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D4.4 : Report on intercalibration with green repeater initiative

Task 4.3 : Solid earth – Marine common operations of platforms : benthic stations

WORK PACKAGE 4 – JOINT OPERATIONS ACROSS THE RI DOMAINS

LEADING BENEFICIARY: IFREMER

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1. Executive Summary

This Milestone report repeatedly refers to "Smart Cables" (Science Monitoring And Reliable Telecommunication - SMART Subsea Cable systems); this term corresponds to the "Green repeaters" program mentioned in the ENVRIPLUS DoA (Description Of the Action). The Joint Task Force of ITU WMO in charge for the UN organizations initiative decided in 2016 to change the title of the program. We will use the new terminology further on in ENVRIPLUS.

Smart Cables program encourages the collaboration between the owner of communication seafloor cables and the scientific community involved in geo-hazard and climate change studies. The ultimate scope of the program is to utilize existing platforms (cable repeaters) for new sensors or integration of physical, biogeochemical and biological sensors in order to improve observing efficiency. Smart Cable program has set the frame for the joint design, development and deployment of multi-sensor devices suitable for integration in the communication cables repeater providing baseline conditions for ground acceleration, temperature, water pressure.

The ENVRIPLUS task addresses the common interest of EPOS (land) and EMSO (sea) in deep-sea geo-hazard monitoring in reference to the Smart Cable framework. The task provides element to build up a joint long-lasting frame for sharing knowledge and usage of technologies and best practices.

This report presents: (i) an overview of the latest sensor innovations addressing both domains (i.e. able to be implemented on benthic stations), (ii) achievements of standardization effort of EMSO for the data of benthic stations in relation to EPOS/RESIF.

2. Benthic Stations: technology

For many years, benthic stations have been developed and deployed both in the EC Framework Programs (5th to 7th) and in national programs. Some benthic station have been cabled and have been operating at EMSO sites; non cabled observatory deployment still remain a priority need, as the investment cost of underwater cables purchase and deployment is still little affordable by a single entity. An interesting opportunity in this respect, is represented by the integration in benthic observatories of new generation sensors for geophysical measurements with improved characteristics (e.g., power consumption, clock stability and accuracy, broadness of the usable frequency band of the transfer function), also with autonomous operation characteristics, which can be implemented for great depths (of about -4000 m) application.

2.1. Accelerometer sensor innovations

The advances concerning accelerometer sensors have been very numerous in recent years, and in particular, innovations concerning cost- and power-efficiency and the search of solutions to decrease the noise floor.

Neeshpapa et al., explored in 2015, a possible approach to the construction of a hybrid seismic accelerometer combining the superb performance of a MET (Molecular-electronic transducers) sensor in the middle and high frequency range with a conventional on chip MEMS (Micro-Electro Mechanical Systems) accelerometer covering the lower frequencies and gravity. Completing a MET sensor with a cost-effective MEMS permitted the construction of a low noise DC (Direct Current) accelerometer preserving the noise performance of a MET sensing element.

Lainé and Mougenot (2014) described a practical solution to decrease the noise floor of MEMS accelerometers with the development of a new generation of MEMS-based digital sensor. It provides a significantly lower noise floor (at least –10 dB) and thus a higher dynamic range (+10 dB). This performance has been tested in an underground facility where conditions approach the minimum terrestrial noise level. This new MEMS sensor will even further improve the detection of low frequencies and of weak signals such as those that come from deep targets or from microseismic events.

Paros J. has recently developed a Nano-Resolution Accelerometers which proposes a full-scale range of several G’s, parts-per-billion sensitivity and excellent long-term stability. This new accelerometer consists on a Quartz Crystal triaxial accelerometer assembly with an internal alignment matrix uses the invariance of the gravity vector as a reference to measure seismic events and resultant earth movements. It allows to measure strong earthquakes without clipping and can use the invariance of Earth’s 1 G gravity vector as a reference.

Miniaturization and progress on OBS Ocean Bottom seismometer

Several discussions on the practices of EMSO for ocean bottom seismometers have taken place within FixO3 and ENVRIPLUS meetings. No conclusion can be established on a best choice of technology: costs are high, reliability not certain and maintenance requires very skilled personnel. The context of JTF Smart Cable is promising for our project to be in relation with the users and manufacturers of the most reliable underwater accelerometers.

Contacts with providers were made during the ENVRIPLUS Forum in Grenoble during May 18-19, 2017 (Environmental Research Infrastructures (RIs) meet industrial partners). The list of companies (a task of WP1) was prepared during the Task 4.3 session of the November 2016 ENVRIWEEK in Prague. Contributors for the list were Jean-François Rolin, Wayne Crawford, Mickaël Langlais, Florian Haslinger, Laura Beranzoli, Mamadou Lamine Fall and Helle Pedersen.

At Ifremer, a new acquisition electronics for short period geophones is being developed, in collaboration with the industrial SERCEL

(http://www.sercel.com/products/Lists/ProductSpecification/MicrOBS_specifications_Sercel_EN.pdf)

This development tackles the following

- Lower the consumption needs (from 700 mW/h to 200)

- Increase the accuracy of the internal clock
- Miniaturization of the electronics
- Very high sensitivity of the short period analog sensor (4.5 Hz; this level of sensitivity is not reached by the MEMS sensors yet). The sensitivity of the sensor is critical to allow for long offset records during refraction operation, therefore deeper earth penetration.

This improvement reduces the size of the MicrOBS while improving its acquisition performance. The autonomy will remain very close to the current model with 24 days of registration for 31 days of deployment.

Benefiting from these developments, IFREMER will improve the deployment time of its LotOBS, which is designed to record short period sensors over a long period. The LotOBS is designed to record local seismology, the total duration of the recording may be up to 12 Months while keeping a very compact instrument, easy to implement. Deployment of the first instrument is panned in 2020.

2.2. EGIM - the EMSO Generic Instrument Module

EMSO ERIC has developed an EMSO Generic Instrument Module, called EGIM, in the frame of the H2020 project "EMSODev"[1]. This type of benthic station could be associated to any existing cable via junction boxes.

The module aims at consistently and continuously measuring seven Essential Ocean Variables at the various regional facilities pertaining to EMSO, placed at key sites around the European seas. The EGIM core variables include temperature, conductivity, pressure, dissolved O_2, turbidity, ocean currents, and passive acoustics. These parameters support the GOOS - Global Ocean Observing System, and the *Marine Strategy Framework Directive* towards evaluating the Good Environmental Status of the European seas. EGIM aims at recording a set of core variables measured homogeneously by identical hardware, same sensor references, same qualification methods, same calibration methods, the same data format and access, ad the same maintenance procedures.

The EGIM includes:

Seven core parameter sensors: temperature, conductivity, Pressure, Dissolved O2, Turbidity, Ocean currents, Passive acoustics. In addition to these core sensors, The EGIM can host additional sensors, including chl-a, pCO2, pH, seismic and photographic/video images or new sensors as long as their Technology Readiness Levels is sufficient.

- An electronic core: COSTOF2 - COmmunication and STOrage Front-end, 2nd generation is a recent development (Ifremer) already proven in deployment at sea, presenting an optimal innovation/reliability ratio. It was primarily designed for non-cabled applications, yet perfectly matches the requirements/constraints of the standalone EMSO nodes. In the case of cabled nodes, COSTOF2 may be operated as a transparent junction box between shore and sensors, with the option of sensor drivers on shore.
- A data and power converter unit called DPI: for 300-400V DC cabled installations, the DPI ensures the node power voltage conversion and provides backup power in case of failure.
- A basic frame
- Batteries for standalone deployment

The EGIM is designed to adapt to the various EMSO node configurations: mooring line, cabled or non-cabled sea bed station and surface buoy. Its compact and modular nature, low power requirements, mechanical design and embedded software allow for flexible deployment scenarios and can accommodate new instruments. This is a key point to the modularity, inter-operability and capacity of the future evolution of the system.

[1] Funding from the European Union's Horizon 2020 research and innovation n program under grant agreement N°676555.

The EGIM has been tested and a few deployment are finished or currently on going. The longest deployment was performed during one year on EMSO-Azores observatory, on the mid-Atlantic ridge, at a 1700 m water depth. The data is made available through precisely documented DOIs referenced in the EMSO data catalogue (https://campagnes.flotteoceanographique.fr/campagnes/17000500/).

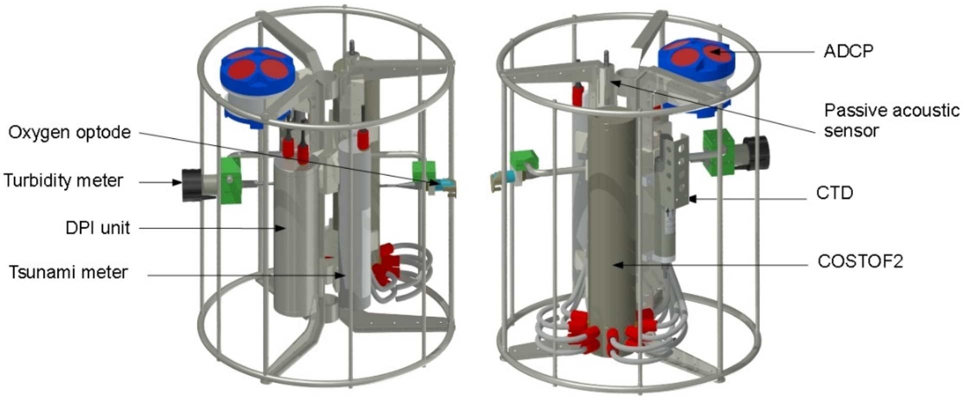


Figure 1: Sketch of the EGIM

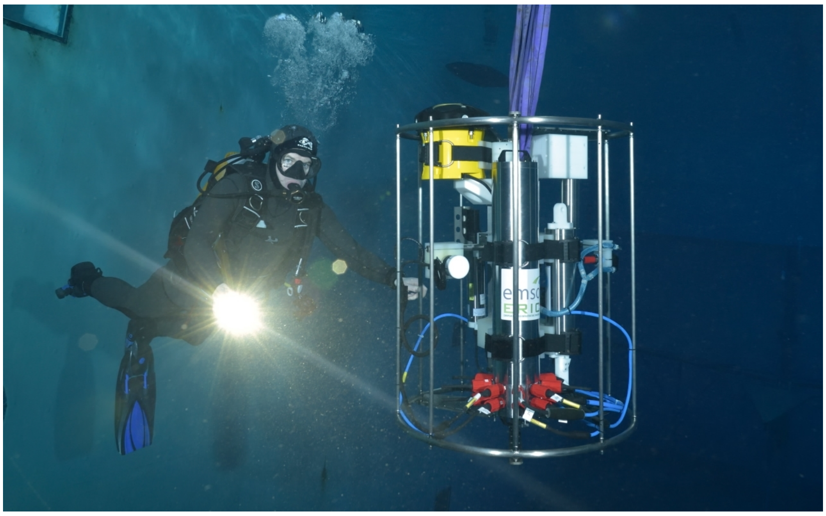


Figure 2: Photo of the EGIM prototype. The diver helps appreciating the volume of the EGIM

2.3. The FOCUS project: use of fiber-optic cables for imaging seismological and structural features

The goal of the ERC (European Research Council) funded project – FOCUS Fiber Optic Cable Use for seafloor studies of earthquake hazard and deformation (ERC Advanced Grant), is to connect a 6-km long strain cable to the EMSO seafloor observatory in 2100 m water depth.

Laser observations will be calibrated by seafloor geodetic instruments and seismological stations. A long-term goal is the development of dual-use telecom cables with industry partners.

It was recently demonstrated that fiber optic telecommunication cables both on-land and at sea can detect earthquakes (Marra et al. 2018, Jousset et al. 2018). FOCUS goal is the application of laser reflectometry in fiber optic cables to detect movement across active submarine faults also in near real time.

BOTDR (Brillouin Optical Time Domain Reflectometry) is commonly used for structural health monitoring of large-scale engineering structures (e.g. - bridges, dams, pipelines, etc.). It is performed by firing a laser pulse from one end into an optical fiber. As laser light diffracts off microscopic imperfections in the fiber it produces several characteristic diffraction peaks (Raleigh, Brillouin, Raman). If the fiber optic cable is disturbed (through strain or temperature variations) then the Brillouin spectrum will vary at this exact location along the fiber (Fig. 3) compared to a previous measure. Under optimal conditions, deformation on the order of 50 um/m, (1/3rd the thickness of a human hair), can be easily measured at distances of several tens of km, and located to within 1 m (Maraval et al. 2017) These detection limits are 2 orders of magnitude better than typical land-based GPS techniques.

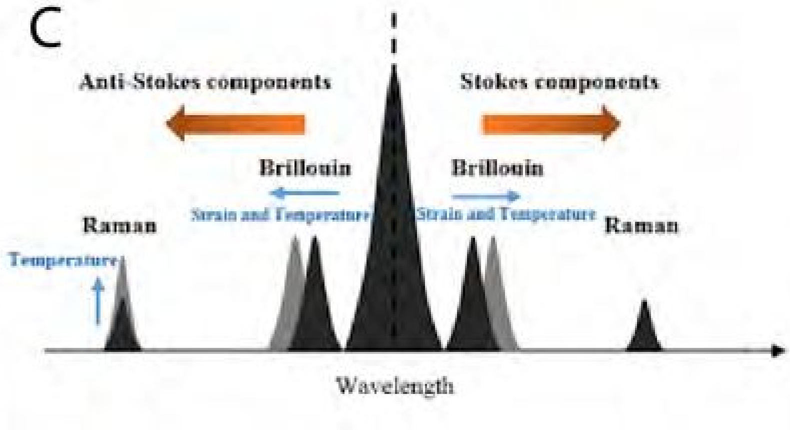


Figure 3: Three diffraction peaks, central peak is the Raleigh peak, the Brillouin peak is sensitive to temperature and strain variations.

The objective of the FOCUS project is to demonstrate that this technique can measure small (1 - 2 cm) displacements on a primary test site offshore Sicily where the 28 km long EMSO Catania cable crosses the recently mapped North Alfeo Fault. About 20 km offshore Catania, an urban area of 1 million people. Here, the Catania EMSO (European Multidisciplinary water-column and Seafloor Observatory) station is located in 2100 m depth and connected to land by a 25 km long electro-optical cable.

The laser reflectometry observations will be calibrated by seafloor geodetic stations and earthquake activity will be monitored simultaneously by seafloor and on land seismometers. The private company IDIL fiber optics will be in charge of the laser reflectometry measurements to be performed over several years on the EMSO Catania cable and a 6-km long extension (dedicated fiber optic strain cable).

Once the cable, seafloor geodetic stations and ocean-bottom seismometers have been deployed, there will be a 3-4 year period of observation, to collect and process the data collected and to calibrate the measurements obtained from the different methods. If all goes according to plan, slow or sudden displacements along the North Alfeo fault will be detected by the BOTDR technique as well as by the seafloor geodetic stations.

Observation with the seafloor geodetic network indicates an active submarine fault about 20 km to the east of Catania, an urban area of 1 million people, and crossed by the EMSO Catania cable. The seismic hazard posed by this major fault and its deep offshore continuation, with a total length of ~80 km and unknown prior to 2010, has yet to be properly estimated. The FOCUS project can provide a major contribution to this seismic hazard assessment by measuring the spatial variation in coupling (i.e. the degree to which the two sides of the fault are locked/sliding) along the fault and by quantifying current slip rates.

Once the BOTDR fault-monitoring technique has been tested and calibrated offshore Sicily, the goal is to expand it to other fiber optic cable networks either existing monitoring networks in earthquake hazard zones (Japan, Cascadia) or to the Mediterranean region through access to retired telecommunication cables, or through the development of dual-use cables with industry partners.

3. Benthic stations: data standardization

An important work on standardization, was carried out by Mamadou Lamine FALL from IPGP (Institut de Physique du Globe de Paris), France. The objective has been to develop a preparation chain for seismic data and implement EPOS standard data into EMSO France web site as a test case.

Here are the highlights of this work.

3.1. Creation of the obsinfo software

The obsinfo ("Ocean Bottom Seismometer Information") software suite allows the creation of data-centre ready seismological metadata (StationXML format) using standardized schema-based text "information" files. It was developed in collaboration with the EPOS project and also generates scripts for the creation of standardized data using the SDPCHAIN software suite (see below). The software is openly available for installation and modification through the PyPI (https://pypi.org/project/obsinfo/) and GitHub (https://github.com/WayneCrawford/obsinfo) websites.

3.2. Validation of the SDPCHAIN software

The SDPCHAIN ("Seismological Data Preparation Chain") software suite allows the construction of data-centre ready seismological data (SeisComp 3 Data Structure, clock drift corrected for each record header) starting from simple, uncorrected data in miniSEED format. The idea is that each ocean bottom seismometer facility will only have to worry about converting their data from their proprietary format to a simple miniSEED representation. The suite adheres to FAIR principals in that it allows ocean-bottom seismometer data to be transformed into a standardized, harmonized (Interoperable) format, put onto international seismological data centers (Findable, Accessible and Re-usable), and it generates a record of the processing steps from the initial files to the final format (Reproducible)

The suite was tested on Linux, Windows and Apple OSX operating systems. Mamadou FALL also developed software to simplify and automate the use of SDPCHAIN and wrote a user manual for SDPCHAIN.

3.3. Transformation of OBS data from the EMSO-MOMAR site

The EMSO-MOMAR site features yearly deployments of 4 OBS (Ocean Bottom Seismometers) around the volcano summit, plus a linked station at the summit. OBS data from 2010-2011, 2011-2012, 2012-2013, 2014-2015 and 2015-2016 have been processed and archived using SDPCHAIN. These data (640 Gb) are online at the EMSO-France website and should be available within a year at the RESIF (REseau SIsmologique & géodésique Français) node. DOIs (Digital Object Identifiers) are being created for these data by SEANOE (Sea Open Scientific Data Publication).

3.4. Documentation of the transformation of temperature and pressure data from the EMSO-MOMAR site

Details of these transformations are now available online at the EMSO-France website. The temperature data (2010-2016) as well as one year of the pressure data are online. Mamadou Fall verified the available data, sensor descriptions, file formats and DOIs for the temperature gauges.

3.5. New EMSO-France webpages

Several pages were added to the EMSO-France website:

- One for the 4 autonomous OBSs (http://www.emso-fr.org/EMSO-Azores/Instruments/Array-of-short-period-OBS)
- One for the summit cabled OBS (http://www.emso-fr.org/EMSO-Azores/Instruments/OBS-C)
- Two for the summit pressure gauges (JP1 and JP2) (http://www.emso-fr.org/EMSO-Azores/Instruments/JP1 and http://www.emso-fr.org/EMSO-Azores/Instruments/JP12)
- One for temperature probe data from 2010 to 20416 (http://emso-fr.org/EMSO-Azores/Instruments/Array-of-temperature-probes) (still waiting for final validation)

3.6. EMSO Western Ionian Sea observatory: standardization of data and equipment

This EMSO site host NEMO-SN1 (Neutrino Mediterranean Observatory - Submarine Network 1) seafloor observatory operating at 2036 m water depth, 25 km from the harbor of the city of Catania.

It is a prototype of a cabled deep-sea multiparameter observatory and the first operating with real-time data transmission in Europe since 2005. NEMO-SN1 is also the first-established node of EMSO,

NEMO-SN1 is performing geophysical and environmental long-term monitoring by acquiring seismological, geomagnetic, accelerometer, physical oceanographic, hydro-acoustic, bio-acoustic measurements specifically related to earthquakes and tsunamis generation and ambient noise characterization in term of marine mammal sounds, environmental and anthropogenic sources. The seismological measurements of NEMO-Sn1 are acquired by means of a Guralp CMG-1T 3 component broadband seismometer (360 s-50 Hz)

This digital database comprises seismological data recorded during the SMO project by a 3 component broadband seismometer. The seismometer is installed in a dedicated vessel integrated in a separate structure connected to the observatory via a special mechanical release. To guarantee a good coupling with the sea bottom, the structure is disconnected just after the observatory touch-down and kept linked to the frame by a slack rope (Favali et al., 2006). The sensor is connected to a 24 bit digitizer on the observatory.

The screenshot below (fig. 4) belongs to one of the NEMO-SN1 webpage and shows the seismometer and seismological metadata. The data format and metadata are compliant with the common seismological standard

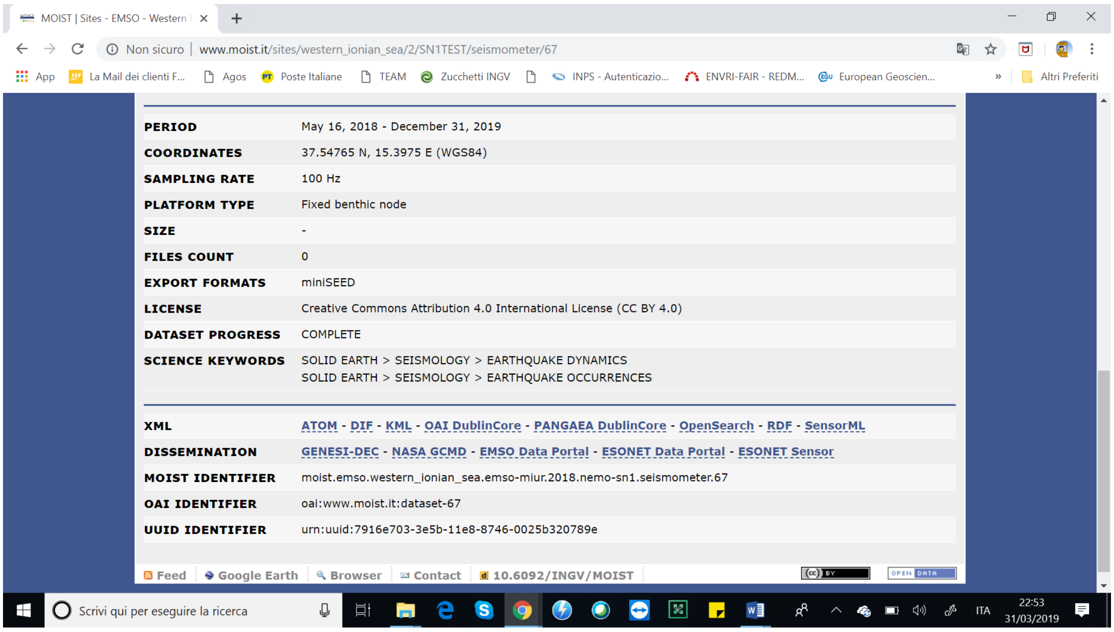


Figure 4: NEMO-SN1 webpage showing the seismometer and seismological metadata. The data format and metadata are compliant with the common seismological standard

Thanks to the recent approval of an infrastructural project, *InSEA - Initiative to Support the consolidation and enhancement of EMSO infrastructure*, an EGIM module is going to be deployed and connected by means of a Junction Box to NEMO-SN1. EGIM will be then the EMSO standard module operating in another infrastructure node and will provide some useful time-series redundancies.

4. European role in JTF initiative

4.1. The JTF initiative

The International Telecommunication Union (ITU), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO/IOC), and the World Meteorological Organization (WMO) established the Joint Task Force (JTF) in late 2012 after Workshops in Rome (2011) and Paris (2012). The Joint Task Force is to investigate the use of submarine telecommunication cables for ocean and climate monitoring and disaster warning. Details of the Terms of Reference, activities, presentations, and publications are available from the JTF website (https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx). The JTF has developed the concept of "Scientific Monitoring and Reliable Telecommunications: SMART cables". The idea is to integrate scientific sensors into trans-ocean submarine telecommunication cables. SMART sensors would "piggyback" on the power and communications infrastructure of a million kilometers of undersea fiber optic cable (fig. 5) and tens of thousands of repeaters, creating the potential for global coverage at modest incremental cost. Initial sensors would measure temperature, pressure, and acceleration. The resulting data would address two critical scientific and societal issues:

- the long-term need for sustained climate-quality data from the under-sampled deep oceans, and
- the near term needs for improvements to global tsunami warning networks.

Indeed, simulations show deep ocean temperature and pressure measurements can improve estimates of ocean circulation and heat content, and cable-based pressure and acceleration sensors can improve tsunami warning times and earthquake parameters.

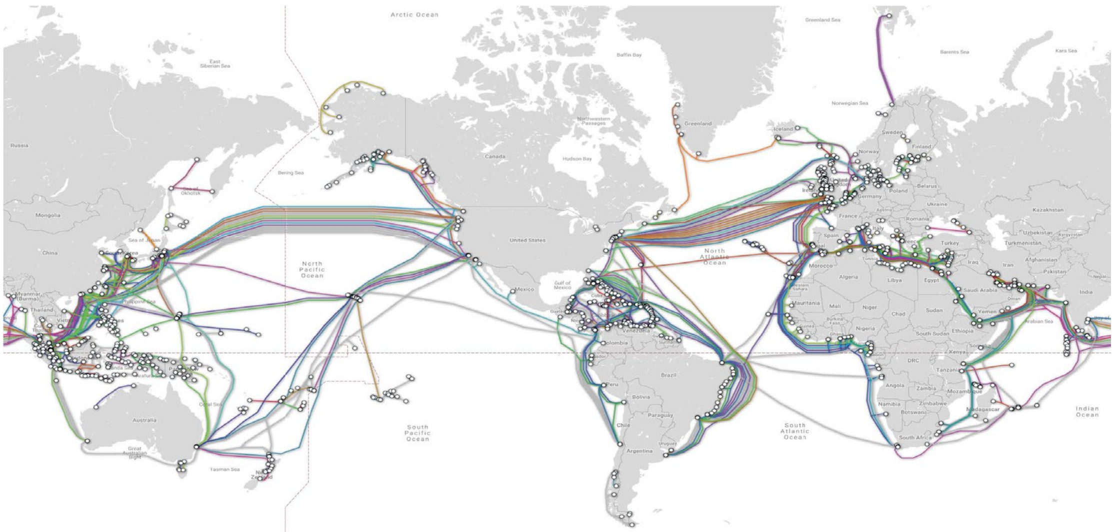


Figure 5: The world's submarine cables. From https://www.submarinecablemap.com (2018)

The SMART cable technological objectives are:

- Integrate Temperature, Pressure, and 3-axis Acceleration sensors into a commercial telecommunications repeater (fig. 6) with negligible impact on the performance and reliability of the repeaters' telecommunications functions.
- Collect sensor data in real time and disseminate it to operational and research agencies (early warning, oceanographic, meteorological, geophysical).
- Sensor nodes 75 – 150 km apart, with cable spanning thousands of kilometers

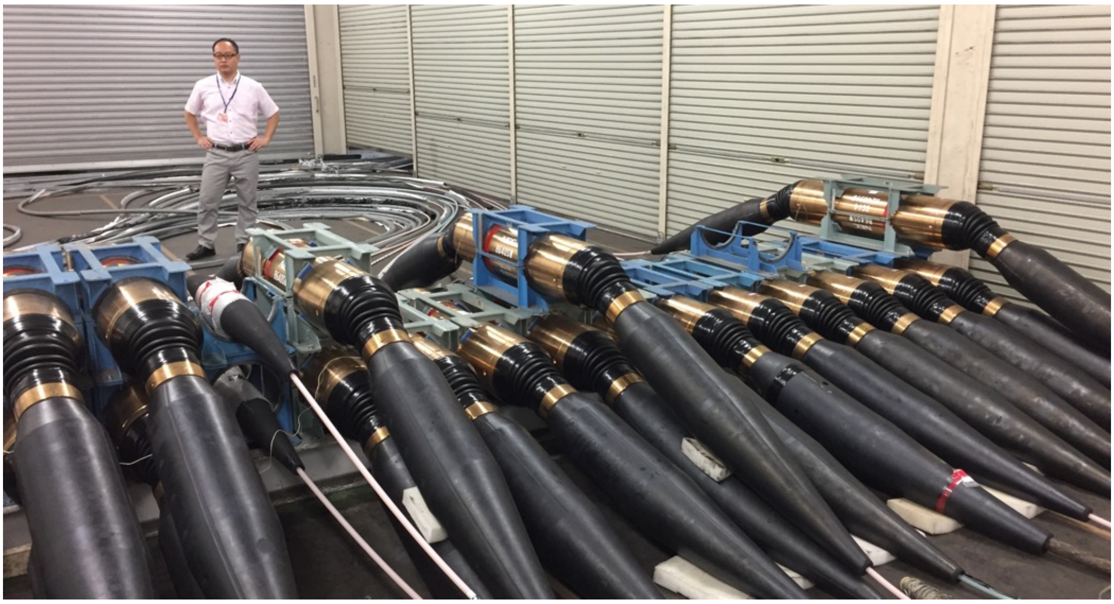


Figure 6 : Repeater stack during factory testing (from Lentz and Howe, oceans'18)

4.2 The future Wet Demonstrator Project of the JTF

To help advance the concept, the JTF is planning a Wet Demonstrator project in which such sensor packages are attached to about three repeaters along a 200+ km submarine cable deployed at depths of about 2000 m using standard industry practices, with data retrieved in real-time over a minimum of one year.

The main objective of the implementation of a wet demonstrator by the Joint Task Force (JTF) is to demonstrate the capability to deploy sensors using unmodified cable laying methods. This project includes the mechanical integration of sensors with housings and cable which are representative of a commercial telecoms cable. In particular, repeater housings and cable which are identical to those used in a commercial telecom system must be used. Cable laying methods must likewise be identical to those used for commercial telecommunications systems, with the exception that the hookup to an existing ocean observatory may employ appropriate methods. Integration of powering and communications functions with a telecom system will not be undertaken; instead off-the-shelf communications components and simple custom power supplies will be employed. These items will be internal to the housings and will not impact the ability to deploy or recover the system. Existing sensor designs and sensor electronics will be used.

4.3 ENVRI+ participation into the JTF initiative

The JTF has held further workshops, published reports and recommendations, with its management operations supported by ITU staff. Its open membership is drawn widely from industry, government and academia.

Through several workshops held in close conjunction to industry conferences (e.g., SubOptic, International Cable Protection Committee (ICPC), Submarine Networks World Conference), the JTF has advocated the urgent societal needs and commercial benefits of advancing into an era of SMART telecommunication cables (Butler et al., 2014; Barnes et al., 2016; Howe et al. 2016; Barnes, in press).

ENVRI+ allowed European participation by EPOS and EMSO to this global green repeater initiative. Within the frame of ENVRI+, three actions were undertaken

4.3.1 Workshop in Smart Cable system, Potsdam, 2016

During the first 16 months of ENVRIPLUS, Ifremer participated to 8 virtual meetings and one physical in Dubaï of the Joint Task Force of ITU-UNESCO-IOC-WMO and contributed to the proposals of full scale experiment (wet demonstrator) of a subsea telecommunication cable measuring temperature, accelerations and pressure. Ifremer attended on behalf of ESONET-Vi, EMSO and ENVRIPLUS. In April 2016, in Dubaï, the decision was taken by Europeans to organize a workshop in Europe, in Potsdam.

A workshop on Smart Cable Applications in Earthquake and Tsunami Science and Early Warning was organized in Potsdam, Germany during the 3rd and 4th November 2016.

See EOS meeting report : Howe, B. M., J. Aucan, and F. Tilmann (2016), Submarine cable systems for future societal needs, Eos, 97, https://doi.org/10.1029/2016EO056781. Published on 09 August 2016.

This Potsdam Smart Cable workshop had for main objectives to improve the warning to science community, to develop new science, to implement simulations, to build a business case and to undertake the implementation of planning and funding. This workshop is made of several presentations that will address topics such as global and regional networks, larges earthquakes and tsunamis, earth structure applications, subsea sensors and cabled observatories. Sessions were also devoted to the evolution of instrumentation, such as acceleration and pressure sensors and to science activities.

Here is below, a summary, presented by Wayne Crawford from CNRS IPGP (Institut de Physique du Globe de Paris), France, of what was realized during these few days. It was presented during the ENVRIWEEK of November 2016 in Prague.

The concept of smart cables resides in the addition of geophysical sensors on already installed transoceanic cables and to implement such sensors on repeaters (situated every 50 km) of new cables (Fig. 7). The lifetime of this kind of cable is particularly interesting, it takes an average of 20 years before having to replace them.

Smart cables have the main objectives to improve the understanding of global change through the study of temperature variations, ocean circulation and acidification. It allows to increase space/time coverage and the accuracy of satellite data.

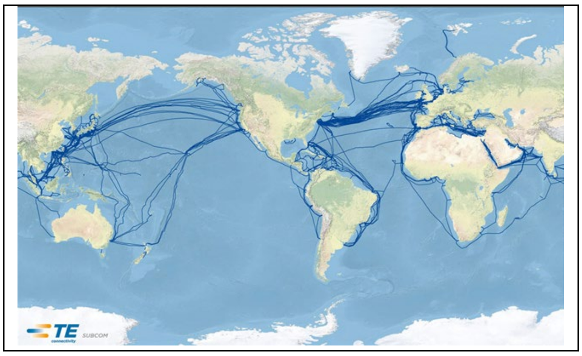


Figure 7: Map of optic fibre cable network

Currently, the problem is that such an implementation has an expensive cost and that it is necessary to find funding. The idea is to go through industrial partners because they are more worried by the costs generated by a cable failure than by costs of cable implementation. Moreover, industrial partners are more sensitive to arguments about societal benefits. However, it is the possibility of detecting tsunamis which is the priority argument for industrial partners.

To develop the concept of smart cables, it needs a broad support from the science community and to follow some recommendations. Firstly, cable routes would be use. Secondly, a smart demonstrator cable system would be identified. More simulations are again necessary on the bottom pressure and the accelerometer in order to quantify the improvement in accuracy of the speed for tsunami and earthquake warning systems.

The cable network already in place is currently deaf, dumb and blind respect to environmental phenomena; it is urgent to become more ocean health aware with the implementation of new smart sensors. Instrument modules will be separated from repeaters by cables in order to allow independent development of repeaters and instruments and also to protect repeaters against risk of faults in instruments.

The new generation of sensors will remain simple to facilitate first tests and deployments, it must be small, not too power hungry and reliable for 20 years. Sensors will have to measure pressure, acceleration and temperature. Their implementations are planned and realized into the Science Monitoring And Reliable Telecommunication (SMART) Subsea Cable systems by the UN (United Nations) Agencies Joint Task Force since 2012. The Joint Task Force plans to implement bottom pressure, temperature and acceleration sensors every 50 km along cables which could be supplement with more sensors later. A “wet demonstrator” project is also planned.

To continue the implementation of SMART cables, it is first essential to build a business case in order to assess financial threats of climate change, sea level change, and tsunami disaster. This business case should also identify new clients for the use of real time data (society, governments, ports, insurance or industry) and should undertake the establishment of the value of Smart Subsea Cable Systems by realizing an evaluation for each major new cable system (large- vs. small-scale systems). It should allow to link together cables owners and suppliers with international and national agencies/NGOs, which are responsible for social and economic benefits, monitoring and disasters.

Societal and environmental benefits of the implementation of smart cables will be obtaining more information and accuracy on climate change by studying ocean temperature change and ocean circulation, to get more information on sea level rise in order to prevent hazard for coastal states and cities and to warm disasters such as tsunamis.

4.3.2 Workshop in Smart Cable system, Brest, November 2017

The workshop “on SMART cable systems: Science, Demonstration and Funding” was hosted by the University of Brest and IFREMER and took place at the Institut Universitaire Européen de la Mer in France on 13th November 2017. It gathered 46 participants from 28 institutions and companies / SMEs.

The meeting report was published in “EOS Meeting report article – 6th JTF workshop” authors Bruce M. Howe, Marc-André Gutscher, and Jean-Francois Rolin.

The main outcome of the workshop was:

- review the progress of modeling work, including fraternal twin observing system simulations that show distinct improvements in estimates of ocean bottom pressure, significant reductions of tsunami warning time by up to tens of minutes (Tilmann et al., 2017), and improvements of the upper mantle seismic coverage for better understanding of global geodynamics (Ranasinghe et al., 2017).
- Several technological challenges need to be addressed. The in-line instrument modules typically self-bury half-way over time, requiring an understanding of how the effective transfer functions are affected by this settling. Some of the sensors must be in contact with water, so robust high voltage isolation is necessary, and the communications interface must be designed to ensure it does not interfere with commercial traffic. Components must be prototyped, then proved through wet demonstration and pilot projects. JTF continues to encourage new technical developments, including improving existing sensors, e.g., in-situ pressure calibration, and adapting new sensing modalities, such as using cable fibers themselves for distributed sensing.
- Review of options for securing European funding by the 2020 timeframe for the wet demonstration/pilot. We consider it critical to have SMART cables included in the roadmap of ESFRI (European Strategy Forum on Research Infrastructures), as well as by the Group for Earth Observations (GEO). The JCOMM (Joint Technical Commission for Oceanography and Marine Meteorology) has recently renewed its endorsement. We are reaching out to regions with high tsunami risk, such as the Pacific, the Maritime Continent, the Caribbean, and the Mediterranean, potentially in partnership with multilateral development banks. SMART cables could also provide much-needed coverage in Arctic areas, which currently have no real-time monitoring, and no warning systems.
- JTF is preparing a Science and Implementation Plan white paper for the OceanObs’19 conference, which will synthesize all the scientific, technical, management, legal, and budgeting elements into one document.

The peculiarity of this workshop was the analysis of the result of the ITU / JTF RFI « Request for Information » initiative launched in 2016: industries and academics were encouraged to express their interest in participating to the Wet demonstrator project (see 3.2). The RFI was questioning the participants about their expertise and the fields their organization was interested in. The table below shows an example of reply to the RFI.

Role	My organization is interested
Owner	
Host Observatory	
Project Management	
Design Authority	
HSE	
QA	
Permitting	
Marine Survey	
Wet Plant	
Supply Cable	
Supply Repeater Housings	
Assemble Repeater Housings	
Perform system assembly and test	
Supply CTA	
Supply Sea Electrodes	
Assemble CTA	
Provide Sensors	X
Temperature	X
Pressure	X
Acceleration	X
Provide Sensor Electronics	X
Temperature	X
Pressure	X
Acceleration	X
Provide Communications Devices	
Ethernet	
Serial	
Provide sensor cabling	
Provide sensor attachment hardware	
Connect sensors to repeaters	
Develop power systems	
Develop chassis	
Manufacture chassis	
Perform thermal modeling	
Perform initial bench testing	
Perform preliminary integration	
Provide marine installation services	
Validate sensor performance	

The table below shows the list of companies that replied to the RFI :

Acronym	Name	Institute / company / country	Expertise	Interest in hosting a use-case
APL - UW	Applied Physics Laboratory	University of Washington	OOI cabled array	yes
	Kongsberg maritime	Norway	Sensors, communication device	
OSI	Ocean specialists, Inc	Florida, USA	Submarine cables	
P20			Geodesy and ocean disaster systems	
PLOCAN	Oceanic platform of the canary islands	Canary	Ocean observatories	yes
RBR		Ottawa, Canada	Oceanographic instrumentation	
IGPP	Scripps Institution of oceanography Institute of Geophysics and Planetary Physics	University of California, San Diego, USA	Tsunami research / warning system OBS and other sensors	yes
EMSO	European Multidisciplinary Seafloor and water column observatory	EMSO ERIC	Sensors, electronics, communication, chassis, test	

The response are summarized below:

- The Ocean Specialists Inc. (OSI) responded to this request by their interest in joining this project. OSI is a developer of submarine cable systems with experience and capability that spans the telecommunications, scientific and oil & gas communities, situated in Florida, USA.

In this wet demonstrator project, they are able to provide all the expertise needed to undertake it, the only exceptions being data archiving and sensor validation. For example, OSI currently operates the Poseidon cable system located South of Cyprus in the Mediterranean Sea and proposes the possibility of becoming a host observatory.

- Kongsberg Maritime is a wholly owned subsidiary of Kongsberg Gruppen, an international technology corporation located in Norway. Kongsberg Maritime delivers systems for dynamic positioning and navigation, marine automation, safety management, cargo handling, survey and construction, maritime simulation and training, satellite positioning, and subsea monitoring. Based upon their own hydro-acoustics technology and sensor carriers, Kongsberg Maritime offer two main platforms for subsea monitoring; Stationary Sensor Networks and AUVs (Autonomous Underwater Vehicle). Both platforms feature a scalable wireless sensor network where each sensor node can carry various sensors for monitoring and communication of sensor data. In the wet demonstrator project, Kongsberg Maritime proposes to offer their expertise on underwater positioning and monitoring positioning
- The Applied Physics Laboratory at the University of Washington (APL-UW) is a national center for engineering research and development, advanced science, and education, formed in 1943 for the U.S. Navy. APL-UW currently operates a subsea observatory infrastructure which comprises approximately 900 km of telecom cable with seven backbone nodes, 18 scientific nodes with instruments, and three hybrid moorings, each with two different profiler systems. A total of 32 different types of instruments have been deployed since 2014, of which approximately 80% are commercial units and the balance are custom devices. Approximately 130 instruments are deployed at this time. In the wet demonstrator project, the APL-UW proposes to become a host observatory, to provide communication devices, sensor cabling or sensor attachment hardware and to develop some devices (chassis, power systems).
- Since 1976, the Richard Brancker Research Ltd (RBR) has been designing and manufacturing oceanographic instruments in Ottawa, Canada. From the ocean abyss to the polar ice cap, their sensors track various water parameters: temperature, depth, salinity, dissolved gases, pH, and many others. Recently, they developed a new sensor called RBRconcerto BPR.ACC, which combines a bottom pressure recorder and a triaxial accelerometer. This sensor is designed for deep-sea deployments, and is enclosed in a titanium pressure vessel that has been deployed deeper than 10km. In the framework of the wet demonstrator project, RBR states that the RBRconcerto BPR.ACC will be easily adaptable to the demonstrator system.
- The Scripps Institution, which is a marine laboratory of the University of California, San Diego (UCSD), is very interested in the Wet demonstrator project of the JTF. They already have a great experience in underwater observatories such as the construction of a long-term telemetered seafloor seismic and acoustic instrument. In the framework of the Wet demonstrator project, they propose to make available their skills on seafloor observatories and their facilities in terms of testing and calibration. Moreover, they are also potentially interested in hosting the observatory.
- The Oceanic Platform of the Canary Islands (PLOCAN) is a joint initiative of the Spanish and the Canary Islands governments, whose main objective is to build and operate a fixed offshore platform located both close to the coast and near the edge of the continental shelf, at 30 m depth. It is an EMSO ERIC site. PLOCAN has shown his interest in contributing to the JTF Wet demonstrator project by proposing to make available their broad experience in the preparation, management and development of large projects in the marine and maritime sectors. They also propose to potentially host the observatory.
- EMSO-France Joint Research Unit, represented by Ifremer proposed to use the planned extension of the MEUST Neutrino telescope for earth science purpose for the JTF. The situation is South of Porquerolle Island in Southern France. It is defined as West Ligurian Sea EMSO node. The testing sites for simulated environment or coastal cabled sites are also available for steps of experiment if needed. The deployment of the extension is planned in 2019, which could be a limitation or an opportunity depending on the schedule of the Wet Demonstrator.
- The major subsea cable providers and laying companies (ASN, NEC, Hengtong Marine…) replied also positively for the infrastructure technologies (not the sensors or scientific interpretation).

4.4 Summary of technical description of the sensors integration

The JTF technical group has worked on technological requirements for the integration of the sensors on the cable. The items below were investigated:

- Bandwidth requirements
- Data transmission: several options have been identified: Ethernet on dedicated fibers, out of band Ethernet on telecom fibers, Edge band signal on telecom fibers. Other options have been considered but do not provide sufficient bandwidth
- Power consumption limits
- Mechanical compatibility issues
- Various mounting options: at the end of the repeater, as pod on cable (fig. 8)
- Power delivery: sensor connected to repeater must either withstand the voltage (up to 10 kV, 70 kV during manufacturing tests) or be isolated from system supply voltage. Three electrical isolation options are considered
- Impact on failure, reliability requirement: reliability goal is ten years of operation, with a rate of no more than one failure per 25 years for each 5 000 km of cable

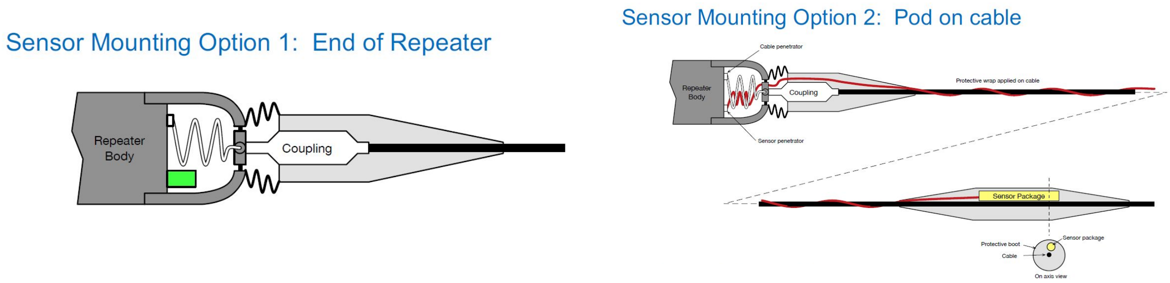


Figure 8: two options of sensors mounting on the cable

As a conclusion:

- Design issues relating to sensor integration have been identified
- Initial set of solutions is proposed
- Further refinement requires industry collaboration
- Reliability is an area requiring further study

4.5 Italian pilot for a SMART-like observation component as extension of EMSO Western Ionian observatory

In the Framework of a project for the enhancement of the ESFRI research Infrastructure, Italy has funded the infrastructural project *InSEA - Iniziative to Support the consolidation and enhancement of EMSO infrastructure*. In the framework of *InSea,* the first Italian SMART-like pilot shall be designed. A commercial telecommunication cable, 18 km long, equipped with 3 commercial repeaters and 3 multisensor modules (accelerometer, bottom pressure and temperature) will be assembled and deployed. This new observatory component will acquire geohazard time series data which will be transmitted I real time to the Western Ionian shore-station and made soon accessible through EMSO ERIC Data Management Platform. The deployment if foreseen in 2022.

5. Synergy between European Research infrastructures and cable industry

The EMSO community and associated ESONET have been supporting the JTF since Rome meeting:

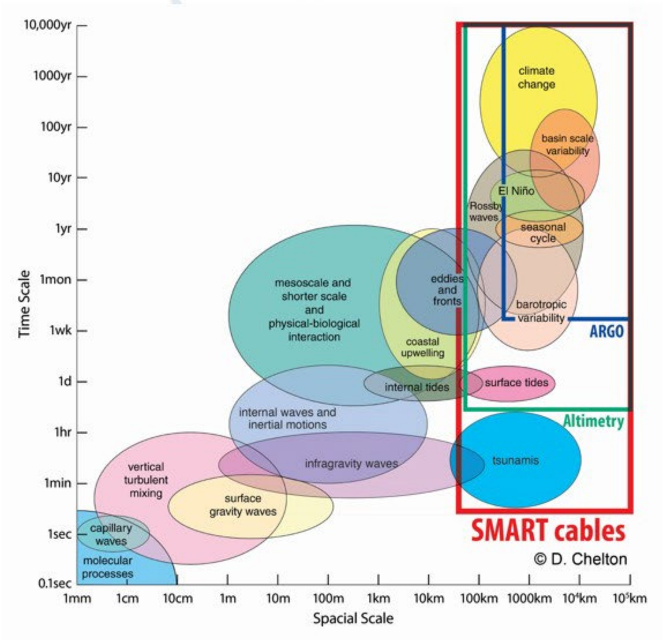
- EMSO sent a letter of support to the JTF,
- PLOCAN replied the Request for Interest survey
- There is a common interest in the EGIM instrument and associated data management
- This task related to SMART cable has been integrated in ENVRI+ project

EMSO has the knowledge and experience on technical issues directly interesting the JTF such as:

- onshore servers Power feed onshore,
- main cable, (branching unit), node, extension cables, Junction Box, Instrument module
- Benthic station, station over seabed, mooring line and surface buoy ; acoustic communication segment, inductive segment, satellite transmission segment
- Cabling of sensors units/instruments to Instrument module/Junction Box
- Connectors
- Also, EMSO has already established the sensor specification and real-tile data management issues have been defined and addressed. EMSO can provide facilities and know-how for testing sensors and prototypes in situ, without the need to develop new test facilities.
- Last, EMSO provides a multidisciplinary community of users, suppliers, developers, value-added providers, advocates and sponsors : all drawn from scientists, policy-makers, business people, educators, media and citizens

5.1. Contribution of SMART cable systems to Ocean and Climate Science

Figure 9 below (extracted from Aucan, 2016) shows the possible contribution of SMART cable to existing earth observing systems over space and time:

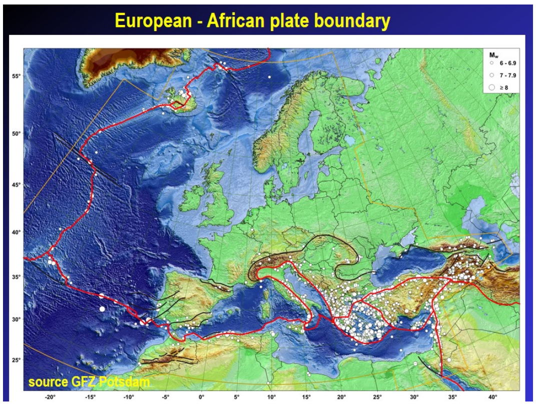


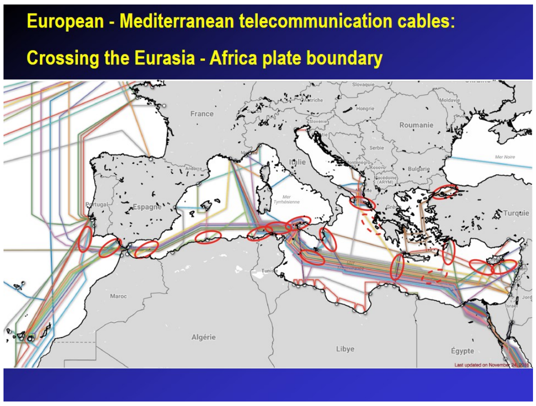
The sensors deployed on SMART cable give access to:

- Spatial and temporal variability of deep-ocean temperatures: SMART cable temperature measurements could detect current deep warming trends (0.003-0.010 ºC / year.). Indeed, within several years, it is expected a much higher temporal sampling (thus, less aliasing problems) than other arrays and much higher spatial sampling as well (20,000 nodes at 50 km spacing, compared to projected 1,000 deep global ARGO floats). SMART temperature measurements will also allow unprecedented exploration of temporal variability of deep ocean temperatures due to tides, eddies, mixing, etc.
- Sea level observation: Sea level, a fundamental property of the ocean, is measured by satellite altimetry. Bottom pressure measurements along cables provide ground truth for models of tides and other high-frequency motions that must be subtracted accurately from altimeter records.
- Gravity observations: the Bottom pressure observations are proportional to total water mass above. They will be valuable ground truth for remotely sensed gravity missions and could provide an alternative ground truth method for wind-stress measurements and large-scale ocean circulation.

- Long surface waves observations: Infragravity waves are expected to be a significant source of error on high-precision altimetry missions. SMART cable bottom pressure data combined with modeling will improve our ability to remove errors due to infragravity waves.

2.4. Contribution of SMART cable systems to Geophysics and geology





The right figure shows the numerous crossing of seabed cable with the European-African plate boundary (left) in the Mediterranean. If BODRT technique proves to be efficient for fault displacement measurements (see § FOCUS project), the cables will provide a close monitoring of plate tectonics.

5.2. Conclusion on SMART cables

The SMART cable systems will be a highly reliable, long-lived component of the ocean observing system. They will complement satellite, floats and other in-situ platforms and measurements.

A white paper called "SMART subsea cables for observing the global ocean: science and Implementation" is currently under construction and will be presented to the Ocean Obs'19 conference. This very comprehensive document addresses all aspects of the project: scientific topics (1- ocean i.e. temperature, pressure, circulation, heat content, climate, 2- Tsunami 3-seismic/geophysics) and relationship to other observing programs, data: transmission, management, distribution, users and products; technical issues as discussed below and also legal and permitting, cost estimate and budget and financing options.

6. Conclusions

The standardization effort both performed and ongoing between EMSO and EPOS through their French and Italian branches would be welcome in other countries.

The EPOS (European Plate Observing System) and ORFEUS (Observatories & Research Facilities for European Seismology) European Research Initiatives sponsored a European OBS (Ocean Bottom Seismometers) and MSP (Mobile Seismometer Pools) coordination workshop on October 27-28, 2016 in Dubrovnik, Croatia. This meeting, hold concurrently with the EPOS Mobile Pools workshop, focused on ways to make OBSs and their data more available to the general scientific community and to support ambitious geoscience research using the large number of OBSs available in Europe.

Following this meeting, EPOS has offered to help fund a technical meeting between the different European OBS facilities. The idea would be to bring together the scientific community of OBSs in order to present new generation of instruments and development plans. The intention is to set-up common projects, which help to improve OBSs. ENVRIPLUS WP3 wishes to promote this technical meeting by proposing to contribute to its organization and by offering the usual fall ENVRI week to host this workshop, the ENVRIweek being dedicated to the connection with providers, including terrestrial accelerometer of new generation.

ENVRIPLUS WP3 also wishes to keep working with the Joint Task Force on Smart Sensors in the framework of their Wet demonstrator project. Real scale cross ocean cable projects may also start with the SMART Cable concept integrated in the call for tender. It has already been the case for a tender of the New-Caledonia (French Territory) –Hawaï Transpacific cable during winter 2016.

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8. Terminology

APL-UW	Applied Physics Laboratory University of Washington http://www.apl.washington.edu/
AUV	Autonomous Underwater Vehicle
DC	Direct Current
DOIs	Digital Object Identifiers
DOW	Description Of Works
EPOS	European Plate Observing System https://www.epos-ip.org/
IPGP	Institut de Physique du Globe de Paris http://www.ipgp.fr/fr
JTF	Joint Task Force
MEMS	Micro-Electro Mechanical Systems
MET	Molecular-electronic transducers
MSP	Mobile Seismometer Pools
OBS	Ocean Bottom Seismometers
ORFEUS	Observatories & Research Facilities for European Seismology http://www.orfeus-eu.org/
OSI	Ocean Specialists Inc. http://www.oceanspecialists.com/
RBR	Richard Brancker Research Ltd. https://rbr-global.com/
RESIF	REseau SIsmologique & géodésique Français
SDPCHAIN	Seismological Data Preparation Chain
SEANOE	Sea Open Scientific Data Publication
SMART	Science Monitoring And Reliable Telecommunication
UCSD	University of California, San Diego https://ucsd.edu/
USA	United States of America