THE GREEN REPEATER

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Abstract: Oceans store more than 90% of the heat and 50 times as much carbon as the atmosphere in the Earth's climate system. Ocean bottom waters originate in the northern North Atlantic and around Antarctica. Global warming causes polar waters to be less capable of sinking, reducing thermohaline circulation and impacting the ocean's capacity for heat and carbon storage. Scientists have identified that a time series of data that provided detailed information on changes in the deep ocean over decades would significantly improve humankind's ability to quantitatively evaluate the rate and degree of changes in climate and in the Earth climate system.

Such long time series data requires a very stable and reliable platform. The only platforms that exist in the deep ocean are subsea fibre optic cable systems. These systems, with repeaters approximately every 50-75 km along the cable and a 25 year design life, appear to the scientists to offer an economical platform for sensors that would provide time series data.

In response to the 2012 Rome Call to Action on "Using submarine telecommunications cables for ocean and climate monitoring and disaster warning", the ITU (***I**nternational* ***T**elecommunication* ***U**nion*) with UNESCO's (the ***U**nited* ***N**ations* ***E**ducational,* ***S**cientific and* ***C**ultural* ***O**rganisation*'s) IOC (***I**ntergovernmental* ***O**ceanographic* ***C**ommission*), and the WMO (***W**orld* ***M**eteorological* ***O**rganization*) jointly published a paper co-written by the author titled "Using Submarine Cables for Climate Monitoring and Disaster Warning – Engineering Feasibility Study" [13]. The conclusion reached in that study was that it is feasible to support a modest number of low power sensors at each repeater without having significant impact on the reliability of the system for telecommunications traffic.

This paper summarises the current status of this initiative by these international bodies. It considers the implications and opportunities for the telecommunications industry of adapting the repeaters in new build systems to support temperature, acceleration and pressure sensors. And it summarises the improvements of our knowledge of large scale processes possible with long term data from such instruments.

1 INTRODUCTION

Global climate change is recognized by the United Nations and impacts all of humankind [1]. Through the WMO's (***W**orld* ***M**eteorological* ***O**rganization*) Global Observing System, extraordinary monitoring resources (many tens of billion US$) using ships, buoys and constellations of satellites are focused upon the surface and upper ocean. However, compared with this extensive scientific monitoring coverage of the upper ocean, there are few resources currently dedicated to monitoring the deep ocean and seafloor [2]. The OceanObs09 conference emphasized the need for global, sustained deep ocean observations [3].

To fulfil this need, this initiative envisions a future when telecommunication companies integrate certain specific ocean-observing sensors within their submarine cable systems [4]. Conveyed to humankind, the data these sensors provide crucially advances our knowledge in monitoring global climate change and tsunami propagation. Led by the telecommunication companies, this transformation occurs gradually as older systems are retired and new systems which support sensors are deployed. Over time, an extraordinary scientific capability evolves for the benefit of humankind.

The purpose of the initiative is to determine whether this vision can become a reality. While a consensus is still evolving and the views expressed in the paper may not be shared by all interested parties, this initiative seeks to encourage the parties to work together towards a practical solution.

2 HISTORY

Humankind's understanding of the oceans has historically been limited by their size and hostile nature. Even today, science investigations tend to be based on the life spans of battery-powered instruments and on the vagaries of ocean storms that restrict ship-based expeditions to field seasons of only a few months each year.

2.1 Cable Ocean Observatories

The vision of instruments connected to shore by cables carries with it solutions to some of oceanography's most difficult challenges: how to study natural phenomena on time scales that range from seconds to decades and on spatial scales from microns to kilometres. It also offers humankind potential progress on one of our major concerns: how to provide early warning of tsunamis and seismic events.

2.1.1 Japan

In answer to a government requirement for improved disaster warning, the JMA (***J**apan **M**eteorological **A**gency*) started developing the first cabled ocean observatory in 1974 to obtain real time seismic data from nearshore fault zones. This observatory was deployed in the eastern Nankai (Tokai) in 1978, and demonstrated the value of long term real time data sets from the deep ocean [5].

There are now nine cabled systems in service in the ocean off the coast of Japan, with several more under development, including the $500,000,000 Japan Trench Cabled Observatory.

2.1.2 USA

Inspired by the successes in Japan, the concept of a regional cabled ocean observatory to provide ocean sensors with continuous power and real-time data transfer to and from shore began to be seriously explored by scientists at the University of Washington in the mid 1990s.

In 1998, the NOPP (***N**ational **O**ceanographic **P**artnership **P**rogram*) funded a feasibility study for the program that became known as NEPTUNE (***N**orth**e**ast **P**acific **T**ime-series **U**ndersea **N**etworked **E**xperiments*) [6]. In 2008, with assistance from NEPTUNE Canada, Monterey Bay Aquarium Research Institute deployed the MARS observatory in Monterey Canyon. In 2012, the Ocean Observing Initiative started deploying the $150,000,000 Regional Scale Nodes observatory off the coast of Oregon and Washington State.

2.1.3 Canada

Canada, inspired by the American initiative, has funded and built two cabled observatory projects: VENUS and NEPTUNE Canada [7], [8]. The $100,000,000 NEPTUNE Canada observatory represents the first truly multi-purpose regional scale platform that can support a wide variety of sensors and experiments with minimal power and data limitations. These cable systems have demonstrated the value of real time continuous time series data in improving our understanding of the ocean.[9][10][11]

2.2 Cable Re-Use for Science

Cabled ocean observatories such as the JAMSTEC (*Japan Agency for Marine-Earth Science and Technology*) observatories and NEPTUNE Canada have the inherent disadvantage that, to control cost, they are able to provide data from a relatively small area, within a few hundred kilometres of shore.

Scientists have attempted to overcome this drawback through re-use of retired transoceanic telecommunications cables. Cutting and recovering the cable allows a single instrument package to be installed anywhere along the cable route. While this approach permits installation of instruments far from shore, it can only economically provide data from a single small area.

2.3 Existing non-Cable Technologies

There are a variety of means used by scientists to obtain data from the wider ocean. These include moored and drifting buoys, traditional battery powered standalone instruments, and various types of gliding vehicles. Some of these programmes are depicted in Figure 2-1, Figure 2-2 and Figure 2-3.

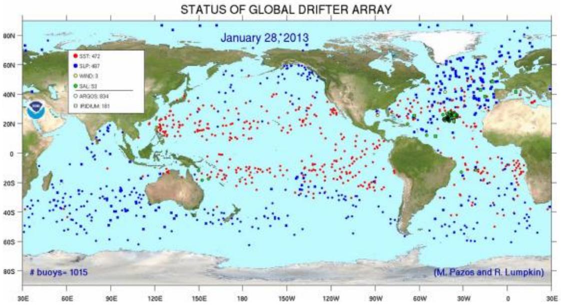

Figure 2-1 Global Drifters (NOAA)

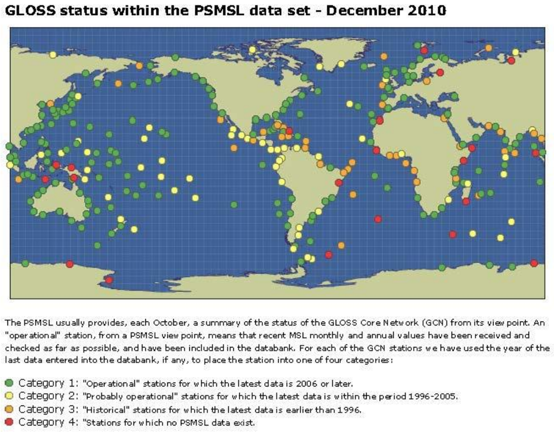

Figure 2-2 Global Sea Level Observing System (GLOSS)

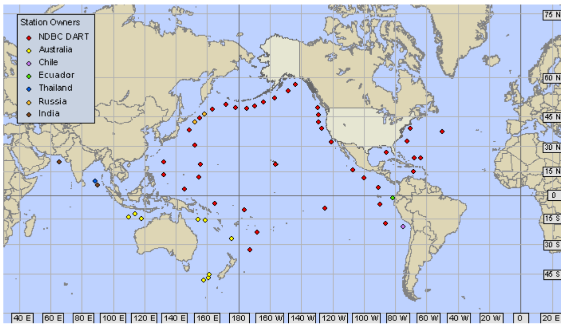

Figure 2-3 DART Buoys (NOAA)

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 2-3). However, buoy failures, vandalism, 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, with the exception of Japan, Taiwan, and the west coast of Canada, there are very few sensors on the seafloor near these earthquake zones.

While all of these technologies have their place, none can offer the reliable, continuous long time series data that can be provided by cabled sensors.

2.4 Submarine Telecommunications Cables.

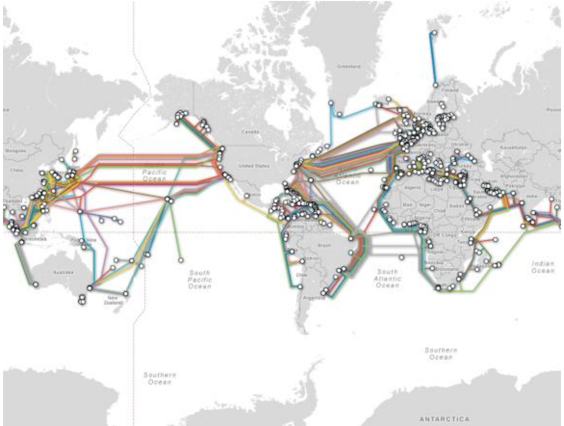

Figure 2-4 Submarine Cables (TeleGeography)

Submarine telecommunications cables represent the only permanent man-made infrastructure in the deep ocean. While the majority of cables are in the northern hemisphere, and they are almost absent from the arctic and southern oceans, they do offer an opportunity to access areas where they are present.

2.5 Summary

Connecting instruments back to shore using subsea cables has been demonstrated to be viable, and to provide a quality of data product that is not available from other sources. However, such instrumentation is currently restricted to small regions of the world's oceans.

While these regional data sets are invaluable, a more diverse set of data points are required both to validate ocean models and to better understand short and long term events in the deep oceans.

3 SCIENCE

3.1 Data Goals

Obtaining long time series data from the deep ocean is crucial if we are to understand planetary processes. However, the exact nature and form of the data are the subject of on-going discussions.

The data types currently proposed as part of this initiative are [2]:

- Temperature
- Pressure
- Acceleration

These sensors could also provide important information for cable owners and operators about the stability of the seabed where nearby earthquake faulting and turbidity flows may affect or damage the cable system.

3.1.1 Temperature

While it may seem that the temperature in the deep ocean will only change relatively slowly, it has been demonstrated that significant data can be obtained by taking measurements frequently and with a high degree of accuracy.

It is proposed to measure temperature every second with sensors accurate to better than one thousandth of a degree Celsius.

The temperature sensor has the most specific location requirements of the sensors, in that it needs to be isolated from any artificial heat source, including the repeater itself.

It is not clear how burial, either by plough or by sedimentation over time, will affect the value of the temperature data. This issue will require further investigation.

3.1.2 Pressure

Temperature and absolute pressure have been measured with great precision and stability for many years, and served as the mainstays for physical oceanography. APGs (***A**bsolute **P**ressure **G**auges*) are also essential for tsunami measurement and are deployed as part of the DART (***D**eep-ocean **A**ssessment and **R**eporting of **T**sunamis*) network of buoys (Figure 2-3). High resolution APGs are also capable of recording earthquakes [12] and determining earthquake locations. As such, APGs contribute to tsunami warning and hazard response.

It is proposed to measure pressure 40 times per second with a resolution of less than 1mm sea water using 24 bit resolution.

The APG is not particularly sensitive to its location, provided it is not subject to large temperature fluctuations. Burial, either by plough or by sedimentation over time, is unlikely to affect the data from the APG.

3.1.3 Acceleration

Broadband seismometers are not proposed, since they do not have long-term stability, they require calibration and re-centring, and they are not considered rugged. However, MEMS (***M**icro **E**lectro **M**echanical **S**ystems*) 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 for recording earthquake strong ground motions. Nano-resolution accelerometers are being deployed subsea on the Japan Trench Cabled Observatory. Augmenting a high resolution APG with an accelerometer provides a simple framework for seismic measurements.

It is proposed to measure acceleration in three orthogonal directions at 200 samples per second with a 24-bit resolution and a full scale level of 2g.

The accelerometer does not appear to be particularly sensitive to its location. Burial, either by plough or by sedimentation over time, may improve the data from the accelerometer by improving the coupling between sensor and seabed.

4 ENGINEERING REQUIREMENTS

These requirements are preliminary. The intention of present activities is to iterate on requirements between system manufacturers, sensor manufacturers and scientists to generate realistic requirements.

4.1 Data Rates

The three proposed sensors can operate passively and autonomously. The data rate is very small. The thermistor will generate less than 60 bps (***B**its **P**er **S**econd*). The APG generates approximately 1 kbps. The 3-component accelerometer sensors generate approximately 15 kbps.

With allowances for overhead and management, these numbers suggest a channel capacity of 20 kbps per repeater. For a 100 repeater system, this capacity could be accommodated in a stream such as a 10Mb/sec Ethernet channel.

4.2 Power

The power requirements of the sensors are low – approximately 350 mW. Total power, including hotel and overhead, will be approximately 5 W per repeater.

4.3 Time Stamping

Data has significantly more value if the absolute time of the measurement is known with certainty. Time allows measurements from different geographic locations to be compared and processed for speed of travel, direction etc.

Ideally, all data would be time stamped with an accuracy of better than 50µsecs. However, delivery of accurate time to the sensors is recognised to be a challenging task, which may drive the choice of data transmission technology. Means for achieving accurate time stamping of data may include IEEE 1588 PTP, accurate time signals sent from shore or stamping data at the shore station with allowances for transmission time differences.

4.4 Maintenance

After the system is installed, there will be no access to the sensors. The ocean observation sensors are secondary in importance and priority to the primary telecommunications traffic on the cable system. Repeaters are not repaired until telecommunications systems performance is affected, and normally require no maintenance during the system life. Therefore, failed sensors will not be repaired except in the unlikely event that the associated repeater has to be repaired.

4.5 Design

Under their contracts with system owners, system manufacturers are responsible for system design. This initiative anticipates that manufacturers will choose to develop a solution so as to allow them to offer support for sensors to potential customers. While details of the solution will differ between manufacturers, it is hoped that each manufacturer will offer support for a similar or identical set of instruments.

The sensors integrated into a telecommunications system must meet the same standards for ruggedness for cable deployment and repair by cable ships as are met by repeaters.

Any changes to the system design must not affect system performance and reliability of telecommunications, nor change methods of cable system assembly, deployment, or repair; i.e., a cable system with integrated sensors can be deployed in the same manner as a cable system without sensors.

5 IDENTIFIED DESIGN OPTIONS

Various design options have been identified. The intent of these design options is to demonstrate the existence of feasible solutions. The actual solutions will be developed by the system manufacturers.

5.1 Physical

In the feasibility study [13], the location considered for the sensors was in the bell end of a repeater housing. However, further discussion has revealed that the sensitivity of the temperature sensor makes this location unsuitable, since the temperature in the bell will be strongly affected by the heat generated by the repeater.

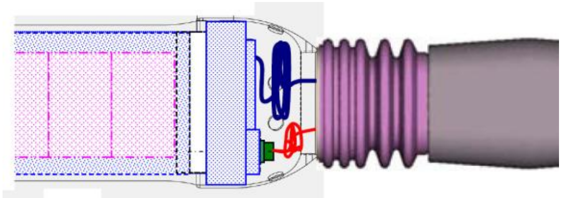

Figure 5-1 Repeater bell showing penetrator for sensor connection below telecom penetrator (TE SubCom)

An alternate location, in a separate protective sheath mounted on the cable a few metres from the repeater, has been proposed [14]. In this scheme the sensors would be attached to the cable, protected by an over-wrap or moulding. The instruments would be powered and provided with a transmission path via a small cable from the repeater which could replace an armour wire on the repeater tail cable.

Figure 5-2 Conceptual deployment of sensors on repeater tail cable (TE SubCom)

5.2 Sensor power

Conceptually, sensor power will be provided by a standard repeater pump power supply mounted in the repeater housing. This solution will require the repeater housing to be longer than would be required for the telecommunications system alone.

The sensor power requirements are small. However, depending on the data transmission system used, the transmission equipment power requirements will increase the power draw.

5.3 Sensor data transmission

The feasibility study [13] proposes that data be transmitted on its own unrepeatered fibre pair in the cable. At each repeater, the optical signal would be regenerated and the local data added.

Typically this fibre pair would use the Ethernet protocol. However, there are other options.

An alternate solution, using discrete bursts of data on an out of band carrier wavelength on the telecommunications fibre, is outlined in the Strategy document [2].

6 LEGAL [15]

While scientific applications of submarine fibre-optic cables rely heavily on telecommunications technology, up to now no in-use submarine telecommunications system supports subsea science sensors. This initiative will require multipurpose telecom-sensor systems that both transport commercial telecommunications traffic and support sensors for scientific observations.

The various international treaties that address submarine cables grant them unique freedoms and restrict the ability of coastal states to regulate them. By contrast, MSR (Marine Scientific Research) is subject to significant national jurisdiction and regulation.

The legal-regulatory regimes relevant to commercial submarine cables and marine data collection are complex, and telecom-sensor cables do not fit easily within these regimes. There is concern that the dual use of submarine cables for telecommunications and marine data collection would threaten the freedoms held by submarine cables. Such concerns are well-founded and should not be ignored, but neither should they be overstated.

There is a wide variety of viewpoints on the desirability of telecom-sensor cables, and if such cables are deployed, the legal-regulatory treatment that is appropriate for them. At one extreme, it is assumed that coastal states will regulate telecom-sensor cables as MSR and use them to try to erode submarine cable rights and freedoms. At the other extreme the complexities are denied, and the ongoing dispute over MSR is ignored. Where any project lies on this continuum will depend on the position taken by the nations in which the system lands.

In the near term, the deployment and operation of telecom-sensor cables is most likely to be restricted to systems that run between receptive nations, where the risks of MSR regulation and erosion of submarine-cable freedoms are least likely to occur. Such nations are likely to consider that the benefits provided by the sensor data outweigh any possible benefits that could ensue from a protracted fight over submarine cable rights and MSR regulations. Indeed, in such nations a telecommunication system that provides sensor data in addition to telecommunications services may be categorised as more beneficial than a conventional telecommunications system.

7 THE INITIATIVE

7.1 Parties

The initiative to use submarine telecommunications cables for ocean and climate monitoring and disaster warning is being led by the ITU (***I**nternational **T**elecommunication **U**nion*) with UNESCO’s (***U**nited **N**ations **E**ducational, **S**cientific and **C**ultural **O**rganisation*) IOC (***I**ntergovernmental **O**ceanographic **C**ommission*), and the WMO (***W**orld **M**eteorological **O**rganization*) [16].

7.2 Current Tasks

7.2.1 Science

The science community is continuing to iterate on the technical requirements specification for sensors. This effort, which will require feedback from the system designers, will culminate in ocean observing system simulations.

7.2.2 Engineering

A draft set of requirements will be produced for the interface between the cable system and the sensors. These draft requirements will then pass through several iterations to make sure they fit the system technology while still meeting the needs of the investigators.

7.2.3 Business Model

Efforts are being made to identify potential stakeholders who may be able to replace existing data sources with data from the sensors on a cable.

As noted in Section 2.3, there are existing funds dedicated to obtaining marine data. In some areas it may be possible to replace existing facilities such as buoys with the sensors on a cable, and reallocate those capital and operating funds to cable sensors.

In addition, there may be sources of funding from a variety of government and non-government sources. These opportunities are being investigated.

8 CONCLUSIONS

8.1 Summary

The international community has identified a need for time series data from multiple locations in the deep ocean. One proposed method to meet this need is to place sensors on telecommunications cables.

An initial review suggests that suitable sensors exist or can be developed, and that there are possible engineering solutions to placing the sensors on cables prior to deployment.

Various legal issues have been identified. However, a cable system between two consenting nations is likely to avoid raising these legal issues.

Some possible sources of funding have been noted. However it is acknowledged that the cost of fitting a cable with sensors will be significant.

8.2 Next Steps

An engineering requirements document must be completed and input from manufacturers sought in order to determine the technical feasibility and limitations of the initiative.

A wet demonstration must be completed to evaluate the data from sensors deployed in this manner.

Further efforts must be made to secure funding for both development and for on-going support.

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