Using submarine cables for climate monitoring and disaster warning

Strategy and roadmap

IOC

WMO

ITU

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Scope and vision

Submarine telecommunication cables today traverse the oceans and transmit the global Internet. However, these cables are deaf, dumb and blind to their ocean environment around them. A future is envisioned when telecommunication companies integrate ocean-observing sensors within their submarine cable systems. Conveyed to mankind, this new sensory data would crucially advance our knowledge in monitoring global climate change and tsunamis in the deep ocean. Through leadership of the telecommunication companies, this transformation occurs gradually as new, environmentally-aware cables are deployed, and older systems retired. Over time, an extraordinary scientific capability evolves for the benefit of mankind.

This report presents a strategy and roadmap for the United Nations – through its agencies ITU, WMO, and UNESCO/IOC – to work together with telecommunication companies to begin the first steps toward this vision for incorporating sensors into submarine cables.

Executive summary

The joint workshop of the International Telecommunication Union (ITU), World Meteorological Organization (WMO), and UNESCO Intergovernmental Oceanographic Commission (UNESCO/IOC), *Submarine Cables for Ocean/Climate Monitoring and Disaster Warning*, held in Rome in September 2011, initiated within its *Call to Action* the development of a strategy and road map for enabling the availability of submarine cable repeaters equipped with scientific sensors for climate monitoring and disaster risk reduction. Compared with the extensive scientific monitoring coverage of the upper ocean by satellites, ships, and buoys, there are few resources available for monitoring the deep ocean and seafloor. The vision is for today's commercial submarine telecommunication cable networks to morph over time into broader telecommunication networks that also sense their ocean environment. Synthesizing and integrating the scientific, engineering, business, and legal issues raised at the workshop, this report presents a series of strategic considerations and steps forward on a path toward submarine cable repeaters equipped with scientific sensors.

The cable repeater design and its deployment mode by cable ships place very strong constraints on possible scientific sensors. It is important to keep it simple at this initial stage to build confidence and success. Primary sensors, which meet scientific monitoring objectives and take into consideration the repeater and its deployment environment, include temperature, pressure, and acceleration sensors. An acoustic modem and hydrophone should be considered secondarily, if engineering is possible. Two possible modes for transmitting data from the repeaters include a dedicated science fiber, or use of an out-of-band carrier on a commercial fiber. Telecommunications companies develop, own, and operate the submarine cable systems, and integration of scientific sensors must fully conform within this commercial framework. Reviewing the UN Convention on the Law of the Sea, limitations are imposed on environmental monitoring on the continental shelf and exclusive economic zone of coastal states using submarine cables. Steering clear of these restrictions, UNCLOS suggests that environmental monitoring by submarine telecommunication cables be conducted within the high seas, unless consenting arrangements are made with coastal states.

Raising the visibility of the joint efforts of ITU, WMO, and UNESCO/IOC toward integrating environmental monitoring sensors within submarine cables repeaters is essential for progress and in sustaining momentum forward. The ocean observation sensors to be incorporated into the repeaters should be vetted by ITU, WMO, and UNESCO/IOC. A workshop is needed to bring cable repeater manufacturers together with sensor manufacturers in order to build a mutual understanding of the specific challenges for integration of scientific sensors, and areas where there is latitude in design to accommodate and resolve these challenges. Current ocean/climate and tsunami monitoring costs need to be collected and compared with estimated costs for environmental monitoring using submarine cables. Scientifically rigorous monitoring objectives must be established for networks of sensors deployed with submarine cables. Toward prototype development, national interest following the Japan tsunami of 2011 or philanthropic interests by foundations, corporations, or individuals should be explored in order to catalyze funding for non-recurring engineering costs.

1 Introduction

This strategy and roadmap identifies and motivates a path for the International Telecommunication Union (ITU), the World Meteorological Organization (WMO) and UNESCO Intergovernmental Oceanographic Commission (UNESCO/IOC), to consider for enabling the availability of submarine repeaters equipped with scientific sensors for climate monitoring and disaster risk reduction.

It primarily addresses the "Call to Action" of the ITU, WMO, and UNESCO/IOC workshop: *Submarine Cables for Ocean/Climate Monitoring and Disaster Warning: Science, Engineering, Business and Law,* held in Rome, Italy, 8-9 September 2011, with specific focus on the second point of the Call:

> 2. Develop a strategy and roadmap that could lead to enabling the availability of submarine repeaters equipped with scientific sensors for climate monitoring and disaster risk reduction such as pressure, temperature, salinity/conductivity, seismic, hydroacoustic and cable voltage in the near future;

It also addresses areas of discussion and questions raised in each of the four principal subtopics at the workshop regarding scientific sensors and submarine cable repeaters, and outlines the next steps forward to sustain momentum generated by the Rome workshop.

1.1 Where we want to go

Commercial submarine telecommunication cables crisscross hundreds of thousands of kilometers of the oceans' seafloor (Figure 1a), providing the fundamental Internet and telecommunications infrastructure for mankind. These cables are now blind, deaf, and dumb to the environment surrounding them, and simply transport information between terminal stations near cities on the coasts. The vision is for these submarine cables to perceive their environment, and transmit these data to mankind.

As global communications continue to expand and develop, older submarine cable systems are systematically retired after a lifetime of about 25 years and replaced with more modern, capable equipment. When submarine cable repeaters, which amplify optical data as it travels across the ocean, are designed to include basic ocean observation sensors, this capability enables the possibility for extensive networks of sensors crossing the oceans at the seafloor. Incorporating such repeaters into future submarine telecommunications cable systems would lead over time to a progressive expansion of environmental monitoring. These sensory data are fundamental to ocean and climate monitoring for global change and for disaster risk reduction for tsunamis and earthquakes. The vision is for today's broad telecommunications networks to morph over time into broader telecommunications networks that also sense their ocean environment.

Figure 1a: Global Submarine Telecommunication Cables. Source: TE subcom, International Cable Protection Committee, 2012

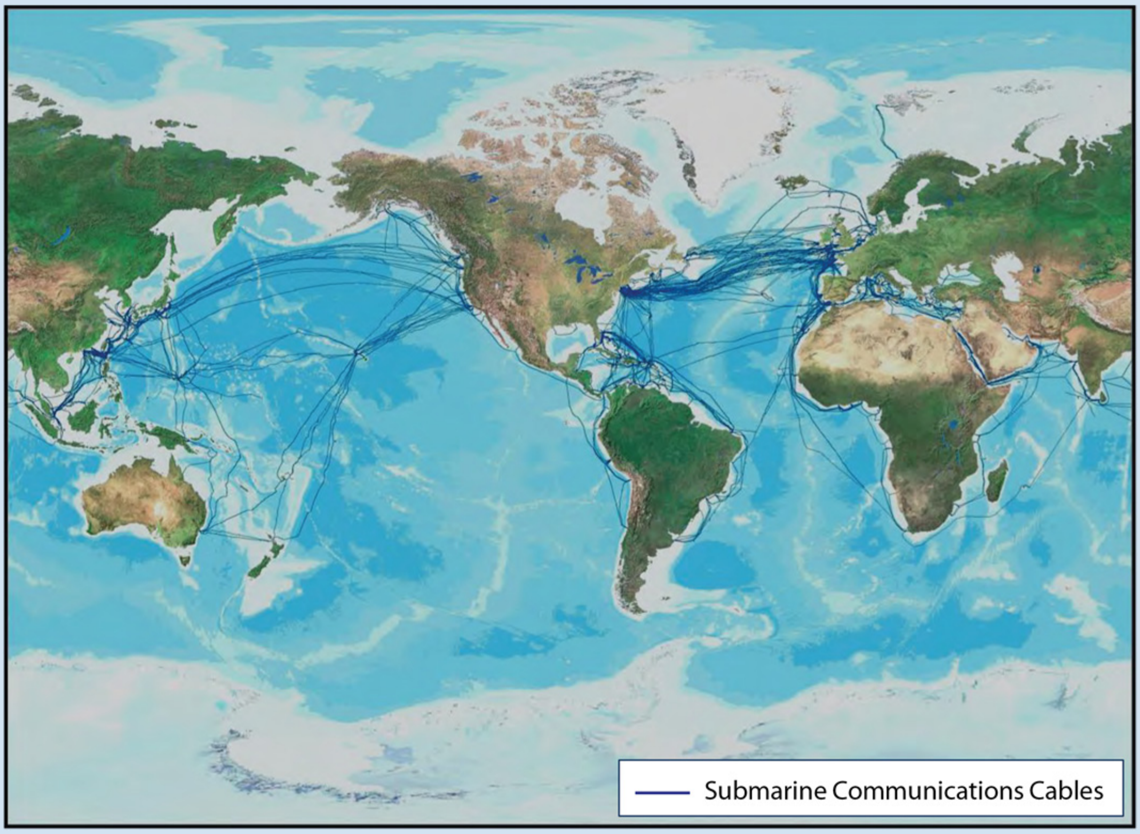
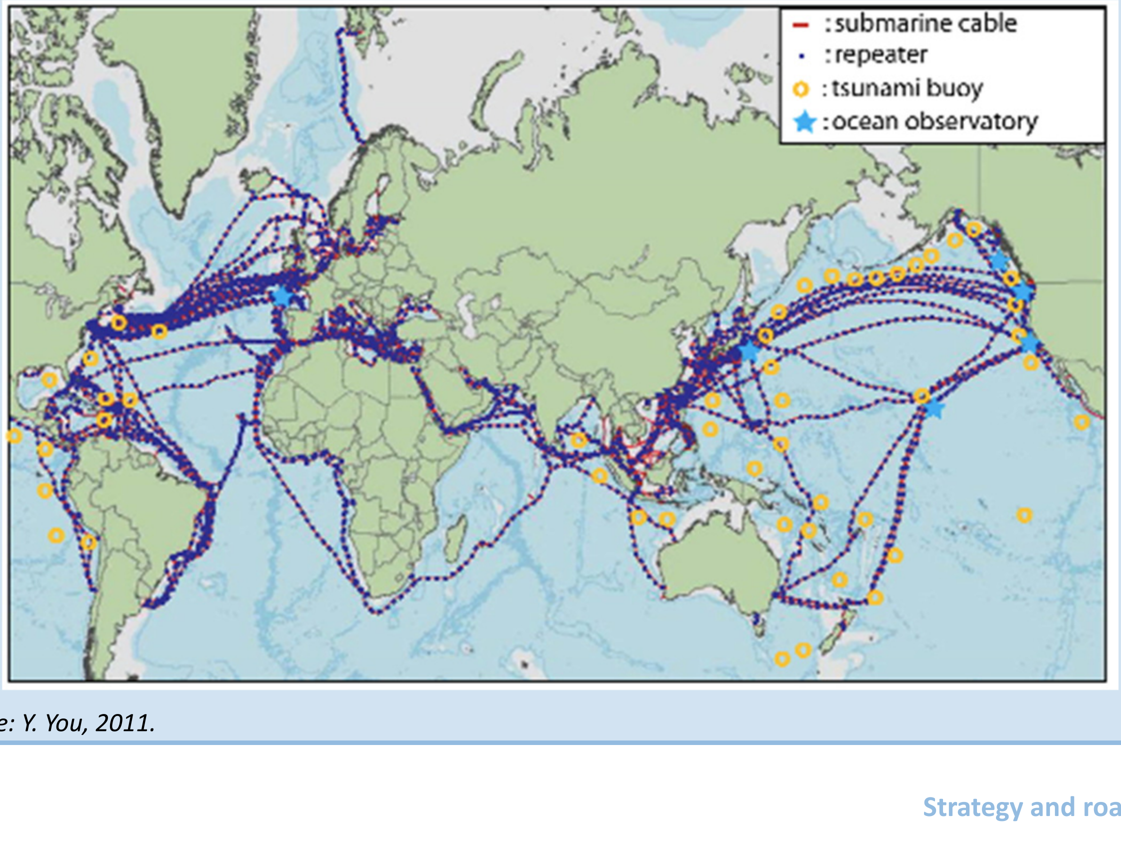


Figure 1b: Abridged map of cable routes. Submarine cable repeaters (blue dots) are symbolically plotted overlapping the cables (in red). Actual number of repeaters is about 4 times more than that plotted with a distance of about 40-150 km apart. For example, a typical transpacific cable would contain about 200 repeaters. Tsunami buoys and other ocean observatories are also plotted.



Source: Y. You, 2011.

1.2 What we need in order to get there

To realize this vision ITU, WMO and UNESCO/IOC must sustain their positive engagement with the submarine telecommunications companies, both cable owners and manufacturers. Representing people everywhere, the joint action of ITU, WMO, and UNESCO/IOC brings necessary gravitas in finding mutual advantage in the way forward for all concerned. Visibility for this vision is important for broadening the awareness of companies, governments, agencies, and the public, and building their support.

Currently the global environmental monitoring systems for ocean, weather, climate, tsunami, and earthquakes are developed, installed, and operated by governments. However, monitoring the environment of the seafloor with submarine telecommunication cables relies exclusively on infrastructure developed, installed, and operated by the private sector. Recognizing the primacy of telecommunications on these systems and working through commercial companies, the framework for adding sensors to submarine cable repeaters must necessarily reflect and be congruent with the interests of the cable owners and manufacturers in minimizing cost and risk. Acknowledging the leading role of the commercial sector is essential for building confidence.

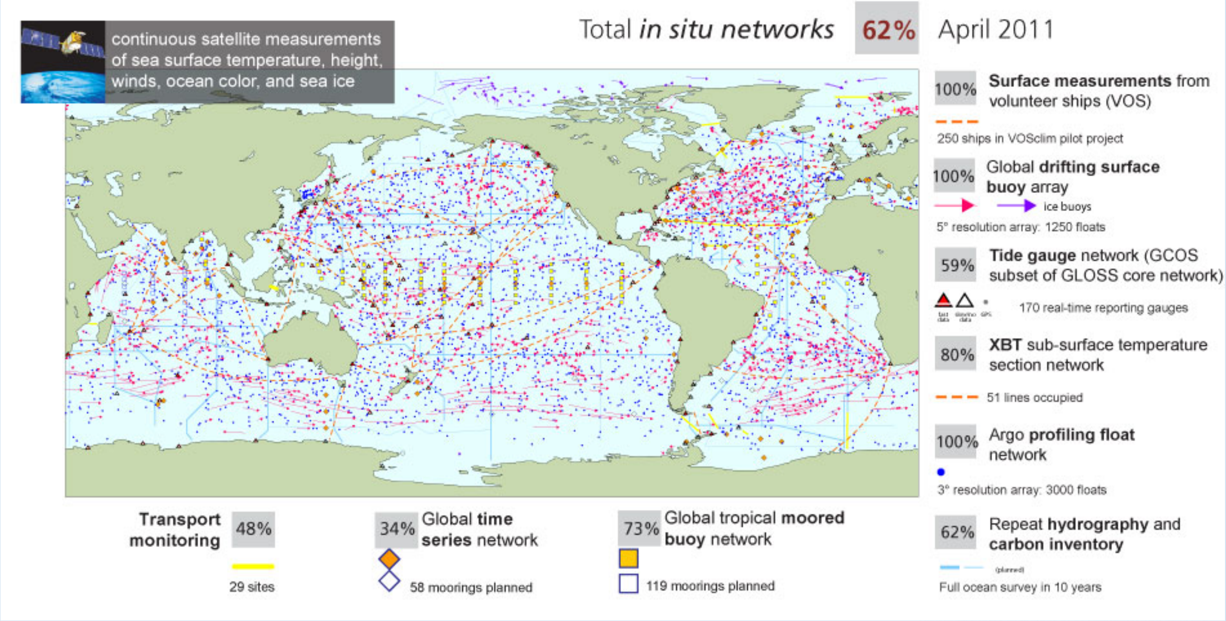
The cable repeater design and its deployment mode by cable ships place very strong constraints on possible scientific sensors. It is important to keep it simple at this initial stage to build confidence and success. Key sensors that meet scientific monitoring objectives must fully take into consideration the repeater and its deployment environment. The scientific and monitoring communities must be engaged by ITU, WMO, and UNESCO/IOC in order to vet the sensor specifications. Sensor spacing and integration of data from potentially many cable systems must be reviewed with respect to science objectives by national science agencies or academies to better understand cost-benefit trade-offs. Costs for current global monitoring of the upper ocean by satellites, ships, and buoys (including tsunami) must be weighed with respect to the incremental costs for adding sensors to submarine cable repeaters for the deep ocean and seafloor. Cable system manufacturers and sensor manufacturers must be invited by ITU, WMO, and UNESCO/IOC to meet for engineering discussions and to build necessary contacts for beginning development of prototype repeaters incorporating ocean observation sensors.

The use of submarine telecommunications cables for environmental monitoring requires consideration of the United Nations Convention on the Law of the Sea (UNCLOS, 1982). According to UNCLOS, whereas the international legal regime for installation and maintenance of submarine cables recognizes unique freedom to lay, maintain and repair submarine cables – freedom not granted for any other marine activities – the international legal regime for marine data collection recognizes the right of the Coastal State to regulate certain forms of marine data collection in the territorial sea, in the exclusive economic zone (“EEZ”) and on the continental shelf where its consent is required to conduct marine scientific research (“MSR”). However, all States have the right to conduct MSR in the high seas and in the Area. Due to the newness of submarine telecommunication cables equipped with scientific sensors for environmental monitoring, it is not mentioned in UNCLOS whether this activity falls into the international legal regime for installation and maintenance of submarine cables, or whether it is subject to MSR regime. The lack of international agreement on this issue might slow down this progress (see Bressie, 2012).

1.3 Where we are

Global climate change is recognized by the United Nations and impacts all of mankind. Through the WMO Global Observing System, extraordinary monitoring resources (many tens of USD Billion) using ships, buoys and constellations of satellites (Figures 2 and 3) are focused upon the surface and upper ocean.

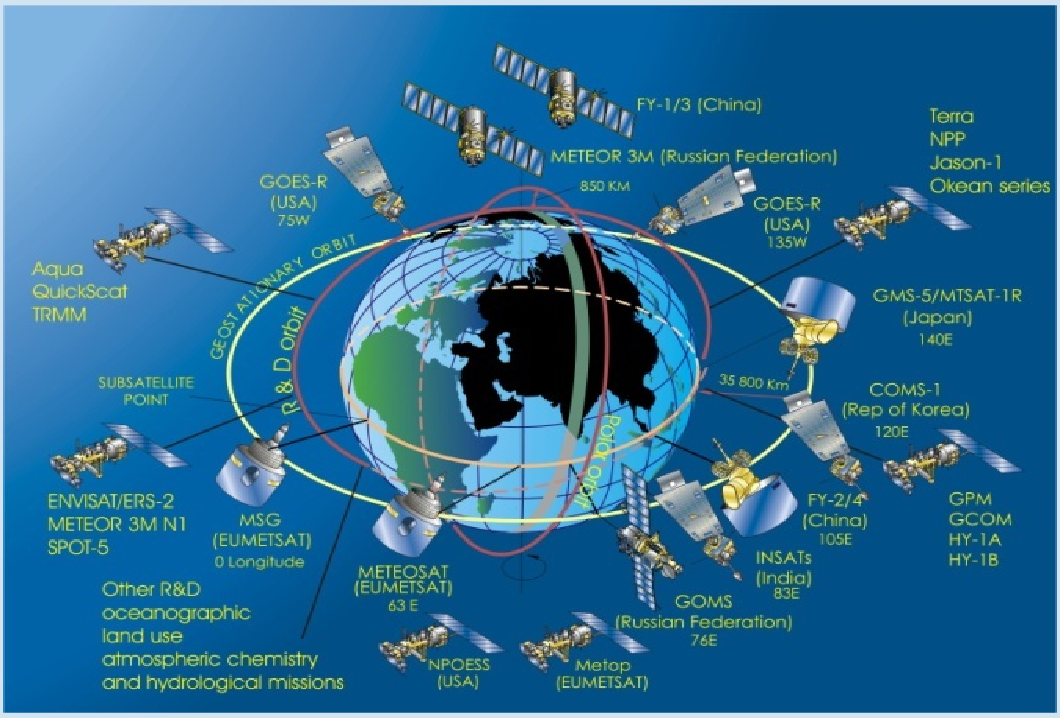
Figure 2: Elements of the Global Ocean Observing System (GOOS) implemented through April 2011.



Source: D. Meldrum, 2011.

In comparison, scant few resources are focused on monitoring the deep ocean and seafloor (e.g., Garzoliet et al., 2010). The OceanObs09 conference in 2009 (www.oceanobs09.net) emphasized the need for global sustained deep ocean observations.

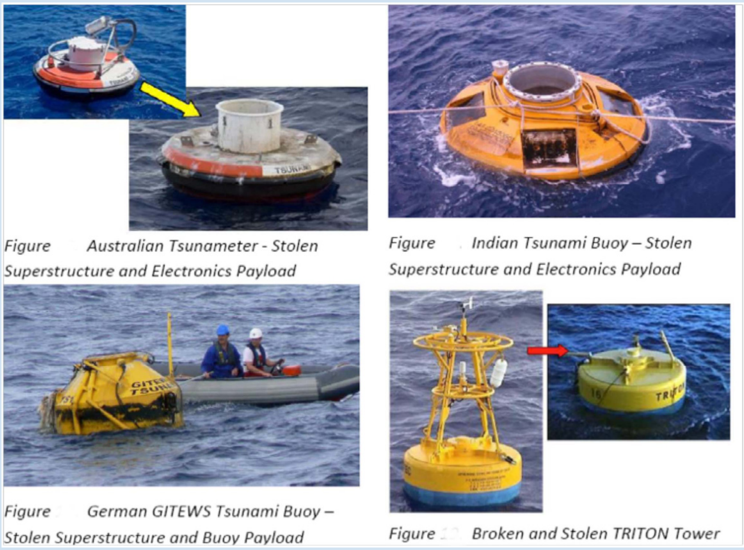
Figure 3: Satellite constellations of the WMO Global Observing System (GOS) for monitoring weather and climate.



Source: W. Zhang, 2011.

The tsunamis of 2004 in the Indian Ocean and 2011 on the shore of Japan caused extreme damage and loss of life. Networks of tsunami gauges deployed on the seafloor at moored buoys now surround the edges of the Pacific, and are at edges of the Indian and Atlantic Oceans (e.g., Figure 1b). However, buoy failures, vandalism (Figure 4), long down time due to limited weather windows for repair, lack of coverage in the vast open ocean, and high-maintenance costs by ships have abridged the effectiveness of this resource. Tsunamigenic earthquakes are monitored almost exclusively on land, and there are very few sensors on the seafloor near these earthquake zones.

Figure 4: Vandalism is a major problem for tsunami buoys in the Indian Ocean.



Source: D. Meldrum, 2011.

An extraordinary system of commercial submarine telecommunication cables exists in oceans. In principle, governments could lay environmental monitoring cables themselves – and have to a limited extent done so near coastal areas of Japan, northwestern area of North America, and Europe – but have not in the vast open oceans. Although there is a recognized need, costs for laying cables are high (>USD 100M). Revenue generation offsets the costs for commercial cables. Through working with the leadership of the telecommunication industry for expanding environmental monitoring to the seafloor, it makes better sense to invest in a small, incremental change to the repeaters of submarine telecommunication systems that will continue to be routinely deployed across the oceans. This last idea is at the heart of the Rome workshop.

The Call to Action (see Annex A.1) from the Rome workshop laid forth ten points for a joint ITU, WMO, and UNESCO/IOC task force to pursue. To the extent that several other points interact directly or indirectly with the second point (ii) presented herein, I have included discussion.

1.4 The way forward

This roadmap presents a set of suggested actions grouped under two headings. The first focuses on strategic choices that need to be made at the outset in order to create a simple path through the many complexities raised and discussed at the workshop in Rome. The second focuses on steps that follow from the strategic choices and represent bridges to cross on the way forward. These steps are not entirely distinct, and there is overlap to be considered in sequence or parallel. Discussion is itemized in the following section.

1.5 Key stakeholders for this report

Key stakeholders for this report include governments, climate and weather agencies, tsunami warning centers and agencies, earthquake information and response agencies, disaster risk reduction agencies, submarine cable telecommunication companies, and scientific organizations.

2 Strategic considerations

2.1 Sensors

The Rome workshop focused on a number of sensors to be considered for deployment in submarine cable repeaters. These specifically include: temperature, pressure, salinity/conductivity, seismic, hydroacoustic, and cable voltage. These were selected as key measurements with a focus on ocean and climate monitoring and disaster risk reduction. Additional sensors could be considered, such as an inverted echo sounder, or for measurement of anthropogenic carbon, or even cameras. However, even though there is merit in broadly considering the types of measures that could be performed on the seafloor, it is more important to focus on *keeping it simple* at these beginning stages in order to build confidence and to insure success. In addition to sensors, the capability to communicate via an acoustic modem at a repeater could open up future possibilities for deployment of sensors nearby and data transmission with nearby gliders.

Emplacement within a repeater places strong constraints on the types of sensors that are feasible (see also Lentz and Phibbs, 2012). There is limited power, perhaps a few watts at most. If there is a dedicated science fiber pair, then there is potentially great data bandwidth; however, other forms of telemetry, such as using out-of-band carriers, could be substantially more limited and without any two-way communication for command and control. *In-situ* calibration that requires visits by ships is not simple, and will be costly. The space available within the repeater is very limited, and the form and shape of the repeaters are partially dictated by the requirements for laying and repair/recovery of cables with a standard cable ship (Figure 5). Any "wet" components of the sensor are essentially limited to within the "bell" at each of the ends of the repeater where the cable enters the repeater bulkhead, and must not interfere with the fiber tail.

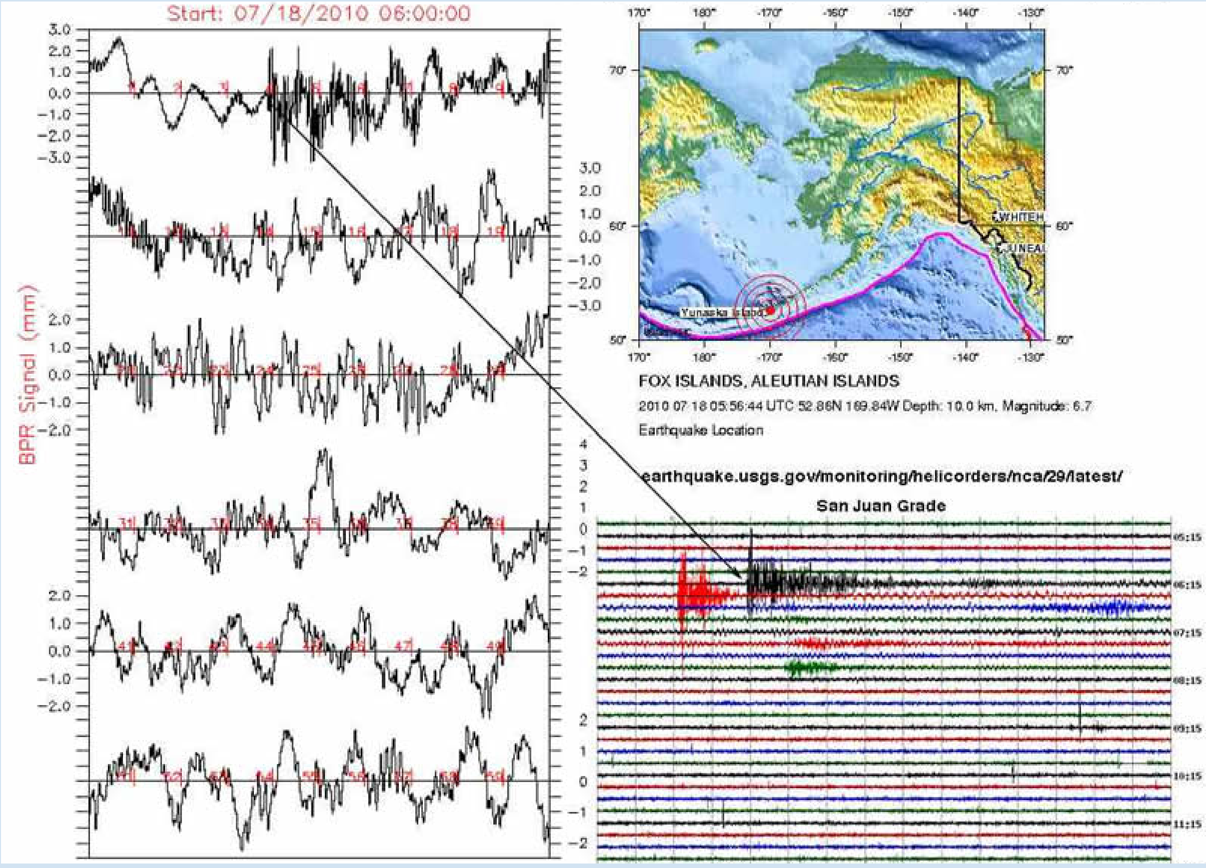
Figure 5: Optical repeaters are shown during a cable installation. System electronics and lasers are located in the copper-hued housing.

Source: P. Phibbs, 2011.

The sensor system electronics must be isolated at the bulkhead of the repeater. The repeater may experience shocks of ~40g during shipboard handling. The long-life design of the repeaters at about 25 years argues for great instrument stability, proven reliability, and comparable lifetimes for sensors that have been tested and deployed across several generations of development. In addition to sensing characteristics, the instrumentation should not raise security concerns. This last point is a significant consideration in seismic and hydroacoustic sensing capabilities for potentially monitoring submarines.

Temperature and absolute pressure have been measured with great precision and stability for many years, and served as the mainstays for physical oceanography. Absolute pressure gauges (APGs) are also essential for tsunami measurement and are deployed as part of the United States National Oceanic and Atmospheric Administration (NOAA) Deep-ocean Assessment and Reporting of Tsunamis (DART) network of buoys. High-resolution APGs are also capable of recording earthquakes (Figure 6), and as such contribute to tsunami warning, and earthquake location and hazard response. Using APGs for earthquake monitoring has been implemented by the United States in its Cascadia ocean bottom sensor system.

Figure 6: A magnitude 6.7 earthquake in the Aleutian Is. (see map) is detected in California on a high-resolution absolute pressure gauge in Monterey Bay (left) and on a nearby seismometer on land.



Source: *www.pmel.noaa.gov/vents/geology/mars/nanoeq.html*

A thermistor installed in the bell would be partially shielded from the flow of seawater, and as such would act as a low-pass filter of temperature. Engineering consideration will guide the placement of the thermistor, whose response must be modeled. Because the repeater itself is a heat source, a parallel thermistor in the repeater housing itself is needed to monitor internal temperature.

Seismic sensors measure vibration, and as such do not require access to the "wet" environment. In principle, they can be installed within the repeater housing. Normally installed to measure three orthogonal components of motion (Z, NS, EW), a seismometer could require substantial space in the repeater. Furthermore, broadband seismometers used in seafloor applications require appropriate orientation to work properly, even if only a vertical component is used. Broadband seismometers do not have long-term stability, require calibration and re-centering, and are not considered rugged. All of these factors obstruct straightforward emplacement of standard seismometers into cable repeaters. However, Micro-ElectroMechanical Systems (MEMS) accelerometers (used extensively for air-bag deployment systems in cars) have the appropriate characteristics for placement in the repeater environment, and are used by the United States Advanced National Seismic System (ANSS) for recording earthquake strong ground motions. Augmenting a high-resolution APG with a MEMS accelerometer provides a simple framework for seismic measurements. These sensors also provide important information for cable owners and operators, where nearby earthquake faulting and turbidity flows may affect or damage the cable system.

These three sensors can operate passively and autonomously. The data rate is very small. Two thermistors may generate less than 1 bit per second (bps) when sampled at 1 sample/minute. The APG and 3-component MEMS sensors generate less than 2 kbps, when sampled at 20 sample/sec. Using a sample rate of 20 sample/sec, pre-filtered to exclude data above the 10 Hz nyquist frequency, also avoids national security issues with detection of submarines. For example, in the Canadian NEPTUNE observatory the hydroacoustic and seismic data are band-pass filtered from 10 Hz to 3 kHz to remove signatures of submarines. By excluding seismic and acoustic monitoring in the 10 Hz to 3 kHz band, we lose the ability to monitor large marine mammals and earthquake T-phases but avoid national security concerns. Nonetheless, the principal earthquake and tsunami monitoring functionalities are not abridged.

Hydroacoustic sensors (hydrophones) when monitored above 3 kHz are very useful for monitoring rain and wind, and can hear smaller marine mammals. However, it is not clear whether a hydrophone could effectively operate within the repeater bell without modifying the bell to be acoustically more transparent. Mounting the transducer openly could lead to potential damage during deployment, or being located in the seafloor mud if a repeater were unfortunately oriented on the seafloor. Including a hydrophone sampled at about 50 kHz will increase the sensor data rates to over 1 Mbps.

Conductivity/salinity sensors would need to be more substantially ruggedized to avoid damage during the deployment of the repeater. The lack of seawater flow within the bell may be a problem for some designs. However, the principle limitation for conductivity/salinity sensors is their requirement for *in-situ* sampling of seawater for their careful calibration. These factors argue against including a conductivity/salinity sensor within cable repeaters at this initial stage.

The voltage signal in a submarine cable is affected by a motionally induced signal due to oceanic transport variations and by fluctuations of the magnetic field of the Earth. These signals are also affected by the dielectric properties of the sediments on which the cables lay. In principle, the oceanic transport can be derived with sufficient knowledge of the other variables. However, the NOAA Atlantic Oceanographic and Meteorological Laboratory notes that a combination of magnetometers and careful *in-situ* calibration of the ocean transport and sediment properties are necessary to resolve the ocean transport signal from the cable voltage. As much as the necessary ship time for calibrating each repeater is large, the measurement of ocean transport between repeaters appears to be initially impractical.

An acoustic modem installed within the repeater bell could be of substantial benefit. Instrumentation that is ill suited to installation within a repeater, such as an inverted echo sounder, could communicate its data to shore when deployed nearby the repeater. Gliders could, in principle, collect data along a traverse and download it at a repeater. If two-way communications were feasible on the system, new commands could be sent to the glider. The acoustic modem also provides the opportunity to deploy future instruments in this remote *in-situ* environment that do not exist today; e.g., for measurement of anthropogenic carbon.

However, the acoustic modem suffers from challenges similar to the hydrophone. The optimal acoustic transmission location for the transducer is external on the repeater, where it can be damaged upon deployment and possibly buried in the mud. Also, acting as a hydrophone, the acoustic modem potentially can detect submarines, and therefore its range would need to be limited to avoid national security concerns. Data rates will depend upon proximity to the acoustic modem. Implementing bi-direction communications may prove to be substantially more difficult for the ocean observation sensor system for some repeater telemetry arrangements. Another challenge for the acoustic modem is that it may not be used, unless there is specific follow-up in the future. This would mean that a key component of the scientific sensory system could be initially under-utilized, but would still drive engineering design. Nonetheless, the future potential for including new instrumentation nearby a repeater location strongly invites consideration of an acoustic modem if engineering is feasible.

Reviewing the sensors suggested by the Rome workshop, the simplest approach is to include thermistors, APGs, and MEMS accelerometers as the primary sensors within the repeaters in any initial engineering integration. These are low power, low data rate, rugged, small, and can be passively monitored. Each of these sensors is also central to ocean/climate monitoring and disaster risk reduction.

On a secondary tier are the acoustic modem and hydrophone. It would be valuable to have these, but their additional challenges in integration lowers their priority relative to the simplest approach. Nonetheless, cable manufacturers should be encouraged to meet with manufacturers of acoustic modems and hydrophones in order to creatively consider engineering possibilities for the future.

2.2 Communications of sensor data via the cable repeaters

Whereas the optical repeater carries prodigious (>1 Tbps) communications traffic, there is no routine access to the communications within the repeater itself, which simply amplifies the light signals passing through. Furthermore, there can be no risk to the existing channel traffic, whatever method is proposed in sharing the repeaters for scientific sensors. Two methods are discussed representing very different approaches. It is likely that the creative minds of cable manufacturers may suggest other, perhaps better possibilities.

Using a dedicated fiber pair for science on a cable system is discussed by Steve Lentz and Peter Phibbs, Mallin Consultants Ltd., (2012). This puts all science traffic on its own fiber, thereby physically separating the science traffic from the normal communications traffic. Electronics within the repeater can convert the optical signals to electrical and back, using robust regenerator technology that served as the basis for the first generation electro-optical fiber systems, such as the TAT-8 and Hawaii-4 cables (see Howe et al., 2011 regarding the Hawaii-4 cabled scientific observatory). In principle, ethernet could be adopted for the whole science system, permitting full networking with the sensors, including command and control, as well as the possibility for communication with an acoustic modem. The bandwidth of such a system is potentially 100 Gbps, which may be far greater than needed for the suite of sensors being considered. Each repeater would require an electro-optical regenerator for the science fiber pair, substituting into the space normally allocated for the optical amplifier for communications fibers. Although there are many excellent advantages in this approach, the additional fiber pair is costly, >>USD 1 M for each cable system.

A more limited approach, suggested by Mark Tremblay (personal communication, 2011), could use the cable and repeater system with fewer modifications. Rather than having a dedicated fiber pair for science, an "out of band carrier" would be utilized from an existing fiber pair in the cable. This optical carrier could be at the upper-end beyond the pass band of regular communications channels, not interfering with any communications traffic. Data could be added to the carrier by a simple modulation scheme turning it on/off. With very short, redundant data bursts, science data from the 100+ repeaters with sensors could be added randomly in time to the carrier with few data collisions. There is a trade-off in the carrier data capacity due to distance through both optical dispersion and signal/noise (the power must be much lower than the traffic channels), which favors lower bit rates. If 100 Mbps capacity is assumed, <1% data collisions implies <10 kbps for each of the 100 repeaters, that easily carries the low-data-rate primary data (temperature, pressure and accelerometer), but challenges the hydrophone channel at 3-50 kHz. An acoustic modem could be incorporated in a passive, listening-only mode. This "out of band carrier" method is much simpler in passively accepting data from the sensor, and basically needs only to turn on/off the carrier in the repeater. Two-way command and communication requires more complicated schemes, including a transmit laser in the shore equipment that could be a risk element for the regular communications traffic on the fiber.

2.3 Building confidence with submarine telecommunication companies

Sharing submarine cable repeaters with ocean observation sensors requires recognition of the primacy of the basic function of the telecommunication system: to move vast amounts of information across the ocean. Fulfilling all of their requirements for this primary telecommunication purpose for the submarine cables is the main issue for telecommunication companies. Submarine cables are the basic infrastructure of the Internet, and as such are essential to governments, commerce, public safety and health, science, and the public in general. In sharing this infrastructure for scientific ocean/climate monitoring and disaster risk reduction at submarine repeaters, the extraordinary reliability of the system cannot be reduced or abridged. It immediately follows that installing scientific sensors within the repeaters in the cable system must be engineered and managed by the cable system manufacturers, who must stand by the reliability of their product. Furthermore, the existing framework of commercial cable owners and maintenance authorities is a highly successful model that has established the current submarine cable system globally. Including ocean observation sensors within submarine cable systems implies working within this commercial rubric. Nonetheless, the scientific monitoring effort is congruent with telecommunications interests: both desire an extremely reliable, long-life system. Interfacing with this fundamental commercial telecommunications system imposes strong, reasonable conditions on ocean observation sensors.

The cable system owners have ownership of the scientific sensors in the cable repeaters, and the data that comes from these sensors. This data has value to mankind for ocean/climate and disaster monitoring. The high seas are a common heritage of mankind, and governments and international organizations will need to work with the cable system owners to determine a commercially equitable way to distribute the sensor data for societal benefit.

The ocean observation sensors are secondary in importance and priority to the primary telecommunications traffic on the cable systems. Cable owners do not repair/replace repeaters if overall telecommunications systems performance is maintained, and therefore the failure of the sensors will not in general be repaired. Telecommunications traffic will not be disrupted for sensor repair. At the cable owners' discretion, sensors may be repaired in the context of a primary system repair. In general, the sensor data from nearby repeaters serves for sensor system redundancy.

The sensors integrated within the basic repeater design must meet standards for ruggedness for cable deployment and repair by cable ships. Sensors should have operational lifetimes comparable to those for optical repeaters. Recognizing that optical repeaters have been carefully engineered through several generations, only modest and carefully tested changes may be anticipated for sensor integration within repeaters. Any changes must not affect system performance and reliability of telecommunications, nor change methods of cable system assembly, deployment, or repair; e.g., a repeater with integrated sensors can be deployed in the same manner as a repeater today. Several generations of prototypes for optical repeaters incorporating integrated sensors may be necessary before an operational system is ready for market. Sensors and their specifications will need to be vetted by ITU, WMO, and UNESCO/IOC in order to meet scientific requirements, which must recognize possible limitations imposed by being installed within a repeater.

The integration of sensors into cable repeaters need to meet cable industry risk issues raised in the Rome workshop by Maurice Kordahi, TE SubCom, (2011):

- Mechanical isolation from the network through fusible links and greater distance isolation from the telecom network;
- Power isolation from the telecom network;
- Fiber and data isolation from the telecom network.

The actual implementation of sensor integration to mitigate risks will depend upon the engineering direction of the cable manufacturers.

Whereas a long-term science goal is to integrate sensors for optimum ocean/climate and disaster monitoring, the realistic short-term goal is to integrate the minimum complement of sensors meeting the long-term objective and affording the clearest opportunity for success for both science and the cable telecommunications industry. Temperature, high-resolution pressure, and MEMS accelerometer sensors meet this requirement, having achieved prerequisite ruggedness, low power, and low data rates, through multi-generational development and ocean deployment.

2.4 Environmental monitoring in the high seas

The Rome workshop highlighted issues in the United Nations Convention on the Law of the Sea (UNCLOS, 1982) affecting submarine cables and marine scientific research. Environmental monitoring can be construed to fall under the rubric of "marine scientific research", in as much as scientific sensors are proposed to be added to submarine cable repeaters in the marine environment:

> *Article 258: Deployment and use*
>
> *The deployment and use of any type of scientific research installations or equipment in any area of the marine environment shall be subject to the same conditions as are prescribed in this Convention for the conduct of marine scientific research in any such area.*

Further, it was clearly noted in Rome that UNCLOS prescribes within the EEZ, continental shelf, and territorial sea of Coastal States different regimes for marine scientific research versus the special freedom granted to the laying of submarine cable and its maintenance and repair. E.g.,

> *Article 245: Marine scientific research in the territorial sea*
>
> *Coastal States, in the exercise of their sovereignty, have the exclusive right to regulate, authorize and conduct marine scientific research in their territorial sea. Marine scientific research therein shall be conducted only with the express consent of and under the conditions set forth by the coastal State.*
>
> *Article 246: Marine scientific research in the exclusive economic zone and on the continental shelf*
>
> *1. Coastal States, in the exercise of their jurisdiction, have the right to regulate, authorize and conduct marine scientific research in their exclusive economic zone and on their continental shelf in accordance with the relevant provisions of this Convention.*
> *2. Marine scientific research in the exclusive economic zone and on the continental shelf shall be conducted with the consent of the coastal State….*
> *(see also, Articles 247, 248, 249, 253, 254)*
>
> *Article 58: Rights and duties of other States in the exclusive economic zone*
>
> *1. In the exclusive economic zone, all States, whether coastal or land-locked, enjoy, subject to the relevant provisions of this Convention, the freedoms referred to in Article 87 of navigation and over flight and of the laying of submarine cables and pipelines, and other internationally lawful uses of the sea related to these freedoms, such as those associated with the operation of ships, aircraft and submarine cables and pipelines, and compatible with the other provisions of this Convention.*
>
> *Article 79: Submarine cables and pipelines on the continental shelf*
>
> *1. All States are entitled to lay submarine cables and pipelines on the continental shelf, in accordance with the provisions of this article….*
>
> *However, the specific restrictions and obligations placed upon marine scientific research by UNCLOS within the EEZ and continental shelf of a Coastal State do not extend into the high seas or the Area (sea bed). E.g.,*

> *Article 256: Marine scientific research in the Area*
>
> *All States, irrespective of their geographical location, and competent international organizations have the right, in conformity with the provisions of Part XI, to conduct marine scientific research in the Area.*
>
> *Article 257: Marine scientific research in the water column beyond the exclusive economic zone*
>
> *All States, irrespective of their geographical location, and competent international organizations have the right, in conformity with this Convention, to conduct marine scientific research in the water column beyond the limits of the exclusive economic zone.*
>
> *Article 87: Freedom of the high seas*
>
> *1. The high seas are open to all States, whether coastal or land-locked. Freedom of the high seas is exercised under the conditions laid down by this Convention and by other rules of international law. It comprises, inter alia, both for coastal and land-locked States:*
> *…*
> *(c) freedom to lay submarine cables and pipelines, subject to Part VI;*
> *…*
> *(f) freedom of scientific research, subject to Parts VI and XIII.*
> *…*
>
> *Article 112: Right to lay submarine cables and pipelines*
>
> *1. All States are entitled to lay submarine cables and pipelines on the bed of the high seas beyond the continental shelf….*

In order to eliminate concerns by submarine cable owners and telecommunications companies about marine scientific research restrictions within the EEZ and continental shelf, the strategy for ocean/climate and disaster monitoring using submarine cables should be limited to the high seas and outside of the EEZ and continental shelf. Therefore, the sections of cables laid in the EEZ and on the continental shelf would be for communications only and not for marine scientific research, with no sensors installed within cable repeaters in this region. Sensors would be installed only within the repeaters of cable laid in the high seas. Whereas this will restrict the edges of scientific monitoring coverage of the ocean, it should be noted that cables are typically buried on the continental shelf in order to prevent damage from fishing, trawling, and anchors. Such buried cables would be impractical for sensors in any case.

Nonetheless, many scientific entities have focused activities within coastal waters and it would be beneficial to find a way for using submarine telecommunication cables to aid these scientific endeavors. Within the existing framework of UNCLOS, a dispensation of requirements (franchise, legal, etc.) by the coastal state to be arranged creatively between the government and the telecommunication consortia/company would be required in order to achieve these scientific benefits and to ensure advantages for all parties. Such arrangements may not be possible in many cases, but creative solutions should be studied and explored where prospects are promising.

For the submarine cable owners, there may be an advantage in conducting marine scientific research on the high seas:

> *Article 260: Safety zones*
>
> *Safety zones of a reasonable breadth not exceeding a distance of 500 metres may be created around scientific research installations in accordance with the relevant provisions of this Convention. All States shall ensure that such safety zones are respected by their vessels.*

These safety zones are not afforded to submarine cables without marine scientific research.

Whereas UNCLOS clearly argues that MSR conducted in the EEZ and on the continental shelf requires the consent of the Coastal State versus the special freedom grated to the laying, maintenance and repair of submarine telecommunication cables, it is not clearly specified what MSR is. UNLCOS asks its States parties to define MSR. Some States argue that multipurpose submarine cables should fall into the international legal regime for installation and maintenance of submarine cables, while others associate multipurpose submarine cables with MSR. The lack of an international agreement on the definition MSR nourishes concerns by submarine cable owners and telecommunications companies about future prospects and benefits. Even limiting the multipurpose, environmental monitoring use submarine telecommunication cables to the high seas may face scrutiny.

In this regard, it may benefit the efforts for ocean/climate and disaster monitoring using submarine cables if ITU, WMO, and UNESCO/IOC were to bring this question to the UNCLOS International Tribunal for their judgment and clarification, in order to have a clear path forward.

A case may be considered for fostering international cooperation in order to promote ocean/climate monitoring and disaster risk reduction using submarine cables. Such efforts currently exist under the WMO-UNESCO/IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) for the moored buoy, drifting buoy (ARGO), ship-based and space-based observational networks and related telecommunications facilities. Nonetheless, the unique contributions and interests of the commercial submarine cable owners and operators would first need to be carefully accommodated. Given ITU's multi-stakeholder membership and close participation of the telecommunication industry sector, discussion may be sought also here. The Management Group of JCOMM, which has met recently and been apprised by its Observations Coordination Group (OCG) on the joint ITU-WMO-UNESCO/IOC workshop and its outcomes, has asked that OCG pursues the workshop initiative in collaboration with ITU, UNESCO/IOC, and WMO action.

3 Bridges to cross

3.1 Visibility

The efforts to incorporate scientific environmental monitoring sensors into repeaters will take many years before coming to fruition. It is important to raise public awareness of the potential for using submarine cables for ocean/climate and tsunami/earthquake monitoring in order to build on the momentum generated by the Rome workshop. Continuous affirmation by ITU, WMO, and UNESCO/IOC is necessary. There is increasing public interest in being "green", and linking the submarine cables with "green" science builds a reservoir of good will that may tapped by commercial cable owners, manufacturers, and operators who participate. Ideally, it would beneficial to create a public relations bonanza for the first telecom that implements a "green" submarine cable system. Toward this end, it is crucial to publicize the Rome workshop and its "Call to Action". ITU, WMO, and UNESCO/IOC should take the opportunity to highlight this new activity at every forum they attend and within the media.

WMO and UNESCO/IOC should directly advise national monitoring agencies for climate/weather, tsunami and earthquakes on the potential prospects for new, real-time sensors within submarine telecommunications cables in the deep ocean at seafloor in order to engage their interest and receptivity to the data. Integration of new technology and data into the existing monitoring frameworks of countries takes time, and coordination with the established national processes for improving sensor and data infrastructures must begin.

WMO has the capability to manage and distribute the data collected from environmental monitoring repeaters. It would be helpful for WMO to formally offer to provide data management services for the future data, thereby giving recognition to the value and importance of the data.

ITU, WMO, and UNESCO/IOC should advise the Group on Earth Observations (GEO) about their efforts to engage the private sector in ocean/climate and tsunami/earthquake monitoring through submarine cables.

Visibility of submarine cables with environmental monitoring sensors may engender greater protection for all active cables. Recognizing essential societal benefit and value for scientific monitoring by submarine telecommunication cables, local governments may be more proactive in protecting them. In practical terms, once there is a security protocol for one cable, it would be easier to convince a local navy to extend the same protection shield (non-fishing areas, Vessel Monitoring System or radar monitoring, high penalties for those fishing nearby, etc.) to other cables in its local waters.

Finally, the sensor-cable engineering workshop, sensor specification vetting, and scientific review of monitoring objectives present important public relations opportunities. Engaging active talents of the scientific, engineering, and monitoring communities in open discussion also creates opportunities for proposing possible pilot projects as follow-up to developments.

3.2 Sensors specifications

The ocean observation sensors to be incorporated into the repeaters should be vetted by ITU, WMO, and UNESCO/IOC. It is important for specifications to be set early in order to clearly meet science objectives for ocean/climate and tsunami/earthquake monitoring. Having clear minimum specifications permits cable manufacturers to select among several manufacturers and designs in order to best meet their particular concerns. Input on the specifications should be selected from the ITU, WMO, and UNESCO/IOC members operating instrumentation in the deep ocean. This interaction with ITU, WMO, and UNESCO/IOC membership also affords the important opportunity to highlight the international efforts toward integrating environmental sensors with submarine cable repeaters. At the sensor-cable engineering workshop, presentation of the accuracy and precision, signal/noise performance, life expectation, and calibration of the sensors should be discussed in the context of the science goals.

ITU coordinates telecommunications standards. With the concurrence of ITU, WMO, and UNESCO/IOC, the establishment of an "environmental monitoring repeater" standard could be considered for repeaters containing a minimum set of sensors. This could allow cable owners and manufacturers to reap the benefits of good public relations through the stages in developing, testing, and adopting these "environmental monitoring repeaters".

3.3 Sensor and cable repeater engineering workshop

A critical next step toward the integration of scientific sensors within repeaters is to bring the cable repeater manufacturers together with sensor manufacturers, and their respective engineers, in order to build a mutual understanding of the specific engineering challenges for integration, and areas where there is latitude in design to accommodate and resolve these challenges. The focus of this workshop should be a free exchange of engineering ideas, with the outcome being that the cable manufacturers will be able to work directly with the sensor manufacturers in designing prototype repeaters incorporating sensors. Diverse international representation of sensor manufacturers is recommended. Nominations could be requested by ITU, WMO, and UNESCO/IOC from science organizations operating deep ocean instrumentation – e.g., Japan Agency for Marine-Earth Science and Technology (“JAMSTEC”), Neptune Canada, European Seas Observatory NETwork (“ESONET”), United States National Science Foundation (“NSF”), NOAA, etc. Given the explicit desire to protect cable systems, it would be helpful to invite the International Cable Protection Committee (“ICPC”) to co-sponsor the event and provide a neutral playing field for cable manufacturers to openly discuss repeater engineering. The ICPC motto fits the occasion: "Sharing the seabed in harmony".

ITU, WMO, and UNESCO/IOC need jointly to engage with the cable repeater manufacturers, highlighting the Rome workshop and their interests in the potential for monitoring the ocean/climate and tsunamis via sensors in optical repeaters. Peter Phibbs, Mallin Consultants Ltd., has initiated this first contact, and there should be positive follow-up by ITU, WMO, and UNESCO/IOC inviting engagement in a workshop.

The recent, tragic tsunami in Japan in March 2011 may have heightened the awareness and interest of key cable manufactures in Japan, NEC Corporation and Fujitsu, in the societal need for including tsunami sensors into cable repeaters. Since leadership by key companies can strongly motivate progress forward for the whole cable community, it would be helpful if ITU could intermediate to cultivate this potential in Japan.

3.4 Environmental monitoring costs

Without some estimates of costs, it is impossible to weigh the cost effectiveness of various scientific monitoring frameworks. Publicizing these costs places into proper perspective the relative costs for environmental monitoring using submarine cables. Towards this end, it will helpful for ITU, WMO, and UNESCO/IOC to work together through a working group to roughly summarize environmental monitoring costs. These include the costs for various components of the Global Observing System for monitoring the oceans, including satellites, ships, and *in-situ* networks such as ARGO. Current deep ocean monitoring at Ocean SITES would be included separately. It would be helpful to estimate the costs of installed equipment, development, and annual operation. Submarine cable costs would include the "average" cost for a commercial cable system, the government cost to lay a comparable, dedicated scientific cable incorporating the primary science sensors, and estimated incremental costs for incorporating primary science sensors into repeaters for a commercial cable system. In the latter case it would be good to separate non-recurring engineering costs from the installation. It would also be a useful benchmark to estimate the annual revenue generated by a commercial cable system.

3.5 Establishing scientifically rigorous monitoring objectives

The Rome workshop brought endorsement by WMO and UNESCO/IOC for the scientific goals in using submarine cables for ocean/climate and tsunamis/earthquake monitoring. Professor John You, University of Sydney, eloquently presented the potential for scientific monitoring by these cables (i.e., You, 2011abcd; You, 2011; You and Howe, 2011). However, specific numbers and configurations of sensors to meet scientific monitoring goals have not been established. Basic questions include how many repeaters (and at what spacing) meets scientific objectives. Does enhanced spatial coverage from many cables crossing the seafloor aid the objectives? Having environmental monitoring repeaters at all locations may be best, but how few would be adequate or necessary? Does the science return increase with increasing numbers of sensors? How much redundancy with nearby sensors mitigates potential sensor failure at a repeater? What scale of spatial resolution is optimal?

These questions are best answered by the underlying science. How many thermistors are needed to resolve ocean warming, and at what spatial scale? This may require ocean climate simulation and modeling. For pressure data, what are the appropriate spatial scales that must be resolved? Absolute pressure gauges can supplement /augment /replace current tsunami sensors at DART buoys, but cables do not necessarily traverse the same areas where DARTs are situated. Real-time APGs in the open ocean could substantially improve tsunami forecast models in real-time, but are there areas where more dense coverage would make the most improvement? APGs and MEMS sensors can significantly augment land-based earthquake monitoring, but what are the trade-offs for improving earthquake location and source characterization? These questions enter into the cost-benefit trade-offs that must be considered in weighing the numbers of environmental monitoring repeaters with respect to the science return.

In order to provide the fundamental scientific basis for ocean/climate and tsunami/earthquake monitoring using a network of sensors deployed within submarine cable repeaters, it is necessary to involve key science agencies. Both WMO and UNESCO/IOC should invite lead science organizations within their membership to advise them through studies of these issues. For example, in the United States the National Research Council of the National Academy of Sciences could address this. Many countries have comparable institutions for providing key scientific advice. Internationally, input from the Scientific Committee on Oceanic Research (SCOR) could be sought. By seeking discussion with the highest scientific councils, WMO and UNESCO/IOC can build the strongest scientific framework for the submarine cable monitoring effort. At the same time by engaging countries, the potential value and importance for these cable efforts may be brought to the attention of the highest levels of governments, thereby creating the prospect for future government action in support. Linking this activity with ITU, countries could be selected where there are large numbers of submarine cable landings, bringing to focus where the environmental data from the high seas would be accessed. Such countries could include: Japan, United States, United Kingdom, France, China, Australia, etc.

3.6 Toward prototype development

The beginning of prototype development of environmental monitoring repeaters is the most crucial step. Without this step, submarine cables remain deaf, dumb, and blind to their ocean environment and simply transport data. There is growing recognition by the scientific community and governments in the need to monitor the deep ocean in order to meet with the challenges and societal risks entailed by global climate change and tsunamis. However, raising the visibility of this monitoring need in the eyes of the public and the private sector is an essential step for creating a market for this new technology. A rigorous scientific framework for the network of sensors establishes the numbers of environmental monitoring repeaters needed.

Governments are a potential source of funding. However, submarine telecommunications cable systems are unique in their ownership and operation exclusively by the private sector. Whereas government funding might be welcomed, government intervention would be resisted. A special circumstance may now exist in Japan following the March 11, 2011 tsunami disaster, wherein the cable manufacturers NEC Corporation and Fujitsu and the telecommunication company KDDI Corporation may appreciate the benefit to the Japanese people for taking the lead in creating a new generation of environmental monitoring repeaters equipped with tsunami sensors for future cables landing in Japan. Given a critical need to improve monitoring for local and regional tsunamis, both the JAMSTEC and Japan Meteorological Agency (“JMA”) may be favorably receptive to collaborating on initial non-recurring engineering costs. A diplomatic overture with Japan by ITU, UNESCO/IOC, and WMO jointly could enhance prospects.

Alternatively, it would be advantageous to find a way to catalyze and finance prototype development privately in the near future. Through their global contacts with governments, non-governmental organizations, and individuals, the ITU, WMO, and UNESCO/IOC should be aware of private foundations, corporations, or individual philanthropists active in global climate change or disaster risk reduction, which would be interested in funding the initial, non-recurring engineering costs in development of environmental monitoring repeaters. Possible names include the Keck Foundation (which has built telescopes, perhaps now an oceanscope?), the Packard Foundation (marine and climate research), Google, and Steven Bing. This opportunity is ideal for philanthropy. It leverages large private sector resources for a cause that benefits all of mankind. The funding could come directly or as matching. Nevertheless, it would be prudent to support at least two manufacturers to create competition. Overtures jointly by ITU, WMO, and UNESCO/IOC would have a substantial benefit for enhancing prospects.

4 Suggested actions

- Environmental monitoring sensors need to be integrated into the next generation of submarine telecommunication cable repeaters in order to address mankind's global monitoring needs for ocean/climate change and disaster risk reduction.
- Visibility for this vision is essential for progress in broadening the awareness of submarine telecommunication companies, governments, agencies, and the public, and building their support. Toward this end, it is crucial to publicize the Rome workshop and its "Call to Action " in sustaining momentum for-

ward. ITU, WMO, and UNESCO/IOC should take the opportunity to highlight this new activity at every forum they attend and within the media.

- To realize this vision ITU, WMO, and UNESCO/IOC must sustain their positive engagement with telecommunication companies who develop, own, and operate the submarine cable systems. Integration of ocean observation sensors must fully conform within this commercial framework and recognize the primacy of telecommunications. The reliability of telecommunication systems must not be abridged.
- Temperature, pressure, and acceleration sensors comprise the primary sensors that meet scientific monitoring objectives and take into consideration the repeater and its deployment environment. An acoustic modem and hydrophone should be considered secondarily if engineering is possible. Cable system manufacturers must be responsible for engineering the installation of scientific sensors within the cable repeaters.
- ITU, WMO, and UNESCO/IOC should encourage cable manufacturers to recommend and engineer reliable, low risk and cost-effective ways for transmitting sensor data from the submarine cable repeaters.
- WMO and UNESCO/IOC should apprise national monitoring agencies for climate/weather, tsunami and earthquakes on the potential prospects for new, real-time sensors within submarine telecommunications cables in the deep ocean at seafloor.
- Reviewing the UN Convention on the Law of the Sea (UNCLOS), limitations are imposed on environmental monitoring on the continental shelf and exclusive economic zone of coastal states using submarine cables. Steering clear of these restrictions, UNCLOS suggests that environmental monitoring by submarine telecommunication cables be conducted within the limits of the high seas, unless consenting arrangements are made with coastal states. ITU, WMO, and UNESCO/IOC should seek concurrence from UNCLOS experts regarding this view.
- Specifications of ocean observation sensors to be incorporated into the repeaters should be appropriately vetted by ITU, WMO, and UNESCO/IOC.
- ITU, WMO, and UNESCO/IOC should organize an engineering workshop to bring cable repeater manufacturers together with sensor manufacturers in order to build a mutual understanding of the specific engineering challenges for integration of ocean observation sensors, and areas where there is latitude in design to accommodate and resolve these challenges.
- ITU, WMO, and UNESCO/IOC should collect, compare, and contrast the current costs for ocean/climate and tsunami monitoring with the estimated costs for environmental monitoring using submarine cables.
- ITU, WMO, and UNESCO/IOC should engage national and/or international science organizations to establish scientifically rigorous monitoring objectives for networks of sensors deployed with submarine cables.
- ITU, WMO, and UNESCO/IOC should engage the interests of commercial submarine cable companies, national governments, and philanthropy by foundations, corporations, or individuals to explore ways to catalyze funding for non-recurring engineering costs for prototype developments.

5 Conclusions

Abundant submarine telecommunication cables traverse the sea floor on mankind's common heritage in the oceans. New cables are continually being deployed, both over new routes and to replace older systems as they retire. Scientific sensors installed within next and future generations of submarine cable repeaters at the sea floor present an extraordinary opportunity and vision for ocean/climate monitoring and disaster risk reduction. Engaging the mutual interests and leadership of commercial telecommunication companies with the international scientific community through the support and advocacy of the United Nations – ITU, WMO, and UNESCO/IOC – builds upon the momentum generated by the Rome 2011 workshop for this vision.

A strategy and way forward are presented in twelve recommendations, emphasizing both the primacy of the telecommunication companies with respect to their submarine cable systems, and the necessary visibility for action by ITU, WMO, and UNESCO/IOC in engaging the next steps. Focus is given to a realistic short-term goal to integrate a minimum complement of sensors meeting the long-term objective and affording the clearest opportunity for success for both science and the cable telecommunications industry. A framework is proposed for working within international legal constraints imposed by the UN Convention on the Law of the Sea. Beginning the development of a submarine-cable-system qualified, prototype environmental monitoring repeater is the crucial step for eventual success. The way forward is straightforward.

Annex

A.1 Call to action (Rome, 9 September 2011)

We, the participants at the ITU, UNESCO/IOC, WMO Workshop on Submarine Cables for Ocean/Climate Monitoring and Disaster Warning: Science, Engineering, Business and Law in Rome, Italy from 8 to 9 September 2011 call upon 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) to establish and coordinate a joint task force composed of world renowned experts from science, engineering, business and law, which will:

i. Study and evaluate scientific, engineering, business, and societal benefits, opportunities, challenges and risks associated to the use of submarine telecommunications cables for ocean and climate monitoring and disaster warning, as well as legal aspects of such use;

ii. Develop a strategy and roadmap that could lead to enabling the availability of submarine repeaters equipped with scientific sensors for climate monitoring and disaster risk reduction such as pressure, temperature, salinity/conductivity, seismic, hydroacoustic and cable voltage in the near future;

iii. Analyze the development of projects that could include renovation and relocation of retired out-of-service cables for disaster warning, ocean and climate monitoring;

iv. Cooperate closely with the International Cable Protection Committee (ICPC) to investigate and report on the technical feasibility of incorporating the required scientific sensors into the design, manufacture, installation and operation of submarine repeaters in a safe manner without affecting cable systems and telecommunication signals, and avoiding risks that could affect the normal operation of the cables;

v. Consider a business model of how sensor data from submarine cables could be provided and could be made available for scientific purposes and societal benefit;

vi. Identify financing models and opportunities to promote the development of ocean climate monitoring and disaster warning systems by the use of submarine cables;

vii. Consider ways to further promote the implementation of the legal regime, as reflected in the United Nations Convention on the Law of the Sea (UNCLOS) and other instruments, for the protection of submarine cables, including awareness building and mobilization of support at the national and global levels;

viii. Organize similar workshops to report on the progress;

ix. Ensure that the outcomes of the above efforts/activities take into account and are consistent with international law, as reflected in UNCLOS;

x. Invite ITU to consider providing secretarial support for the joint task force.

We encourage ITU, UNESCO/IOC and WMO to bring this Call to Action to the attention of the United Nations Framework Convention on Climate Change (UNFCCC), the States Parties to UNCLOS and the United Nations Secretariat.

Glossary

APG	Absolute pressure gauge
ARGO	Array for Real-time Geostrophic Oceanography
DART	Deep-ocean Assessment and Reporting of Tsunamis
EEZ	exclusive economic zone
ESOnet	European Seas Observatory NETwork
GEO	Group on Earth Observations
GOOS	Global Ocean Observing System
GOS	Global Observing System
IOC	Intergovernmental Oceanographic Commission
ITU	International Telecommunication Union
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JCOMM	Joint Technical Commission for Oceanography
JMA	Japan Meteorological Agency
kHz	Kilohertz
MEMS	Micro-ElectroMechanical Systems
NOAA	U.S. National Oceanic and Atmospheric Administration
OCG	Observations Coordination Group
SCOR	Scientific Committee on Oceanic Research
TAT-8	TransAtlantic-8
Tbps, Gbps, Mbps, Kbps	Terabits, Gigabits, Megabits, Kilobits per second
UNCLOS	United Nations Convention on the Law of the Sea
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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