO-PP) with a project of EC-FP7. This project will establish the legal entity EMSO which is able to manage the scientific, technical, logistic and administrative components of the infrastructure. EMSO-PP has started in April 2008 and will run for 4 years.

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INGV (CO: A, B, D, E, F, I; PA: C, G, H)

ISMAR-CNR (CO: G; PA: A, B, D, E, H)

Tecnomare SpA (ENI Group) (PA: A, B, D, E, F, H; SC: C, G)

TFH (PA: A, B, D, E, F, G, H)

TUB (PA: A, B, D, E, F)

IFREMER (CO: C, H; PA: A, B, D, I)

SER (PA: A, B, D, H; SC: C)

IFSI-INAFA (PA: E; SC: B, D, G)

IPGP (PA: B, C, H)

HCMR (PA: C, H, I)

INFN (CO: E [NEMO]; PA: E [SN1], H)

FFCUL, UTM-CSIC (PA: G, H, I)

LOB-CNRS (PA: A, B)

INOCS (PA: E, F)

KDM, IMI, UGOT, NOCS, UiT, ITU, NIOZ (PA: H, I).

IFM-GEOMAR (PA: D)

Patras University, CAPSUM, NGI, FUGRO (PA: C)

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CO = Co-ordinator; PA = Partner(s); SC = Sub-contractor

## 6. ACRONYMS AND ABBREVIATIONS

ADCP - Acoustic Doppler Current Profiler

APG - Absolute Pressure Gauge

ASSEM - Array of Sensors for long-term SEabed Monitoring of geo-hazards

AWI - Alfred-Wegener-Institut für Polar und Meeresforschung

CAPSUM - CAPSUM Technologie GmbH

CNR - Consiglio Nazionale delle Ricerche

CNRS - Centre National de la Recherche Scientifique

CNRST - Centre National pour la Recherche Scientifique et Technique

CSIC - Consejo Superior de Investigaciones Científicas

CTD - Conductivity, Temperature vs Depth

DACS - Data Acquisition and Control System unit

DESIBEL - DEep-Sea Intervention on future Benthic Laboratory

DM - Demonstration Mission

DPG - Differential Pressure Gauge

DONET - Dense Oceanfloor Network system for Earthquakes and Tsunamis

EC - European Commission

EMSO - European Multidisciplinary Seafloor Observatory

ENI - Ente Nazionale Idrocarburi

ERA - European Research Area

ESFRI - European Strategy Forum on Research Infrastructures

ESONET-CA - European Seafloor Observatory Network-Concerted Action

ESONET-NoE - European Seas Observatory Network-Network of Excellence

FFCUL - Fundação da Faculdade de Ciências da Universidade de Lisboa-Centro de Geofísica da Universidade de Lisboa

FP - Framework Programme

FUGRO - FUGRO Engineers  
 GEOS - Global Earth Observation System of Systems  
 GEOSTAR - GEophysical and Oceanographic STation for Abyssal Research  
 GEOSTAR-2 - GEOSTAR 2<sup>nd</sup> Phase: Deep-sea mission  
 GMES - Global Monitoring for the Environment and Security  
 GMM - Gas Monitoring Module  
 GNDT - Gruppo Nazionale per la Difesa dai Terremoti  
 HCMR - Hellenic Centre for Marine Research  
 IFM-GEOMAR - Leibniz-Institut für Meereswissenschaften an der Universität zu Kiel  
 IFREMER - Institut Français de Recherche pour l'Exploitation de la Mer  
 IFSI - Istituto di Fisica dello Spazio Interplanetario  
 IM - Instituto de Meteorologia Divisão de Sismologia  
 IMI - Irish Marine Institute  
 INAF - Istituto Nazionale di Astrofisica  
 INFN - Istituto Nazionale di Fisica Nucleare  
 INGV - Istituto Nazionale di Geofisica e Vulcanologia  
 INOGS - Istituto Nazionale di Oceanografia e Geofisica Sperimentale  
 IGP - Institut de Physique du Globe de Paris  
 ISMAR - Istituto di Scienze Marine  
 ITU - Istanbul Teknik Universitesi  
 KDM - Konsortium Deutsche Meeresforschung e.V.  
 LIDO - Listening to the Deep Ocean  
 LOB - Laboratoire d'Océanologie et de Biogéochimie  
 MABEL - Multidisciplinary Antarctic Benthic Laboratory  
 MACHO - Marine Cable Hosted Observatory  
 MAST - MARine Science and Technology  
 MODUS - MOBILE DOcker for Underwater Sciences  
 NEAREST - Integrated observations from NEAR shore Sources of Tsunamis: towards an early warning system  
 NEMO - NEutrino Mediterranean Observatory  
 NEPTUNE - North East Pacific Time-series Underwater Networked Experiments  
 NGI - Norges Geotekniske Institutt  
 NIOZ - Stichting Koninklijk Nederlands Instituut voor Zeeonderzoek  
 NOCS - National Oceanography Centre Southampton  
 NRC - National Research Council  
 NSF - National Science Foundation  
 OOI - Ocean Observatories Initiative  
 ORION-GEOSTAR-3 - Ocean Research by Integrated Observation Networks  
 PEGASO - Potenziamento di reti Geofisiche e Ambientali Sottomarine  
 PNRA - Programma Nazionale di Ricerche in Antartide  
 ROV - Remotely Operated Vehicle  
 RSN - Regional Scale Nodes  
 SNn - Submarine Network n (n = 1 ÷ 4)  
 SER - SERCEL Underwater Acoustic Division (former ORCA Instrumentation)  
 TFH - Technische Fachhochschule Berlin  
 TUB - Technische Universität Berlin  
 UBO - Université de Bretagne Occidentale  
 UGOT - Goteborgs Universitet  
 UGR - Universidad de Granada, Instituto Andaluz de Geofísica  
 UiT - University of Tromsø  
 UTM - Unitat de Tecnologia Marina  
 XISTOS - XISTOS Développement S.A

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