Turning submarine telecommunications cables into a real-time multi-purpose global climate change monitoring network

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***Abstract*— Climate change impacts polar water mass formation and its subsequent sinking and spreading along the ocean floor, thus affecting oceanic storage of greenhouse gases. Currently, there is no low cost way to monitor the polar and other abyssal water masses. Here we propose to use submarine cables by integrating sensors and node functionality into repeaters to form a real-time global climate change monitoring network that also includes tsunami warning capability and provides for multipurpose connections.**

***Keywords-** Submarine cables; Cable repeaters; Climate change monitoring; Global climate monitoring network, Sensors; Node functionality.*

I. INTRODUCTION

Oceans govern climate and climate variability since they store more than 90 per cent of the heat and 50 times as much carbon as the atmosphere in the Earth's climate system. Global warming causes polar ice to melt and sea-level to rise, consequently reducing the ocean's capacity for greenhouse gas storage in the abyssal ocean and further reinforces atmospheric greenhouse warming. The deepest water mass covering the world's ocean floor originates from polar regions such as the Greenland Sea, Labrador Sea, Weddell Sea, Ross Sea and around Antarctica. These polar water masses have the highest densities in the world ocean. The densest water plunges along the polar continental slopes and spreads along the ocean floor to fill up the global ocean bottom waters (Figure 1). While doing so, it carries a large amount of atmospheric greenhouse gasses into the deep ocean with residence times on the order of a millennium.

Temperature and salinity are basic state variables of ocean climate. They govern the density and thus, along with wind and solar forcing, the overall circulation of the world ocean. The polar bottom water is formed at the surface of polar seas through air-sea interaction as warm, salty water is cooled and sinks. This process is being affected by climate change, impacting water temperature and salinity as a function of time and space. Consequently, this would affect the formation of the oceans' bottom water and its volume transport, and thus overall ocean circulation. Under a warming environment, polar water masses can absorb less gas and are less capable of sinking. Consequently, the transport decreases and less atmospheric greenhouse gases are brought into the deep ocean. If the ocean-bottom water temperature, salinity and pressure could be measured on the ocean floor at many locations including "choke points", changes of the planet's climate could be monitored in this crucial part of the Earth climate system. One of the major results from the recent OceanObs09 conference 21-25 September 2009 in Venice, Italy (http://www.oceanobs09.net), was the need for abyssal measurements below 2000 m since the current Argo program can measure temperature and salinity only above 2000 m.

It is generally understood that climate change monitoring requires very long-term observations from decades to centuries. These observations need sustainable technical and financial support. Currently, there is no low cost way to effectively monitor the ocean climate in the long run. Particularly, the high pressure at abyssal depth (~6000 m) and complicated bottom topography cause instrumentation to be extremely difficult and costly. In traditional oceanographic measurements from ships, the sea bottom is intentionally avoided for possible damage of the instruments in case they hit the bottom. Due to its vast extent and volume, the measurement of the layers of polar water mass on and just above the ocean floor is virtually nonexistent. However, submarine telecommunications cables typically with repeaters (optical amplifier) 40-120 kilometers apart, lie on the ocean floor and can fill this gap (Figure 1). They can be used to measure the bottom water flowing by on a continuous, sustained basis for many decades – something that cannot be done by other means. At the same time, electric signals from the cables can yield information about the ocean currents crossing the cables and as well as average temperature. Importantly, the cables and the repeaters can provide power to transmit data from general purpose observatory nodes on the sea floor.

The rest of the paper is organized as follows. From a historical appoint of view, Section 2 emphasizes the importance of turning submarine telecommunications cables into a real-time multipurpose global climate change monitoring network. Such an opportunity was missed and should not be missed again. Section 3 calls for facilitating the usage of retired and in-service submarine cables for ocean climate monitoring. This section also describes the technical feasibility of designing future generation of cables and repeaters, which enable climate measuring sensors to be integrated into repeater housing and to allow for node functionality. The technologies have been developed in

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oil/gas industry and ocean observatory in the last decade and are ready to be implemented into the global climate monitoring network. Perspective of realizing the network is given in Section 4 to meet the demand for real-time global tsunami warning, sea-level rise observation and climate change monitoring.

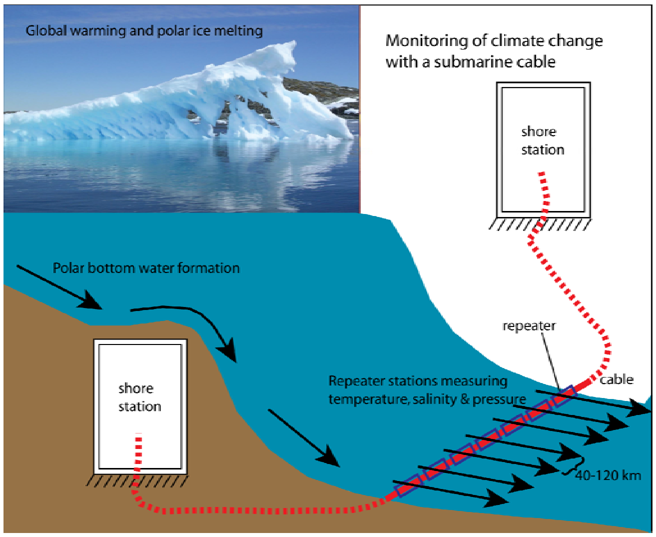

Figure 1. Schematic of polar water formation. It sinks and spreads across the ocean floor, which is affected by global warming and ice melting at its polar source formation region. The change of water properties such as temperature and salinity can be measured with sensors installed in the repeaters (optical amplifiers) of a submarine cable [1] [2].

II. A MAJOR OPPORTUNITY

Since 1850, over a million kilometres of submarine cables have been laid on the ocean floor, covering a significant part of the global oceans [2]. Thousands of repeaters in these cable systems are currently serving only the single purpose of amplifying communication signals (Figure 2). Slight modification of these repeaters – plugging in only one pressure sensor into their housing, for example – could turn the single purpose telecommunication network into multipurpose, real-time global tsunami warning and sea-level rise monitoring network [4] [1]. Such a global network could quickly locate the source of the tsunamis triggered by an earthquake or other factors from most of the ocean floor. The very dense repeater stations – typically about 100 repeaters for a transatlantic cable and 200 repeaters for a transpacific cable – can provide tsunami-wave travel times, amplitudes and speeds for early warning in real time. Such a network can be sustained for decades at low cost. The long-term bottom pressure time series data has also important scientific value for oceanographers to study tides far from land [5].

If more sensors – such as sensors for measuring temperature and salinity – are installed with the repeaters, the telecom cables can be turned into a much-needed real-time global climate change monitoring network. Those repeaters can also be used as nodes for multipurpose connections, using, for instance, inductive power and communications transfer through the repeater pressure case. In the long run, a robust design enables even more channels to measure additional climate data such as ocean currents (using an up-looking acoustic Doppler ocean current profiler), oxygen, greenhouse gasses, seismicity, large-scale temperature using acoustic tomography, geophysical and biochemical properties, and underwater video and acoustics. This very useful resource has been overlooked. This is a major opportunity that should be taken advantage of.

III. PLUG SENSORS INTO NEW GENERATION OF CABLE REPEATERS

At present, only a tiny fraction of the existing cables (about a thousand kilometres or 0.1 per cent) is used for measuring climate change data such as the Florida Current cable that has been used to take daily measures of the volume of water transported by the Florida Current over the past 25 years (derived from the voltage fluctuations measured at the shore station; [4] [2]; [6]). In particular, repeaters have not been modified for this potential of climate monitoring capacity. This is a significant opportunity for telecommunication companies to design the new generation of cable repeaters and to provide additional climate data to stakeholders other than their usual telecoms services. The new repeaters that are integrated with integrated sensors and nodes will enable us to measure the major climate variables of temperature, salinity and pressure and in a cost-effective long-term climate change monitoring network. The designing cost of the new generation of repeaters is estimated at several to ten million US dollars [7]. This non-recurring engineering cost is regarded as modest when amortized over thousands of units for many years to come. Telecom companies can make additional profit by serving the additional stakeholders (e.g., government science agencies) and the broad community with very much needed climate data and relevant products.

Modern technologies enable the new type of repeaters to be assembled into one cable body but two operation systems, one for telecommunication and one for other purposes such as oil/gas, local ocean observatory and science in general, without interfering with each other. The dual-conductor cable and four-cable branch unit recently developed by Tyco Electronics Subsea Communications [8] and the Modular Connecterized Distribution Unit by Ocean Design Incorporation (Flynn, personal communication, 2010) enable independent power and fibre connectivity in a layered network allowing three power path and nodes for multiple connections. The currently used repeaters have space to install the temperature, salinity and pressure sensors (Figure 3). The measured signals can be transmitted to shore via the dual-conductor cable with two coloured fibres, one for telecommunication and one for scientific data. As a result, the chain of repeaters in a cable can be turned into a densely sampled mooring-like time-series with instant data availability spanning seconds to several decades. Using just a fraction of the new cable systems being constantly installed would provide thousands of time series stations to form a truly real-time global network. Such a network will effectively monitor global climate change including long-term sea-level rise as well as short term tsunami detection and warning at low cost.

To make the network more useful, future technical development should consider inductive (transformer) transferring of power and communication through a pressure case without connectors. Even power of a watt and communications rate of bits per second is useful. With the inductive capability of power and communication, horizontal electric field (HEF) pressure –inverted echo sound (HPIES) can be placed next to the repeater using a remotely operated vehicle (ROV). A repeater can support an acoustic modem for communications (acomms) [4]. This allows instruments to be placed a farther distance away from the repeater with a large battery.

At present, many of the available technologies are first developed in the oil/gas industry a beneficial situation towards achieving the global climate change monitoring network. As more and more of these technologies are moving to fully instrumented and widely distributed fields for production such as command, control, power and communication as well as 4-D tomographic monitoring of the fields, they, if extensively qualified, can then be migrated to telecommunications.

IV PERSPECTIVE

The recent great earthquakes and resulting tsunamis (Sumatra 2004, Chile 2010, Japan 2011) show yet again how vulnerable our civilization can be to natural disasters. As part of the global effort to build a tsunami warning system, USA has deployed a total 39 Deep-ocean Assessment and Reporting of Tsunamis (DART) tsunami stations (or buoys) in the Pacific and Atlantic Oceans and Caribbean Sea by 2008 (Figure 2). More buoys have been planned in other parts of the world oceans. At the same time, many other coastal countries have deployed or planned to deploy their tsunami buoys as well. The cost for purchasing a DART buoy is typically about US$250,000, and maintaining cost for a buoy is about US$125,000/year excluding ship-time; the latter typically costs much more than the buoy itself [9]. Tsunami buoys are usually deployed as close to potential source locations (e.g., along the entire “rim of fire” in the Pacific) as possible for achieving longer lead and evacuation time. But there are still many gaps, for instance, the current system has not covered the mid-ocean ridges and vast open ocean area which are far from land and would be more costly to maintain with ships. On 11 March 2011 Japanese tsunami crossed the open Pacific and caused damage and casualty in west coast of America. Due to lack of buoys in vast open Pacific, insufficient information is provided to public on tsunami travel time, speed and amplitude.

The principal of the DART (or other types) buoys, for example, developed by US National Oceanic and Atmospheric Administration (NOAA), is the ocean bottom pressure sensor which can record tsunami wave amplitude of less than 1 cm in open ocean. As depicted above, if the pressure sensors are integrated into submarine cable repeaters, harnessing telecoms cable repeaters can form a global real-time tsunami warning network with less cost than the present system. That is because the cabled measurements can save the maintenance/ship costs. Further, tsunami buoy life times are limited to a maximum of 4 years because they are powered by batteries. In contrast, cable systems can power the sensors for decades. The harsh sea-surface environment, possible device failure and potential vandalism reduce the tsunami buoys’ effective availability. Cables lie on the ocean floor avoiding the harsh sea surface condition. The designed operation time for DART buoys is typically 80 per cent but actual available up-time is less than 70% [10]. A cabled tsunami warning network is more reliable in terms of its better global ocean coverage and highly dense sensors.

Because warming water expands, sea-level rise is an integrating measure of global ocean heat content, and global warming. Current sea-level observations rely on tide gauges and satellites. Tide gauge records are affected by land rising and sinking, showing considerable variations in the long term. The estimated sea level rise measured with satellite altimetry is greater than with tide gauges. It is still unclear how much the precision of the satellite measurement is affected by orbital decay and the difference between assumed orbit and the Earth geoid. Cabled measurements of sea-bottom pressures are expected to provide more reliable and accurate sea-level data as they measure the whole water column pressure change and better cover the ocean-basins with less effects of vertical ground movement for decades.

With regard to polar climate change condition, the polar region has been warming stronger than global average. In 2007, the summer minimum sea ice in the Arctic was an unprecedented 40 per cent below the minimum sea ice content of the 1980s. Autumn temperatures were 6°C higher than the 1958-98 mean. The Greenland ice sheet has been melting with a 16 per cent increase from 1979-2002. In Antarctica, a significant temperature anomaly of more than +2°C has been found in the Antarctic Peninsula. In responding to the warming, a collapse of the Antarctic ice shelf and drifting of icebergs away from Antarctica are frequently reported in recent years. The polar region’s augmented warming may have already impacted the polar water-mass formation, transport and greenhouse gas carriage. Details are unknown as no effective monitoring is being performed. With the aforementioned temperature, salinity and pressure sensors, submarine cables and repeaters can effectively contribute to the monitoring of polar and global climate change at a low cost. Since the demand for internet usage continues to grow exponentially, telecom cables will only expand. With little additional cost, a new generation of cable repeaters can meet the requirement of very much needed climate change monitoring system. For example, in January 2010, Kodiak Kenai Cable Co. announced plans for a fibre optic cable on the Arctic Ocean seabed to connect Europe and Asia [7]. Australian Telstra also announced recently it would lay a new cable from Sydney to Oakland and then to Los Angeles using more than 500 repeaters with 40 km spacing. These cables and repeaters are still going to serve only a single purpose, i.e., to amplify the communication signal. Telecommunication companies and scientists are urged to work together to realize the much-needed global climate change monitoring network in future cable systems.

These business opportunities for telecommunication companies are obvious and should not be missed. The current services in tsunami warning and sea-level monitoring are mainly financed by governments. In the future model of invest-outcome/invest-profit for efficiently using tax-payer money, governments should work with and persuade and encourage telecom companies to incorporate the new technologies as part of in the overall emission and mitigation strategy. By encouraging technical standardization, the United Nation (UN) agent, International Telecommunication Union (ITU), as well as non-governmental organizations (NGOs) can facilitate the implementation of the capability. To determine the next step, a workshop has been organized to be held in Rome on 5-9 September 2011 including scientists, engineers, governments and legal experts, in cooperation with relevant organizations and UN agencies. The workshop aims to facilitate the use of retired and in-service submarine cables and encourage the development of new technologies and standards for layered systems and of ocean observing subsystems at each repeater.

At the UN Copenhagen Climate Conference in December 2009, all nations unanimously agreed to curb global warming not to exceed 2 °C. Since human-induced global greenhouse warming will soon cross the 1 °C mark and approach 2 °C [11], the next decades will be crucial for monitoring climate change. As the ocean is one of the most important factors in governing the worldwide warming process and climate variability, they must be closely observed. Without other effective means for long-term climatic measurements, harnessing telecom cables for ocean observation is expected to play a major role in monitoring global climate change for the next decades.

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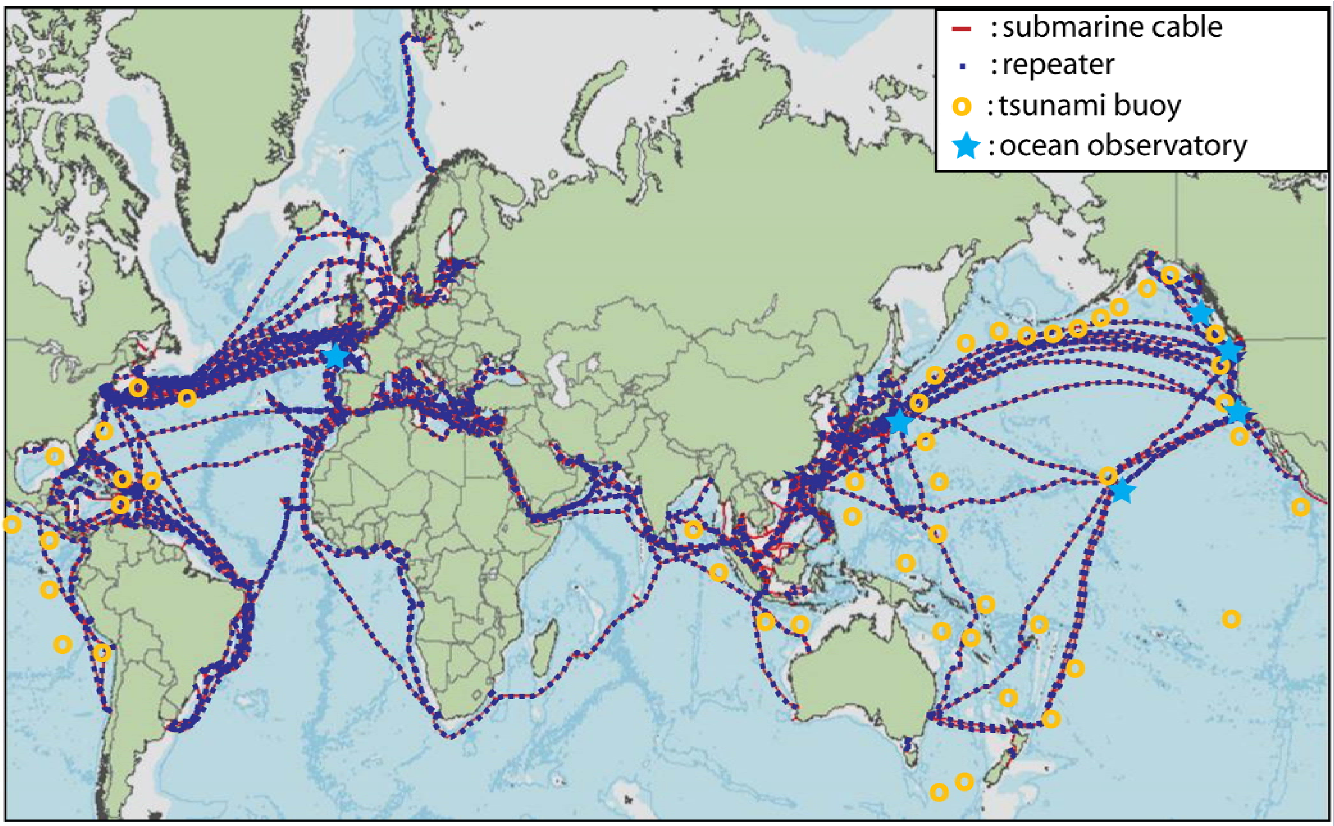

Figure 2. Submarine cables repeaters (blue dots) are symbolically plotted overlapping the cables (in red). The actual number of repeaters is about 4 times more than that plotted with a distance of about 40-150 km apart. For example, a typical transpacific cable would contain about 200 repeaters. Other plotted symbols are tsunami buoys (open circles in orange) and ocean observatories (stars in light blue). The source of background cable distribution is from the cable map of Global Marine Systems Ltd.

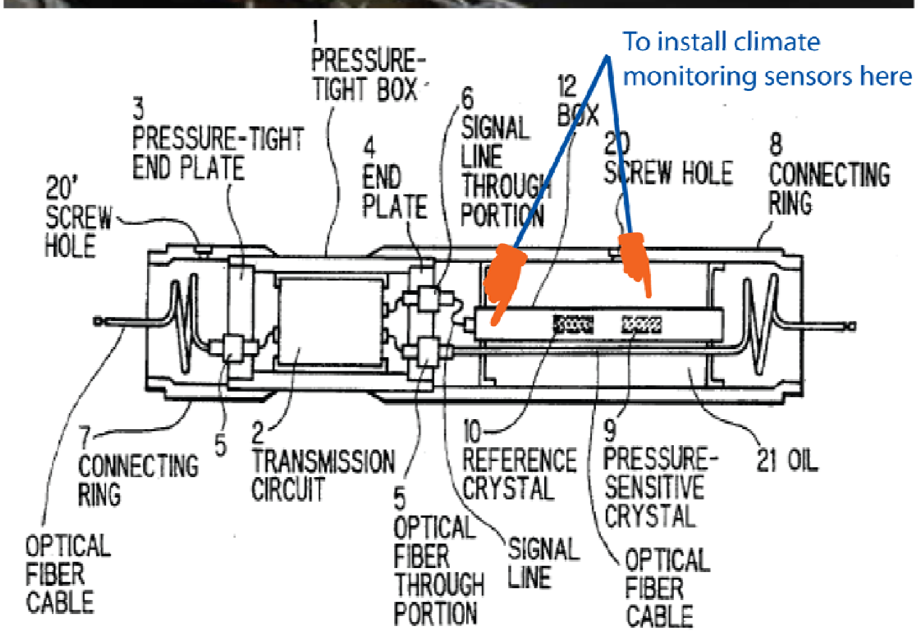
1 PRESSURE-TIGHT BOX
To install climate monitoring sensors here
12 BOX
3 PRESSURE-TIGHT END PLATE
4 END PLATE
6 SIGNAL LINE THROUGH PORTION
20 SCREW HOLE
8 CONNECTING RING
20' SCREW HOLE
7 CONNECTING RING
5
2 TRANSMISSION CIRCUIT
5 OPTICAL FIBER THROUGH PORTION
10 REFERENCE CRYSTAL
SIGNAL LINE
9 PRESSURE-SENSITIVE CRYSTAL
OPTICAL FIBER CABLE
21 OIL
OPTICAL FIBER CABLE

Figure 3. Cable and repeaters are being laid down in the ocean (upper panel), a view of open Alcatel-Lucent repeater (middle panel) and the diagram of a submarine cable repeater (lower panel). Climate monitoring sensors could be integrated into the equipment and the measured signals transmitted back to a shore station via the repeater's transmission device.

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