Using Submarine Communications Networks to Monitor the Climate

ITU-T Technology Watch Report

November 2010

This ITU-T Technology Watch Report gives an overview of how old and new submarine cables could be used for decades to come as a major resource and a real-time global network to monitor climate change and to provide tsunami warnings. Future generations of cables and associated components could have the capacity to directly measure climate variables, such as water temperature, salinity and pressure on the ocean floor. All this could be achieved over long periods of time at low cost. By encouraging technical standardization, ITU can facilitate implementation of this capacity.

The rapid change of the telecommunication/information and communication technologies (ICT) environment requires related technology foresight and immediate action in order to propose possible ITU-T standardization activities as early as possible.

ITU-T Technology Watch surveys the ICT landscape to capture new topics for standardization activities. Technology Watch Reports assess new technologies with regard to existing standards inside and outside ITU-T and their likely impact on future standardization.

Acknowledgements

This report was prepared by Yuzhu You of the Institute of Marine Science, University of Sydney, Australia.

The author very much appreciates comments from Bruce Howe and Rhett Butler on earlier versions. He thanks Bruce Howe for pointing him to the Kordahi paper about the dual-conductor cable in *Sea Technology* magazine. The author is also grateful for the support given to him by staff from the ITU, as well as for comments by Giancarlo de Marchis.

Please send your feedback and comments to tsbtechwatch@itu.int.

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Using Submarine Communications Networks to Monitor the Climate

I. Introduction

Temperature and salinity are basic elements of the ocean. They govern the density of water and thus, along with wind and solar forces, the overall circulation of the world's oceans. If the water temperature, salinity and pressure could be measured on the ocean floor at many locations, including "choke points", changes in the planet's climate could be monitored in this crucial part of the Earth's climate system.

The polar ice sheet is shrinking and summer sea ice is likely to disappear in the foreseeable future, due to rises in temperature brought about by increases in greenhouse gases (GHG) (IPCC, AR4, 2007). Global warming causes the polar ice to melt, consequently reducing the ocean's capacity to store GHG in deep waters, because there is less solubility at higher temperatures. This further reinforces atmospheric warming.

The deepest water mass covering the ocean floor is formed in the polar region as warm, salty water is cooled and sinks. This will likely be affected by climate change, affecting water temperature and salinity, and, in turn, the formation of the overall volume and circulation of deep oceanic waters. Figure 1 is a diagram of the polar water-mass formation under a changing climate. The densest water plunges along polar continental slopes, such as in the Arctic and Antarctica, and spreads along the ocean floor globally. Since these deepest waters are formed at the surface of the polar seas through interaction with the air, changes in water temperature and salinity due to ice-melting and atmospheric GHG are transmitted from the ocean surface to the bottom, and eventually back to the surface as part of the "ocean conveyor belt".

Oceanographers have a wide range of tools at their disposal to monitor the ocean, all with attendant advantages and disadvantages. Satellites can only monitor surface quantities, such as sea surface height, wind stress and temperature. Research vessels can obtain detailed measurements of water temperature and composition at depth, but only from a tiny portion of the sea and rarely on a regular schedule. There is an array of 3,000 free-drifting profiling floats called 'Argo' that measure the temperature and salinity of the ocean. But these buoys cannot go below 2,000 metres in deep seas, and are not used in seas shallower than 2,000 metres as they tend to hit the bottom[1].

At present, oceanographers cannot measure waters at the ocean floor due to their vast extent and volume. Particularly, the high pressure at abyssal depths (~6,000 m) and complicated bottom topography cause finding appropriate instrumentation to be extremely difficult. In ocean ship cruise surveys and autonomous float measurements, the sea bottom is intentionally avoided, due to possible damage of the instruments. Therefore, measurement of polar-formed waters at the ocean floor is virtually nonexistent. However, submarine telecommunication cables lie on the sea floor and could fill this gap. They can be used to measure on a continuous basis the bottom water they run through – something that cannot be done by other means. At the same time, electric signals from the cables can yield information about the ocean currents they run through, as electromagnetic signals and cable resistance vary when ocean currents and temperature change. Cables can also be used to provide power to, and transmit data from, observatories on the sea floor, as exemplified by the recently installed NEPTUNE Canada and Japanese DONET systems[2].

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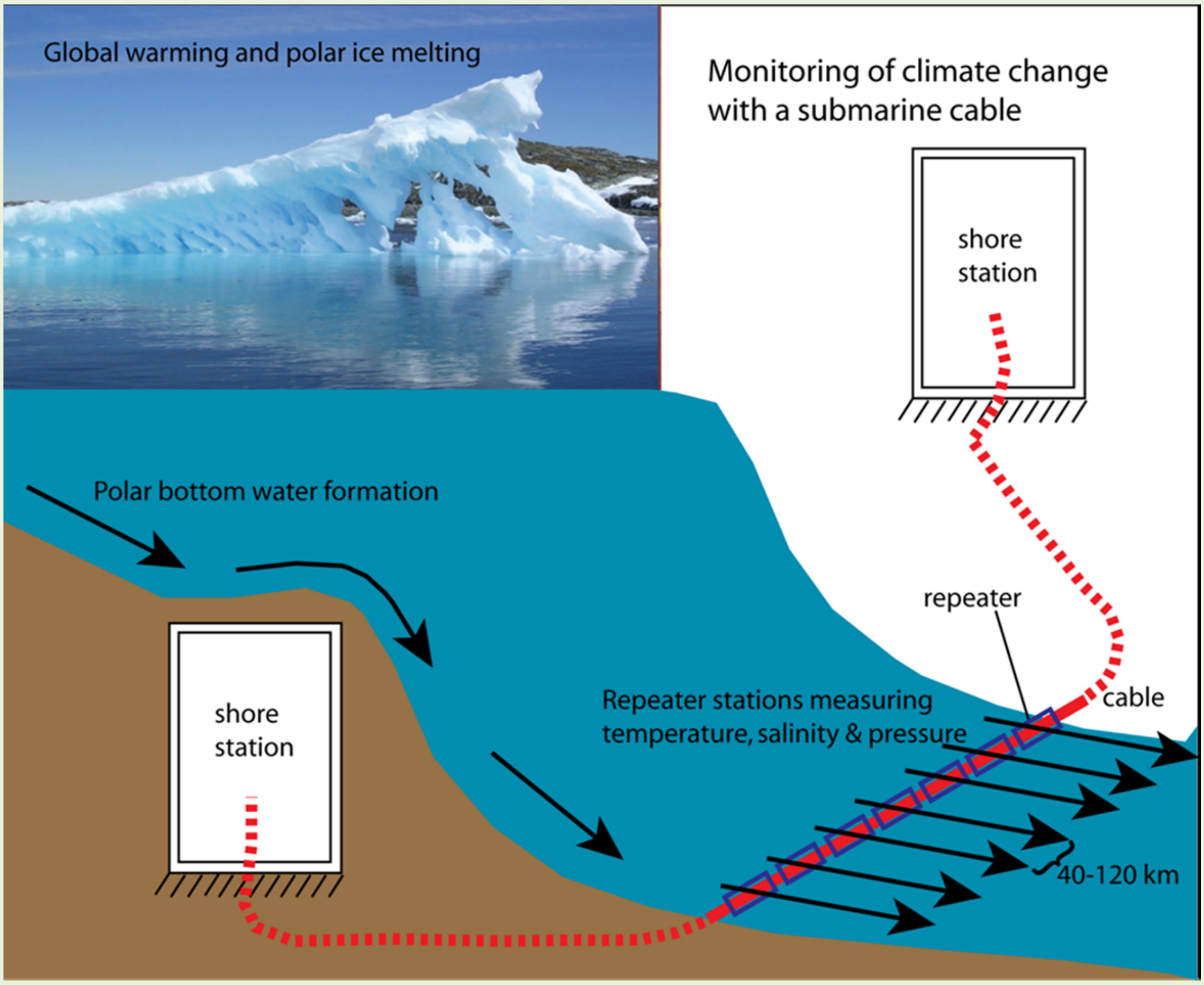
1 See Yuzhu You, Nature, 5 August 2010, 2010a

2 See http://www.neptunecanada.ca and Kawaguchi et al, 2008

Figure 1: Polar water formation



Cold water sinks and spreads across the ocean floor, affected by global warming and the consequent melting of ice. The change in water properties, such as temperature and salinity, can be measured with sensors installed in the repeaters (optical amplifiers) of a submarine cable.

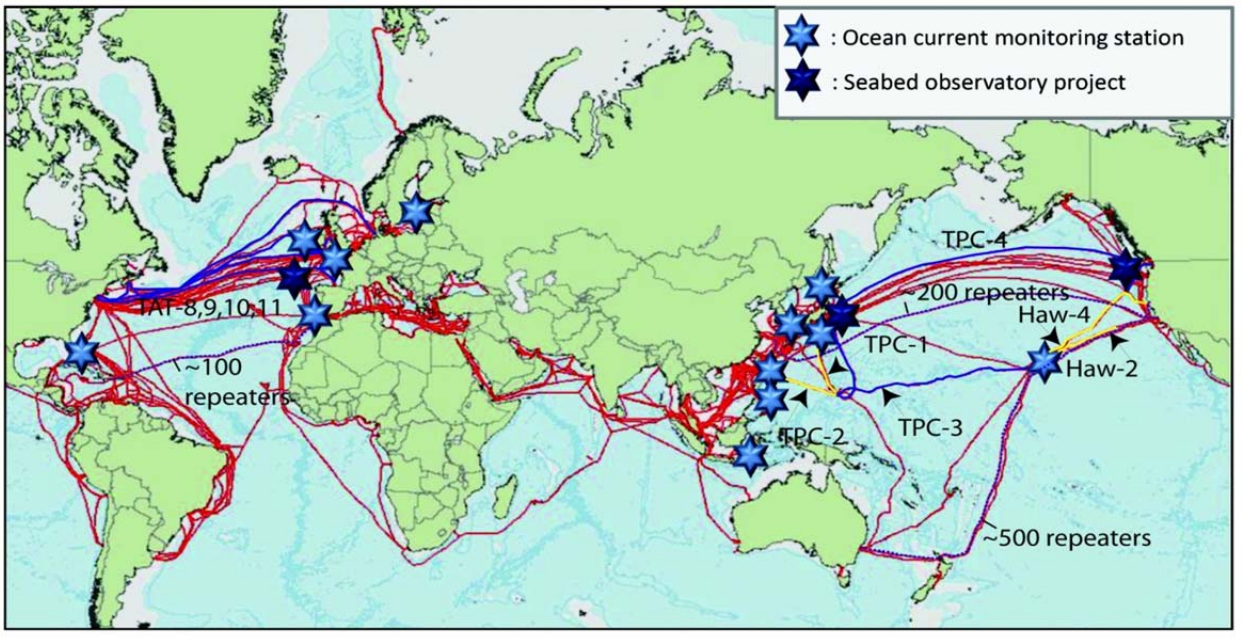
II. Harnessing retired and in-service telecommunication cables for science

Since the first submarine communication cable was laid across the English Channel in 1850, more than a million km of telecommunication cables have been laid on the ocean floor, covering a significant part of the globe[3]. Yet only a tiny fraction of the existing cables is put to scientific use (Figure 2). Telecommunication companies and oceanographers are urged to work together to use existing and new submarine cables in scientific projects to build a global network to monitor climate change[4]. The existing cables include both those that are retired and those still in service.

3 Carter et al., 2009

4 You, ibid

Figure 2: Global submarine cable network



Map of the global submarine cable (red lines), recent and planned cable ocean-current monitoring programmes (blue stars)[5] sea-bed observatories (dark blue stars), out-of-service cables for scientific reuse (yellow lines)[6] and cable systems where ownership transfer to science has been discussed (dark blue lines)[7]. There are three cables which are overlapped with dots that mark the dense repeaters at distances of about 50-150 km apart: one across the tropical Atlantic from Spain to the Caribbean (using about 100 repeaters), one across the subtropical North Pacific from Los Angles to Hong Kong (using about 200 repeaters) and another from Sydney to Auckland and then to Los Angeles (using about 500 repeaters). The map is modified from the cable distribution map of Global Marine Systems Ltd.

The older retired cables are mainly coaxial. In addition, a huge quantity of first-generation fibre-optic cable has been retired long before the end of its useful lifespan, thanks to rapid advances in cable technology. Only a very small fraction of these cables have been used for scientific projects. This is a missed opportunity.

Both retired and in-service cables can generally be turned into generators of ocean-current data sets by connecting a simple volt meter and a computer to the cable's landing station on the shore. An electromagnetic current is induced in a cable by the motion through the Earth's magnetic field of ocean currents, tides and tsunami. These voltage measurements can be made on a normally operating cable system. Thus, submarine cables have been used to measure ocean currents around the world (Figure 2). In particular, a cable has been used to take daily measurements of the volume of water transported by the Florida Current over the past 25 years, creating one of the longest available time series of data on ocean water transport. This cable-generated information provides one of the essential data sets to calculate the North Atlantic meridional overturning circulation – a major driver of global deep ocean circulation, and a phenomenon of importance to climate researchers.

There are several methods to measure the ocean floor temperature using a cable. By measuring the resistance of the copper wire (which is often done to monitor cable isolation and rupture), one can calculate

5 You et al., 2009; You et al., 2010

6 Butler, 2003

7 Butler, ibid

the average temperature along the submarine cable using a method based on the temperature coefficient of the wire[8]. Other ideas include daily estimation of temperature by the use of a crystal to determine frequency measurements in repeaters, and using the fibres in the cable to measure the optical round-trip travel time for a transoceanic cable[9]. The techniques used to estimate ocean bottom temperature at repeater sites from cable signals have a low noise-to-signal ratio, but this could be improved by developing better technologies and methodologies. Not enough attention has yet been paid to the capacity for cable temperature monitoring, which could provide critical information for climate change studies.

Retired cables could also be moved to scientifically important locations such as the Southern Ocean, where existing cables are sparse. Relocation costs are estimated to be roughly half the cost of a new system, i.e., about USD 20,000 per km, compared to USD 50,000 per km for a new cable.

The donation and transfer of ownership of cables for scientific purposes implies some legal and practical difficulties might need to be overcome, especially for transoceanic cables with multinational ownership. There are no standard procedures for transferring the liability from companies to academic institutions.

To form a global network, the first step should be to evaluate the scientific potential of all in-service and out-of-service telecommunication cables. ITU could very usefully coordinate activities including administrators, scientists, engineers and legal experts, in cooperation with relevant organizations and UN agencies.

At present, cables have limitations for scientific usage: they can mainly be used at their landing stations where measuring instruments are connected to them. In particular, the repeaters – typically installed 50 to 150 km apart to amplify the telecommunications signal in a powered telecoms cable – have not yet been modified to their full potential for climate monitoring. This is a significant opportunity for the telecommunications industry to redesign a new generation of cable repeaters to provide climate data to new stakeholders, in addition to providing their normal telecommunication services. The new repeaters could have built-in sensors to measure climate variables such as temperature, which would become a cost-effective long-term climate change monitoring network (Figure 1).

The redesigning cost of the new type of repeater is estimated roughly at several million US dollars[10]. This is a one-time only cost for certain types of repeaters, and might not be regarded as too expensive, as thousands of this new type of repeater would be manufactured afterwards for many years to come.

Furthermore, new types of repeaters can probably be sold at higher prices than the present types. Telecommunication companies could make additional profits and retrieve the necessary investment while serving the broad community with very much-needed climate data and relevant products. Since demand for Internet continues to grow exponentially, the number of telecommunication cables deployed in the oceans will only increase, and the new generation of cable repeaters would be able to deliver vital climate change monitoring data.

The repeaters used currently have space to integrate the temperature, salinity and pressure sensors inside the box or repeater housing, through holes for measuring environmental temperature (with thermistors), salinity (with sensors to measure sea water conductivity) and pressure (with pressure sensors), as shown in Figure 3. These sensors are currently being used in oceanographic instruments such as Conductivity-Temperature-Depth (CTD) and mooring equipment near or at the ocean bottom. The measured signals can be converted and then transmitted to the shore stations by dedicated fibres and lines.

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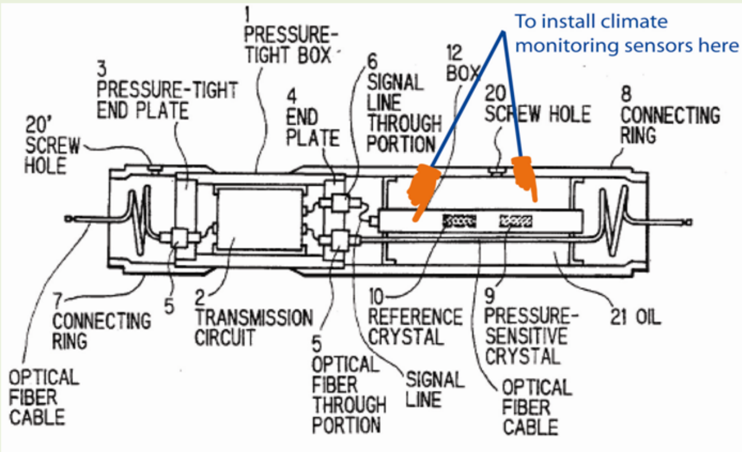
8 Sanford, personal communication to the author, 2010

9 Howe, personal communication to the author, 2010

10 Harasawa, personal communication to the author, 2010

Figure 3: Submarine repeaters monitoring climate change



Top left: Fujitsu Flashwave S100 Submarine Repeater being laid in the ocean.

Top right: A view of an open Alcatel-Lucent repeater (throughput of approximately 1 terabit/second).

Left: Diagram of a submarine cable repeater. 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.

Depending on technical feasibility, an initial model might be designed for measuring basic climate parameters such as temperature, salinity and pressure. With temperature and salinity measurements, climate-change-related warming and freshening of water as a result of atmospheric warming and ice melting can be monitored. With pressure measurements, ocean tides, tsunami and global-warming-induced sea-level rises can effectively be observed worldwide about once every minute and at a low cost.

In the long run, repeaters could even be altered to provide general purpose nodes that provide power, communication and time signals[11]. Scientific instruments could be plugged in – either directly or indirectly, by using acoustic modems and/or inductive power/communications transfer. Thus, a repeater would be turned into an observatory itself, not only for measuring temperature, salinity and pressure to cover present needs, but providing a future channel to measure additional climate data such as on ocean currents (using an up-looking acoustic Doppler ocean current profiler), oxygen or GHG levels, seismicity, large-scale temperature variations using acoustic tomography, geophysical and biochemical properties, and even underwater video and acoustics. This requires engineers to consider a robust and reliable design to provide flexibility as well as stability for fundamental infrastructure for transmitting telecommunication data.

To provide power and fibre connectivity in a layered network, independent of normal telecommunication data transmission, Tyco Electronics Subsea Communications has recently developed two new products: a

[11] You, ibid

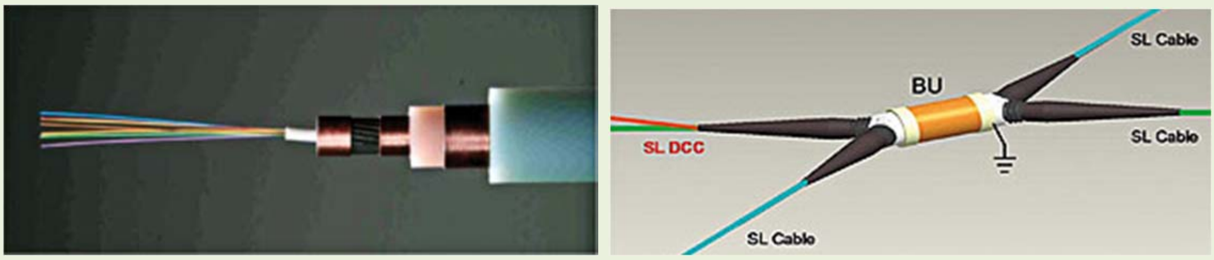
dual-conductor cable (DCC) and a four-cable branching unit (BU) capable of handling a third power path[12] (see Figure 4). The DCC maintains the classic feature of a main conductor in the centre with the second conductor concentric around it insulated by polyethylene between them, much like the earlier shielded analog coax cables. This cable structure is compatible with all available cable armouring configurations and deployment techniques to ensure it can be used anywhere that a traditional single conductor cable may be used. The BU uses special joints capable of connecting two conductors while maintaining power isolation between conductors and the sea ground.

The joints also provide mechanical strength and fibre connectivity. In addition, Ocean Design Inc. (ODI) has recently built a Modular Connectorized Distribution Unit (MCDU) that is a pressure balanced distribution hub that plays "host" for multiple wet mate interface opportunities for "guest" elements[13]. ODI has designed a series of cable terminations to link the telecommunication cable (retired or in-service) to the MCDU and the wet mate interfaces are used to connect other assets, such as science experiments, using a remotely operated vehicle. The MCDU can provide the power and data network interface and is expandable.

These new techniques enable not only the climate monitoring sensors to be integrated into the repeater housing and operated independently from telecommunication structures, but also allow additional capacity for observing other data on the ocean.

Since a typical cable across the Pacific Ocean contains over 200 repeaters 50 to 150 km apart, they could be turned into highly dense mooring-like time-series stations, with real-time data streams back to a shore station. With the world oceans traversed by many cables equipped with such nodes, a truly global ocean climate observing network can be realized. The ITU-T Study Group 15 "Optical transport networks and access network infrastructure" (see Annex 1) can play a role in transforming the present cables and repeaters into the next generation.

Figure 4: Submarine dual-conductor cable and branch



Dual-conductor cable featuring two separated conductors, one surrounding the other (left) and a four-cable branch unit with two functionally independent cables (right).

Source: Sea Technology Magazine: "New Tools for Multilayered Undersea Telecommunication Networks," available at http://sea-technology.com/features/2010/0710/undersea_telecom_networks.html. Permission to reproduce information granted by Compass Publications, Inc.

12 Kordahi, 2010

13 Flynn, personal communication to the author, 2010

III. Cost-effective tsunami warning systems

The principle device of the Deep-ocean Assessment and Reporting of Tsunami (DART) buoy system developed by US National Oceanic and Atmospheric Administration (NOAA) is an ocean bottom pressure sensor which can record a wave amplitude of less than 1 cm in the open ocean. The cost for purchasing a DART buoy is about USD 250,000 and maintenance costs for a buoy are at about USD 125,000 a year, excluding ship-time, which could be several times more than the buoy itself. By 2008, the United States alone had deployed a 39 tsunami stations/buoys in the Pacific, not to mention many other nations that have installed, or intend to install, tsunami buoys for their warning systems.

Assuming that about 200 tsunami warning buoys are to be installed worldwide, the total cost for purchasing would be about half a billion US dollars and the maintenance cost would be about a quarter of a billion dollars per year. Including ship-time, the total cost could come to more than one billion US dollars each year. Tsunami buoys are usually deployed as far away as possible from the coast, in order to give longer warning and evacuation times. But the more distant the buoy, the higher the costs. In contrast, using cable repeaters with installed pressure sensors has obvious advantages. They can form not only a truly global real-time tsunami warning network, but also cost far less than the present tsunami warning system. That is because both maintenance cost and expensive ship-time would be reduced. Yet, conventional tsunami buoys only have a limited lifetime (about four years) as they are powered by batteries. In contrast, cables/repeaters are powered from the shore, supplying the sensors for decades. This clearly indicates a major business opportunity for telecommunication companies.

IV. Conclusion

So far, telecommunication companies have been generous in allowing the scientific community access to their cables and shore stations – and this is much appreciated. The role played by the telecommunications industry has hitherto been somewhat passive. But there are business opportunities for companies to become active players in their contribution to monitoring climate change. The next few decades will be crucial for monitoring climate change. As the oceans are one of the most important factors in governing worldwide warming processes and climate variability, they must be closely observed. Without other effective means for long-term measurements, harnessing telecommunication cables for observing the oceans is expected to play a major role in monitoring global climate change.

The oceans' influence on the Earth's climate is of utmost importance but little understood. The abyssal oceans, in particular, are the planet's last largely unexplored frontiers. A large network of undersea telecommunication cables – currently there are more than one million km of cables spanning the seafloor – and associated repeaters could turn into a formidable resource to measure essential data to monitor and better understand climate change.

The new generation of cables with a layered system will no longer need to have scientific instruments connected to the landing station, as they allow direct measurements with repeaters at the ocean floor and transmit data back to shore. They will also provide multiple connections for other instruments on the ocean floor.

A big step forward, however, would be the creation of a new generation of repeaters – typically installed 50 to 150 km apart to amplify the telecommunications signal in a powered telecoms cable – that yet have been modified to allow climate monitoring at ocean deeps.

ITU-T Study Groups 15 (Annex 1) and 5 (Annex 2) are invited to examine this topic. It is also suggested that a workshop including scientists, engineers, governments and legal experts, in cooperation with relevant organizations and UN agencies, be organized to determine the next steps. The workshop would aim to facilitate the use of retired submarine cables, including arrangements between scientists, business, and governments, and the technology to insert “nodes” in existing systems. Also, such a workshop would encourage the development of new technologies and standards for layered systems and the development of ocean observing subsystems at each repeater/optical amplifier, in order to obtain high spatial sampling resolution along the cable path.

Glossary of acronyms

BU	Branching Unit
CTD	Conductivity-Temperature-Depth
DART	Deep-ocean Assessment and Reporting of Tsunami buoy system
DCC	Dual-Conductor Cable
GHG	Greenhouse Gas
ICT	Information and Communication Technologies
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
MCDU	Modular Connectorized Distribution Unit
NOAA	US National Oceanic and Atmospheric Administration
UN	United Nations

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ANNEX 1: ITU-T Study Group 15 – Optical transport networks and access network infrastructure

ITU-T has been active in the standardization of optical communications technology and the techniques for its optimal application within networks from the infancy of this industry.

ITU-T Study Group 15 is the home of access standards such as DSL-technologies (ADSL 2+ and VDSL2) and optical access, as well as backbone technologies. ITU-T Study Group 15 standards include passive optical networks (PONs). PONs are an effective way of implementing fibre-to-the home/building etc., and a crucial step towards all-optical networks. SG 15 has also played a leading role in the development of standards for backbone networks, including synchronous digital hierarchy (SDH), the key standard for synchronous data transmission over fibre-optic networks. Wave division multiplexing (WDM) technology is another example of a technology in which ITU-T standards have played a very important role. SG 15 is also working on automatically switched optical networks (ASON), which provide quick and reliable service activation to platforms such as switches and routers.

In 2009, ITU-T SG 15 published the handbook "Optical fibres, cables and systems" (http://www.itu.int/publ/T-HDB-OUT.10-2009-1/en).

One of the current 18 study areas ("Questions") of ITU-T Study Group 15 is **Question 8**, "Characteristics of optical fibre submarine cable systems." This Question covers:

- Specifications of terminal equipment and optical fibre submarine cables in optical fibre repeatered submarine cable systems with various optical amplifiers, such as Erbium Doped Fibre Amplifiers (EDFAs) and Raman amplifiers;
- Specifications of terminal equipment and optical fibre submarine cables in optical fibre repeaterless submarine cable systems, including systems with remotely pumped optical amplifiers;
- Specifications of test methods concerning terminal equipment, optical fibre submarine cables and other equipment relevant to submarine cable systems;
- Specifications of forward error correction (FEC) for optical fibre submarine cable systems.

ANNEX 2: ITU-T Study Group 5 – Environment and climate change

ITU-T Study Group "Environment and Climate Change" is also ITU-T's lead study group on ICT and climate change. The following five of its 21 study areas ("Questions") deal with that topic:

- **Question 17:** Coordination and planning of ICT and climate-change-related standardization
- **Question 18:** Methodology of environmental impact assessment of ICT. This Question develops concrete and common methodologies, including a unified metric, to describe and estimate objectively and transparently present and future energy consumption of ICT over their entire life cycles. The methodology for assessing the environmental impact of ICT is based upon the life cycle assessment (LCA), which was standardized in the ISO 14040 series, and is used to evaluate the eco-efficiency of individuals, businesses, and communities.
- **Question 19:** Power feeding systems. This Question mainly focuses on the energy efficiency of the power feeding systems that are used in telecommunication networks or buildings.
- **Question 20:** Data collection for energy efficiency for ICT over their lifecycle. This Question focuses on establishing metrics for collecting data on energy efficiency for ICT over the entire lifecycle of equipment, and collecting that data.
- **Question 21:** Environmental protection and recycling of ICT equipment and facilities.

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Printed in Switzerland
Geneva, 2011