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K2D - Knowledge and Data from the DeepSpace

D1.1 - System specification and conceptualization at global scale

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Executive Summary

The ocean plays an indisputable role on the balance of Earth climate. The disruption of this balance will have unpredictable consequences for humanity. It is therefore of paramount importance to accurately and thoroughly monitor ocean parameters in order to detect any signs of deviation from equilibrium. While ocean surface can be scanned by satellites and thus obtain a synoptic view of large areas, ocean interior remains for the most part inaccessible.

In 2010, a note posted in *Nature* by Yuzhu You, suggested that submarine telecommunications cables crisscrossing the oceans, provided a unique possibility to obtain the much needed environmental information of ocean interior, if they could be equipped with the appropriate sensors. Since then working groups, projects and commissions have been formed, workshops held and a large number of papers and reports published. The case was brought to scientific fora, but also to the economic and political level, to the various relevant international organizations, including 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).

This report provides a review of the state of the art aiming at adopting submarine cables as means for environmental data gathering. It reports on the challenges faced, the advances gained and gives and overview of the actual status, focusing on the global scale. Attention is also given to the technological issues involved in the solution development for maintaining system reliability. Experimental essays and results are reviewed.

The study ends on a set of recommendations for implementation at smaller scales and for cooperation with cable industry, either for existing decommissioned cables or for new installations. The need for an international standard cable repeater is stressed but possibly still far in the future. The need for international regulations regarding the rights to the environmental data gathered is also stressed.

Abstract

This report provides an overview of the global challenges and advances obtained for the design, development, integration, deployment and usage of trans-oceanic submarine telecommunications cables for gathering ocean environmental parameters.

It covers the historical aspects since its suggestion in 2010 until present, focusing on the various initiatives with the same objective, including the installation of ocean observatories either fixed or mobile, shallow or deep water, cabled or non-cabled. Social benefits are stressed and international organizations involved are listed. Legal questions are also mentioned and advances addressed. The focus is clearly on the global scale of the problem and the various solutions provided. A set of recommendations is drawn from the literature.

Chapter 1

Introduction

A problem cartographers have always struggled with is the point of view from which to draw a map: sea level, top of the mountain or bird's view ? Satellite remote sensing provides a view angle well above birds, and therefore a unique synoptic view of the broad area of interest. Other advantages of remote sensing are the ability to provide an (almost) scale independent information (from local to global), easy access to remote sites, information in a broad spectrum of wavelengths (not limited to the visible spectrum) and has a good time resolution. In one word: satellites revolutionized the observation of the Earth.

Remote sensing has those many unique advantages but suffers from a drawback that is inherent to most remote methods: it requires data calibration, that can only be obtained by *in situ* measurements. This is particularly stringent for the ocean, because it is vast (71% of Earth's surface) and of difficult access, specially for the deep ocean, far from coasts and in polar regions. Another characteristic of satellite remote sensing is that electromagnetic radiation penetrates only a few meters below the ocean surface, and therefore can not be used to sample the ocean interior or bottom.

There are of course a number of alternatives for ocean sampling, many of them have an ocean wide reach as for example the recent coverage obtained with ocean gliders, and drifters, as for example the Argos drifters program. Besides this ocean scale international initiatives there are of course national programs for ocean data gathering including moored observation platforms and ship-based experiments. All of these successful attempts have their limitations and, as a whole, remain short of obtaining the much needed global and permanent coverage required for wide ocean monitoring.

In 2010, Yuzhu You published an opinion paper in *Nature* [1] where he emphasized that over a million of km of telecommunication cables laid down across the oceans represented a wasted opportunity for ocean science and could help in a much needed global observation network, if equipped with appropriate sensors. This is specially true for part of the network that is now progressively being replaced by higher performance cables or attaining its expected life-time limit for communications but are perfectly functional for science usage. In You's vision new cables should have scientific sensors for a minimal extra cost, and old cables could still be used for much less data speed demanding tasks such as those needed for science - the so-called cables' second life - as some already did (see Fig. 1.1).

Starting from this idea, a joint initiative of the International Telecommunications Union (ITU), World Meteorological Organization (WMO) and UNESCO International Ocean Commission (IOC) - the so-called Joint Task Force - was formed in 2012 to investigate

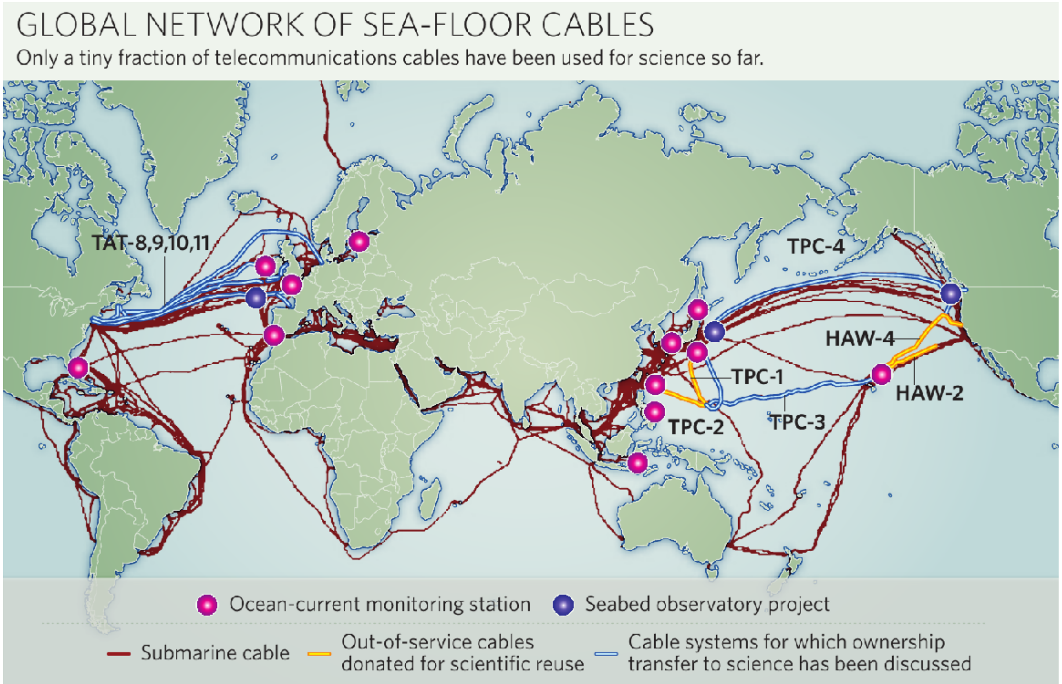

Figure 1.1: *submarine trans-continental telecommunication cables (from You [1]).*

the use of submarine telecommunications cables for ocean climate monitoring, and disaster warning. NASA has later on supported the JTF with the purpose of evaluating the potential of telecommunication cables for improving/complementing satellite ocean observations, namely its contribution to the calibration of altimetry and gravity observations. This initiative, under the leadership of principal investigator Bruce Howe, was named Scientific Monitoring and Reliable Telecommunications (SMART) and known as SMART-cables. Two workshops were held in 2014 and 2015, and an account was published in a joint report [5]. In particular its contribution to the precise estimation of sea level, heat content and ocean circulation and its climate impacts. Other field of impact is that of reliable earthquake detection and tsunami early warning. This last aspect means a potential gain of tens of minutes on warning for populations at risk. Of course the number of minutes gained depends on the relative localization of the epicentre, plate movement, cable sensors and closest inhabited coastal area, but can go from zero to tens of minutes when applied to previous or future scenarios. Several other presentations on the theme were done in the subsequent years [6, 7] and a status on the SMART-cables initiative was published in 2019 [4].

There have been some attempts to advance on the technology side of implementing the connection between science sensors into existing cable repeater technology. It is not very clear, but the strategy seems to be that of prudent steps with a minimal approach of only three sensors (temperature, pressure and acceleration) in order to keep risk low. The “ball” is now in the field of cable laying companies that besides the technological issues are also involved with legal issues. Legal issues deal with the ownership of the data gathered with a privately owned apparatus in international waters. Ramifications also happen when the cable crosses national waters, EEZs or territories under the jurisdiction of third countries (not those of departure or end of the cable). There seems to be the need for an overall international political decision at the UN level, in that regard.

This report gives a thorough account of the onset and evolution of the conceptual ideas, methods and technologies, as well as the justification of the need for ocean observation, and the possible contribution of oceanic telecommunication cables.

This report is organized as follows: chapter 2 gives a generic description of global threats related to climate change and pollution, focusing in the ocean; chapter 3 reviews the state of the art on ocean observation systems focusing on their scope, coverage and technology used; finally chapter 4 draws a long term vision in this area and makes recommendations for future steps into the development of new strategies for ocean observation and forecast.

Chapter 2

Global threats and context

2.1 Climate change

The most recent IPCC[1] report [8] issues a "code red for humanity" for the greenhouse effect due to unprecedented CO2 accumulation in the atmosphere, and consequent global warming and climate change extreme effects. This Assessment Report 6 (AR6) that stresses more than ever the urgency to act to effectively not only to reduce the emission of CO2, but actually stop and then decrease the emission of CO2 and associated greenhouse gas. According to AR6, the limit of 1.5°C increase over the pre-industrial era (Paris agreement) seems already unattainable so, now the goal is not to go over the 2°C that will be reached within the 21st century (forecast).

The report contains one chapter dedicated to ocean effects such as the melting of ice sheets ultimately leading to the loss of summer Arctic sea ice, ocean warming, more frequent marine heatwaves, ocean acidification, and reduced oxygen levels, affecting both ocean ecosystems and the people that rely on them, and this will continue throughout at least the rest of this century.

The message of the IPCC report is crystal clear: we have to raise the ambition level of mitigation and climate adaptation, because changes are already here and more to continue for decades and in some cases for thousands of years. On the words of the report "One powerful way to adapt is to invest in early warning, climate and water services. Only half of the 193 members of the World Meteorological Organization (WMO) have such services in place, which means more human and economic losses. We have also severe gaps in weather and hydrological observing networks in Africa, some parts of Latin America and in Pacific and Caribbean island states, which has a major negative impact on the accuracy of weather forecasts in those areas, but also worldwide."

2.2 Ocean pollution and environmental status

There is a large number of international organization bodies addressing the various aspects of ocean status, or said otherwise, of ocean pollution. Possibly one of the most comprehensive and update study covering the status of the ocean is the World Ocean

[1]Intergovernmental Panel on Climate Change, composed of 234 scientists from 66 countries

Assessment (WOA), carried out every 7 years by the United Nations (UN), that has just issued its second report on April 2021 - the WOA II [9]. Again the conclusions point towards further understanding of processes and monitoring data and simulators are required. Monitoring is particularly needed in some regions of the world badly sampled but crucial for the understanding of the overall ocean circulation and pollution and ocean status assessment.

At European level, the ocean has been at the heart of several initiatives both for exploration, sustainable exploitation and status monitoring. The scope of those initiatives has covered aspects ranging from economic, industrial, environmental and for research purposes. Ocean status in particular has been the subject of the worldwide first policy for assessing and maintaining the "Good Environmental Status" (GES), the so-called, Marine Strategy Framework Directive (or MFSD) first issude in 2008 [10] and then re-adjusted in 2010 [11]. Although rather subjective and sometimes difficult to apply the GES concept, has the merit of existing. For the first time ever, a list of ocean potential pollutants has been drawn up and, according to the directive, should be monitored by the member states. The effects of such pollutants are described in a list of 11 descriptors with, sometimes sub-descriptors. The application of the MSFD has now reached the monitoring status which includes, in some cases, the proposal of mitigation actions to be carried out or implemented by member states or across borders when involving international waters.

2.3 Requirements and challenges

An unanimous and transversal requirement to address the various challenges and threats is the need for increased monitoring. Not just plain repetitive extensive monitoring, but intelligent planned and conclusive monitoring. Taking into account the task at hand, resources for monitoring are scarce so, they need to be used with parsimony. *In situ* monitoring should be complemented with modelling, in a tightly integrated (assimilated) fashion. A more appropriate word would actually be sampling instead of monitoring, where sampling is performed at selected locations and times, as required to decrease uncertainty. When and where uncertainty is low, sampling is not needed. Therefore adaptive optimal sampling should be adopted and strategically used throughout. The scale of sampling is such that it requires interoperability and standardization of methodologies and instruments operation. And this requires, at least generic rules and regulations at international level. This is possibly one of the main challenges ahead since this depends on the political agenda of the most ocean powerful nations with a grip on international organizations and policymakers.

Chapter 3

Ocean observation

Ocean observing is essential for a better understanding of how society and all life on earth is being affected by climate change. The information gathered is invaluable to policymakers, guiding them to make a change happen at a global, regional and local level.

Information from ocean observing is also essential for weather forecast. It delivers early warning of hazards like tsunamis, storm surges and extreme waves that help save lives and enables marine operators to remain efficient.

Looking into the future, a sustainable ocean economy has the potential to be a major source of food, jobs, and energy. The ocean is also the engine for Earth resilience and crucial for controlling or enhancing climate change. Major changes will most likely come from the ocean, starting with ocean rise, acidification, hurricanes and "conveyor belt" current disruption. In one word ocean health and behavior is crucial for all humanity.

3.1 Remote sensing

It is indisputable that satellite observation has changed Earth science. The ability to "see" the Earth as a whole, with fine detail in near-real time and through many different "eyes" was a game changer. Many different "eyes" means eyes pointed to various directions, with various wavelength filter, and with various time and spatial resolutions. Looking to the Earth, includes the atmosphere. For some "eyes" the atmosphere is a drawback, but for others its the objective, with the impact it may have for meteorological studies and forecast. However, satellite imagery does not penetrates into the ocean, or at least not in depth. Depending on wavelength penetration may attain a few meters, while a few tens of meters may be obtained with airborne LIDAR, depending on water color and turbidity.

Imaging of ocean interior was only possible in the visible spectra by bringing light and human presence with exploring submarines. Since acoustic waves propagate very well in the ocean, acoustic imagery developed into commercial systems for water column and bottom exploration (sidescan and multibeam sonar) and to other applications. Nowadays ocean acoustics may be viewed as a means for remote sensing the ocean interior either actively or passively, *i.e.*, by transmitting a sound wave and receiving the reflected echo or just by listening to ocean sound. These techniques, that aim at determining ocean properties by indirect measurement of acoustics, are termed as "acoustic tomography", by analogy to their medical counterpart. Although active ocean acoustic tomography at ocean basin scale, was halted for fear of impact on marine mammals, passive acoustic tomography is still employed at smaller scale. In all cases, the imaging of ocean interior requires the presence of sensors either fixed or mobile, manned or unmanned. Due to the scales involved in ocean observation, this remains a challenge both for men and equipment. Some of the systems and techniques used nowadays are reviewed below.

3.2 Observation systems

For many years ocean observation relied on ships equipped with oceanographic equipment to "image" the interior of the ocean, *i.e.*, both the water column and the ocean bottom: a very expensive and time-consuming endeavor. Even more difficult (and costly) was the observation of ice covered oceans. This effort was complemented with buoys near the coasts.

The Global Ocean Observing System (GOOS), formed by UNESCO/IOC, partners with WMO, UNEP and ISC, is a multinational initiative that leads the effort on ocean observation putting together a number of other local initiatives and projects, as well as a number of open source databases. Among others GOOS defines a list of essential ocean variables (or EOVs) for ocean monitoring[1]. A recent add-on to that list was ocean sound, that became an EOV in 2020.

A comprehensive list of ocean monitoring platforms associated with GOOS may be found in this link. It includes oceanographic ship programs, specific platforms at strategic locations (*e.g.* near reefs, ice regions or pristine areas), arrays of drifters, including the ARGO program, tsunami early warning, moored platforms such as buoys and permanent observatories, and sampling unmanned vehicles including gliders and autonomous robots. Many of the listed systems are networks or arrays of sites with a variety of equipment and sensors. Many of those maintain an open data access policy.

On the European side, the initiative comparable and also affiliated with GOOS is EuroGOOS [2]. EuroGOOS coordinates efforts and projects of 44 institutions in 18 European countries. Another important structure for ocean observation is the European Multidisciplinary Seafloor and water column Observatory which is an European Research Infrastructure (EMSO-ERIC). EMSO-ERIC is dedicated essentially to fixed (cabled and non-cabled) observatories (see locations in Fig. 3.1). Each observatory is adapted to the area where it is located, either shallow or deep water, bottom or water column, cabled or standalone. Each platform is multi-parameter typically covering temperature, salinity, currents, high precision pressure sensor for tsunami detection, CO2, CH4, O2, seismic data, gravity, ocean sound and sometimes includes static images or video. Depending on the particular installation and distance to land, data may be sent through cable, GPRS or satellite link. EMSO-ERIC has an open data policy, and there are a number of tools for data download and analysis, directly from the data access portal.

The philosophy of EMSO is long term ocean observation through the acquisition of long time-series to attempt to understand ocean dynamics. Therefore most of the infrastructure is cabled in order to obtain power directly from land. That is also the objective of a number of fixed observatories around the world, as for example (not-exhaustive),

- the *Hollyrood* observatory is installed in the Conception Bay in the southeast region

[1] a full list of specification sheets for essential ocean variables may be found in this link.
[2] https://eurogoos.eu/

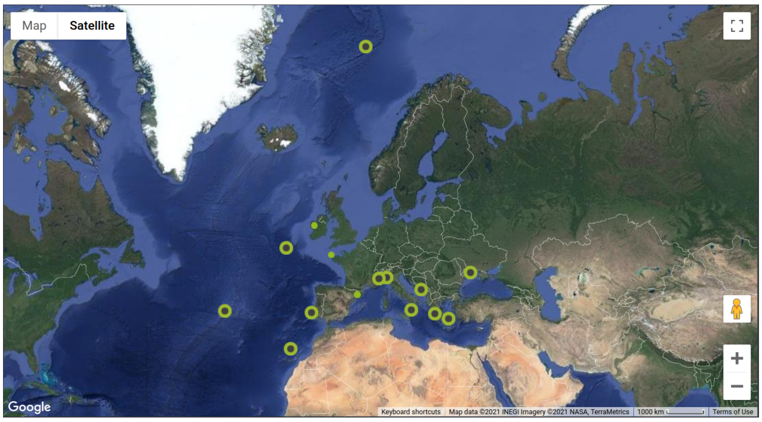

Figure 3.1: *EMSO-ERIC facilities (from emso.eu/observatories/).*

of Newfoundland and Labrador province (Canada). This is a fiber optic connected structure installed at 4 km from the coast in 85 m water depth.

- the *Regional Cabled Array (RCA)* its a high voltage 900 km cabled observatory covering the Juan de Fuca tectonic plate in the western coast of Oregon state (USA). The RCA is part of Ocean Observation Initiative (OOI) that includes other 4 sites in the same area and in the south coast of Greenland. Together with high power connection, the various sensors distributed over a large area, are connected through high speed 240 GB/s Ethernet, which requires several junction boxes and repeaters. A full view is shown in Fig. 3.2.

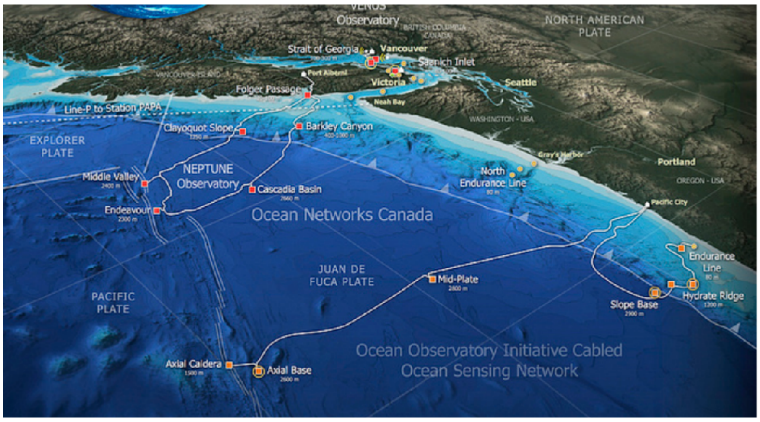

Figure 3.2: *The ONC - OOI ocean observation network.*

- the *Lofoten-Vesterålen* (known as LoVe) ocean observatory is a mixed cabled and non-cabled installation located on the northwest coast of Norway, that has several satellite sensors at various depths between 210 and 2500 m (more information on the web site).

- the Department of Fisheries and Oceans (DFO) installation in the Barrow Strait (Canada) is managed by the Bedford Institute of Oceanography (BIO), Bedford basin, Dartmouth, New Scotland (Canada). This observatory comprises several hubs and mobile nodes with real time data connection to land furnishing a quite exquisite set of data, including bottom perforation and geological analysis (more information and full list of equipment here).

- possibly one of the most known (because one of the first being deployed) is the *Neptune and Venus network* off the coast of Vancouver island, into the Pacific to the west (Neptune) and in a protected bay to the east (Venus). Now this network has other ramifications and Internet interconnected installations in the Arctic, Atlantic and Pacific (Salish Sea, northeast Pacific and British Columbia north coast). A truly ocean observation network with over 15 years existence. More information in Ocean networks Canada).

- along the years JAMSTEC in Japan has developed an array of solutions for fixed and mobile ocean observatories, among which the *DONET seafloor observatory* for earthquake and tsunami early warning see (here for more information and Fig. 3.3).

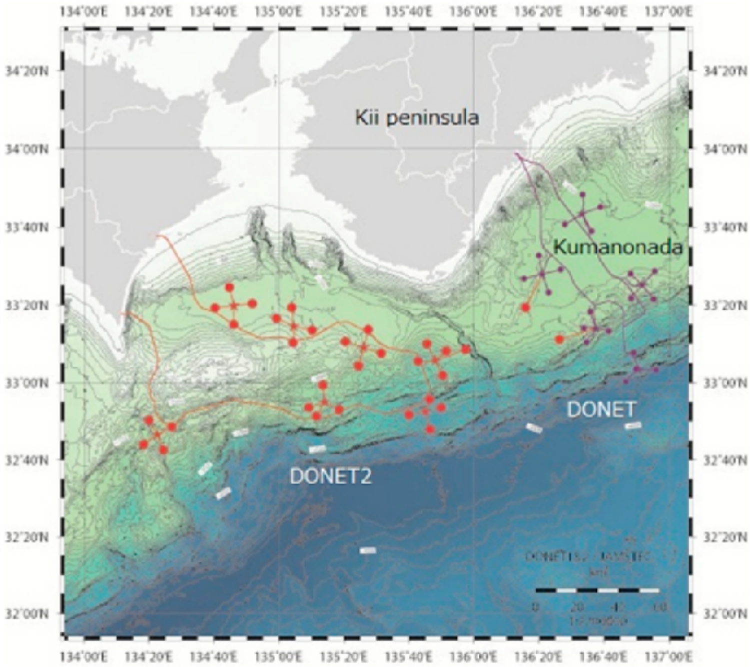

Figure 3.3: *The DONET network, managed by JAMSTEC, off the coast of Japan.*

Other observatories were deployed also in other countries as for example in South Korea and India.

Aside from this non-exhaustive list there is the *ALOHA Cables Observatory (ACO)* located approximately 100 km north of the island of Oahu, in Hawaii (USA), that stands out for two reasons: it is the deepest fixed observatory for permanent observations at 4728 m depth and also because this observatory is connected to land through a inactivated transoceanic telecommunications cable, the HAW-4 cable operated by AT&T. This observatory is managed by the University of Hawaii, and has a number of sensors, which full list and scientific objectives may be found in [12]. Insisting on the topic of the telecommunications cable connection, as it is shown in Fig. 3.4, the cable was cut and a junction box installed, keeping the land connection side both for providing energy and data to the observatory. All the sensor details may be found in [13], but the important and most interesting is the proof of concept of using an existing telecommunications cable and questioning whether such installation could be replicated in other areas.

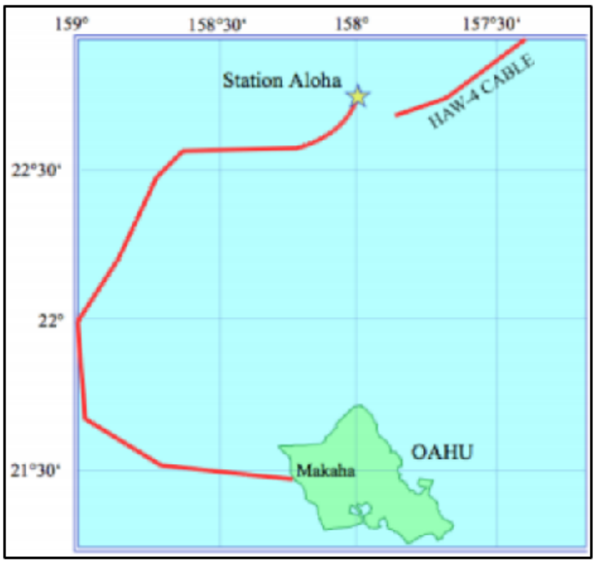

Figure 3.4: *ALOHA ocean observatory connection to the HAW-4 telecommunications cable in the north of Oahu island, Hawaii (USA) (from Howe et al. [2]).*

A common feature of all these observatories is that their installation is extremely expensive and the cable is not a small part of the cost, which of course depends on the distance to land relative to the sensor package and other variables, such as bottom depth at the location site. Most importantly than installation is the maintenance along time, which may represent a substantial continuous effort during the whole operation time. So, a substantial part of the effort goes into providing energy for operation and communications at the observatory final location.

However, as the example of the ACO has shown, data and power are readily available through telecommunications cables that crisscross the ocean, and many of them are already decommissioned for data communications because their data throughput is too low for the maintenance cost, or because they are might have damaged sections that can not be used for data communications anymore. This is exactly the case of the HAW-4 cable and ACO. As suggested by You [1], telecommunications cables are opportunistic for ocean observation at a much smaller cost than dedicated infrastructures. The next section will follow-up on this idea and the development that resulted: the SMART-cables initiative.

3.3 SMART cables

In this context the acronym SMART stands for Scientific Monitoring and Reliable Telecommunications. The vision proposed originally by You was developed by Bruce Howe and co-workers into a series of projects and initiatives with the purpose of showing the benefits of using telecommunications cables for powering and data connecting packages of ocean observing sensors, for providing reliable and online data across the oceans. The long term goal covers - but is not limited to - grand objectives such as : understanding of ocean dynamics and climate, improve knowledge of earthquakes, forecast of tsunamis, complement and enhance existing satellite and *in situ* systems for ocean observation. The overall telecommunications cable infrastructure has an estimated length of roughly 1Gm, or approximately 60 times the circumference of the Earth, for an estimate number of

23.000 repeaters (1 every 65 km in average, for signal conditioning) and the lifetime of each cable is around 25 years. Cables carry energy to power the repeaters.

Therefore, the fundamental premise of SMART cables is that of integrating environmental sensors into commercial submarine telecommunications cables. Crucial objectives are set forth as[3]:

- to obtain long-term ocean bottom measurements of temperature, pressure and seismic acceleration,
- to have little or no impact on the operation of the telecommunications system that hosts the sensors,
- to require no special handling or deployment methods, and
- to be sufficiently reliable that 95% of all sensors operate for a minimum of 10 years with no maintenance.

Initial proposal for sensor package was relatively simple and included only temperature, pressure and acceleration. The goals were to obtain spatial and temporal variability of deep-ocean temperature, the propagation of heat anomalies along ocean basins and boundaries, the temporal variability of barotropic tides, the ocean response to atmospheric pressure forcing on fast time scales and finally the impact of infra-gravity waves, altimetry and gravity. Bottom sensors would complement ARGO floats data to greater depths for atmospheric models. It is claimed that ocean observation using the telecommunications cables infrastructure would provide a much larger life span than satellites, at approximately the same cost.

Under the auspices of the JTF a series of dedicated workshops already mentioned above were held and provided the following recommendations [5]:

- perform observation system simulation experiments
- use the simulator with data assimilation for optimizing cable selection, route layout, instrumented repeater location (interval),
- extend sensor packages to acoustics (both passive and active), cable voltage, bio-optics, bio-geochemical, and a series of other sensors, going by steps: **now:** pressure, temperature, acceleration, **after:** acoustics, salinity, echo-sounding, chemical and biological, **future:** wireless communications, modems, RF, optical, calibration, stability, AUV and a full network.

A series of workshops on green cables took off in Rome in 2011, and then successively in Paris (France, 2012), Madrid (Spain, 2013), Geneva and Singapore (Switzerland and Malaysia, 2014), United Arab Emirates and Postdam (Germany, 2016), Brest (France, 2017) and New Orleans (USA, 2019). Links for all of those and more may be found in the ITU web page.

Nowadays, possible the closest example of SMART-cables implementation is that provided by the S-net, the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench. The S-net was installed after the Tôhoku earthquake and tsunami of

[3]quoting from Steve Lentz, "Special Markets", Submarine Telecoms Industry Report 2019/2020, Issue 8, pp.76-80, STF Inc. 2019.

2011, and has approximately 5700 km of cable with 150 observation nodes divided in 6 independent subsystems. The structure of S-net is shown in Fig. 3.5. This figure is extracted from [3] that analyses the performance of the S-net system for tsunami forecasting using synthetic data. More details of the S-net repeaters and cables' installation will be given in the technological section 3.5.

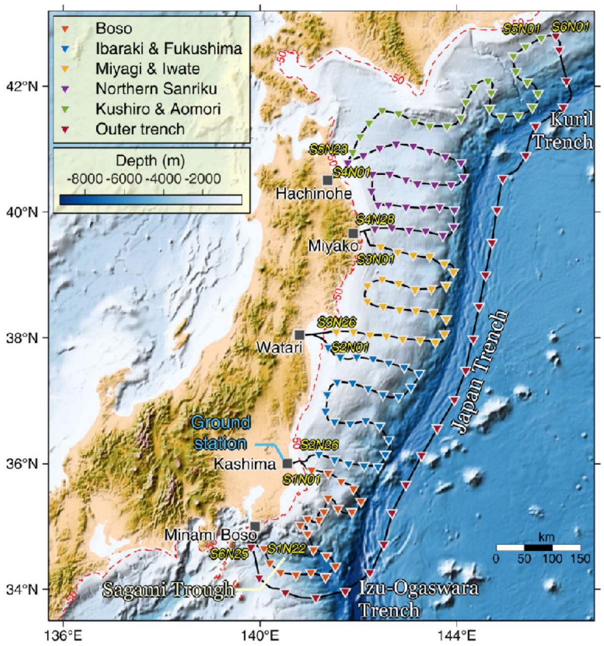

Figure 3.5: *The S-net observatory along the Japan Trench (from Mulia et al. [3]).*

3.4 Societal aspects

The societal benefits in adding sensors for climate and disaster monitoring have been mentioned in several workshops and official reports and in particular brought up by the JTF consortium to the UNESCO Science and Society Committee by a group of authors chaired by R. Butler [14]. SMART cables are re-named as green cables and the case is legally framed in the law of seas and their usage and scope for humanity. Extra costs and benefits are evaluated, specially its potential for contribution to global threats such as the monitoring of climate change, sea level rise and disaster warning. The business case is assessed, including the identification of new clients, stakeholders and the legal framework. Despite the previously addressed social benefits, it should be taken in consideration the possibility of existing, opponent groups in the society, which maliciously will attempt to damage the observatories as it seemed to have taken place recently with the LoVe observatory in Norway (see news here).

3.5 Technological aspects

According to the principles of the SMART cables philosophy of minimum interference with and minimum additional cost to the telecommunications cable installation, the system should be as simple as possible, deployable with existing technology, no maintenance, aiming at a 25 years survival, and data sent through supervisory channel without impact on the telecommunication service, whatsoever (the KISS principle).

However environmental sensors do require contact to the surrounding water, and therefore a flooded enclosure - a potential risk for the associated repeater electronics. Two engineering studies and several other thoughts were put together to approach the technical details of what could be a future standard "green repeater", part of the green cables to be. One of the most common figures found in several publications and presentations regarding SMART cables is that shown in Fig. 3.6 (figure 14 of [4]). The typical 5 m long repeater assembly is shown inserted on the cable with its bending elements, coupling modules and the repeater pressure housing. Two possibilities are suggested for the positioning of the environmental sensors that require exterior contact (temperature and pressure): (A) openings in the main repeater body or (B) on an external pod located on the cable. The accelerometer does not requires external access so, it can be safely located in the pressure housing. As discussed in the paper these two possibilities both have advan-

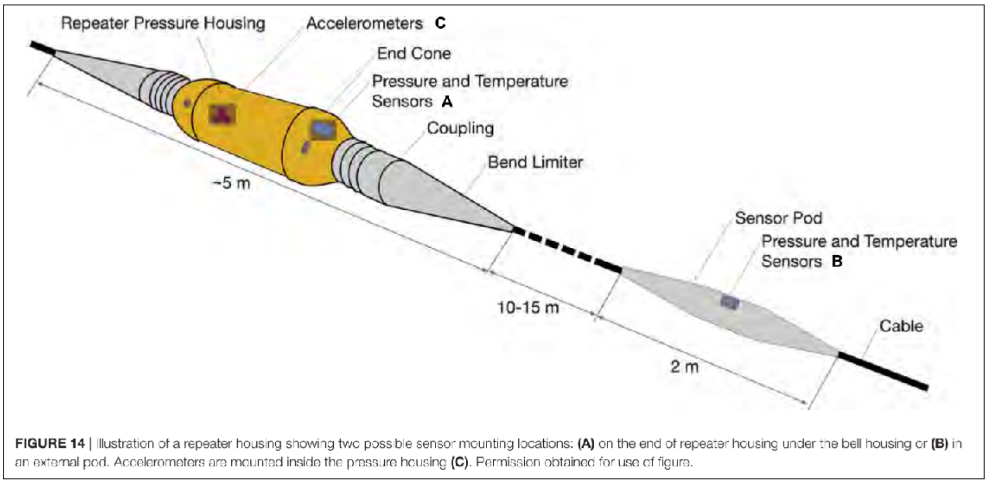

Figure 3.6: *SMART repeater drawing (from [4]).*

tages and disadvantages either operation, flooding or data access risk. Since this issue is complex and many details should be evaluated and taken into account in the final design, two engineering studies were ordered in 2015 by the JTF: (1) "Functional requirements of "green" submarine cable systems", and (2) "Scope document and budgetary cost estimate for a wet test to demonstrate the feasibility of installing sensors external to the repeater and to provide data from such sensors for evaluation". Both texts may be downloaded from here, and here, respectively.

As mentioned above, the most recent, closest and to scale implementation of the SMART-cable concept is that of the S-net in Japan and later on that of the coast of Awashima in 2012, for ocean bottom seismometers. In the latter, conventional cable laying equipment was used, a solution that is since 2015 commercially available for this type of sensors. At last this is a real world proof of concept of the SMART-cables strategy for ocean observation.

Chapter 4

Long term vision and recommendations

There are a number of identified challenges ahead, including the amount and diversity of data and technological / operational cost impact. The main recommendation is to make it simple and unnoticed (KISS). Of course the other challenge is to integrate sensors in existing technology and how to deal with several operational aspects such as routine fast and efficient deployment with existing cable ships and others as simple as how to deal with buried repeaters for sampling water column parameters. Another challenge is on how to deal with worldwide implementation and sort out the legal statues for the data collected when mixing EEZ and international waters. Another aspect and also a challenge is how to incorporate new needs for ocean monitoring as including in the repeater the capability to interact in data and power with AUVs, gliders and other robotic sensing platforms.

Despite these grand challenges, there remains the objective of making current and future cables ocean aware by adding environmental sensors. In other words telecommunications cables become dual use.

Among the recommendations one may find the need for a simulator and a demonstrator. It is believed that medium size cables ($\leq$ 2500 km) involving just one nation, such as the CAM-ring, are better suited for that purpose, than long trans-oceanic cables. Mostly because legal issues would be easily solved with a single government, however, a strong political will would be needed to motivate cables suppliers to allow the scientific community to implement dual use into the cables.

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