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Submarine Cable Protection and the Environment

An Update from the ICPC, Written by Marine Environmental Adviser, Dr Mike Clare

SUBMARINE CABLE PROTECTION AND THE ENVIRONMENT

An Update from the ICPC, Written by the Marine Environmental Adviser (MEA)

PUBLISHER

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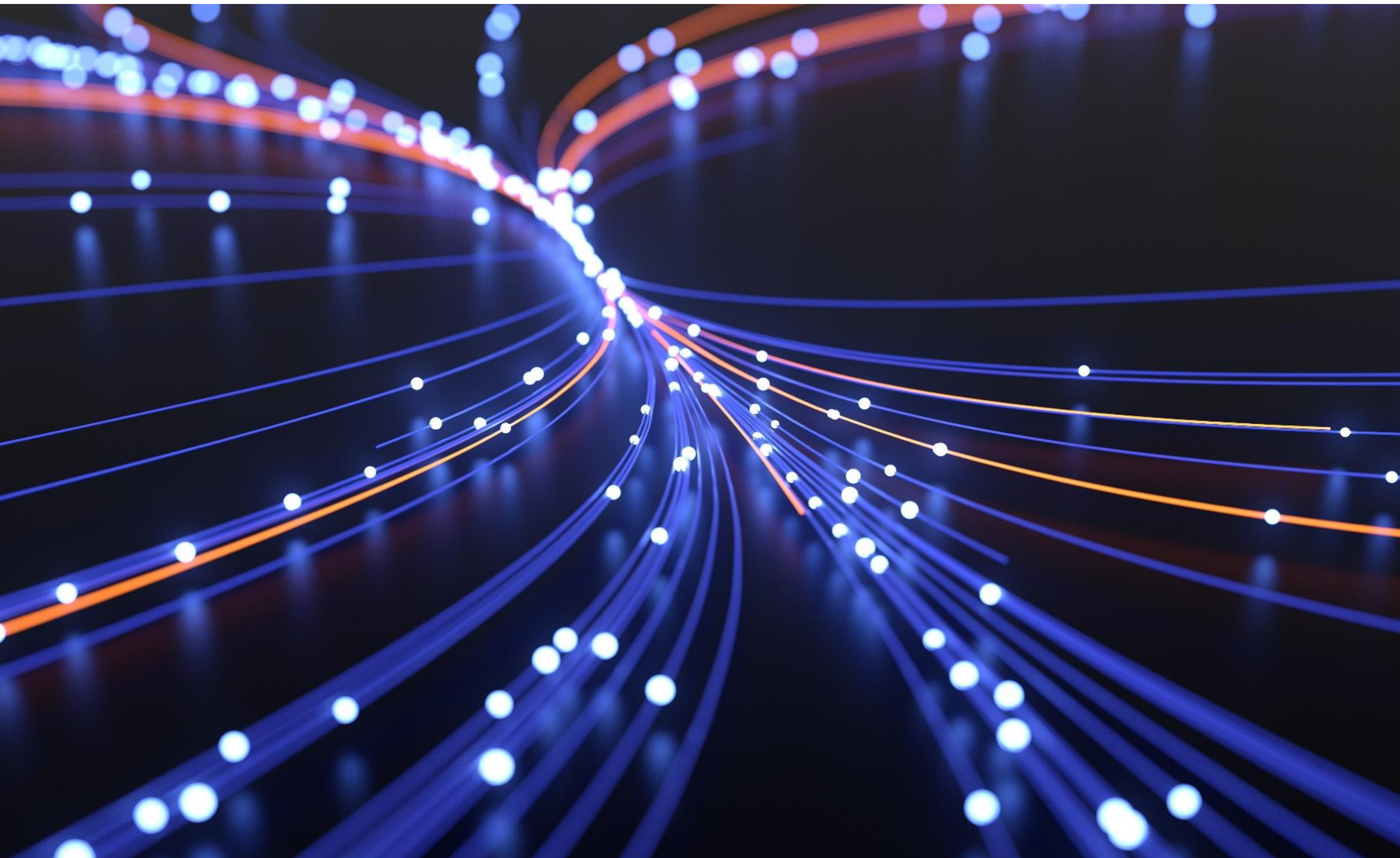
EDITOR'S CORNER

The Internet, personal and enterprise cloud services, social media, financial transactions, phone calls, video conference calls and all other forms and uses of voice and data communications are reliant on submarine telecommunications cables. Additionally, renewable energy sources such as wind, hydrokinetic, and hydroelectric, are increasingly reliant on submarine power cable transmission. The flow, whether it be information or power, and the increasing interconnectedness of these networks is expanding just as our own global society is innovating towards more reliance on data and power transmission capabilities. It is no wonder then that increasing attention is being placed on this infrastructure from the public, media, governments, and corporations. For those not intimately familiar with or embedded in the submarine cable industry, it is easy to ask questions such as, 'how resilient are these networks?' Concepts of single points of failure or questioning where is the weakest link can be conjured up.



EDITOR'S CORNER
(continued)

Resilience diminishes vulnerabilities to global submarine cable networks and is gained through diversification of infrastructure. In order to increase resilience, cable owners and operators routinely implement diversification of landing points and cable landing stations, submarine cable routes, redundant network paths, and robust terrestrial and marine maintenance programs. Resilience is also gained from lessons learned, engineering solutions to mitigate previous impacts through technological advances. As an industry, submarine telecommunications and power transmission continues to evolve, just as the global environment is always evolving. Exciting work can be found at these crossroads; whether it is society's demand for more broadband and capacity, or cleaner power, which drives advances in submarine cable technology, or the crossroads of how this technology interacts with a changing global environment.

This edition of *Submarine Cable Protection and the Environment* dives into these crossroads, where submarine cable technology has improved over time to decrease certain vulnerabilities such as Space Weather and how cables themselves are, and can be, used as tools to monitor our changing environment through remote sensing. Improvements in technology and repurposed applications for submarine cables provide us with these opportunities. The global network is indeed valuable and there is no doubt that the future will continue to demonstrate this value in innovative ways.

Sincerely,
Ryan Wopschall
ICPC General Manager

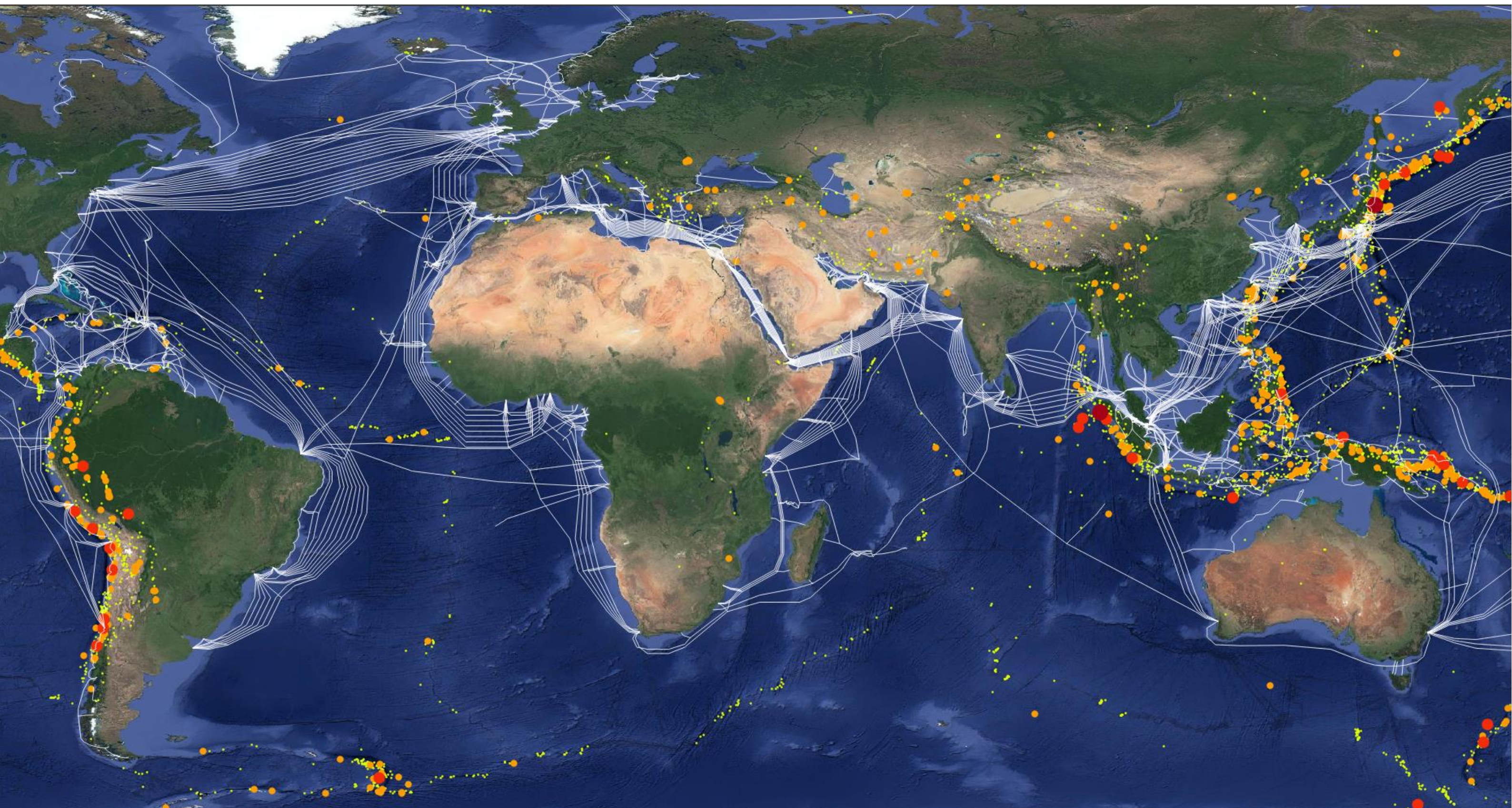
INTRODUCTION

While the global network of submarine telecommunications cables is designed to be resilient, repairs are required from time to time (for more details see Issue 2 of *Submarine Cable Protection and the Environment)*. One cause of this damage relates to natural hazards and, while such events account for fewer than 10% of cable faults worldwide, they can affect large areas, damaging multiple cable systems at the same time. The submarine cable industry has learned from previous damaging hazards, ensuring new routes avoid areas in which they are most likely to occur. However, many offshore natural hazards remain poorly understood due to the lack of offshore monitoring networks, compared to those on land. In fact, the scientific community has benefited from past instances of cable damage, as they provided some of the first indirect measurements of offshore earthquakes, underwater landslides, and sediment avalanches in areas that would have been otherwise unstudied. Collaboration between ocean science researchers and the submarine cable industry has continued since the early days of trans-Atlantic telegraph cables, and now makes use of a host of emerging technologies. In this issue, we introduce how modern fibre-optic cables not only transfer digital data and communications but can also be used to 'listen' to the ocean. The first article focuses on the use of seafloor cables to detect a range of natural processes providing intriguing opportunities for improved hazard monitoring and the development of new early warning systems.

We then look at a completely different hazard that does not originate in the ocean, but instead far away—in space. So-called 'space weather' arises from disturbances on the Sun that creates geomagnetic storms that can bombard the Earth with electrified particles. Widespread disruptions were first documented on early telegraph systems during large geomagnetic storms, and have since led to a variety of impacts on power and communications systems, including the first trans-Atlantic telecommunications cable. Similarly to other Earth-based natural hazards, the submarine cable industry has learned lessons from past impacts. The final article discusses some of the past instances of damaging space weather, and highlights how the industry has improved cable design to ensure it is resilient to future impacts.

Thank you to Dr Gemma Richardson (British Geological Survey) and ICPC Member organisations: Southern Cross Cables Limited (Dean Veverka), Subsea Environmental Services (Simon Appleby,) and Ciena (Brian Lavallée) for their technical contributions.

▼ **Figure 1:** The global network of fibre optic telecommunications cables is responsible for more than 99% digital data transfer worldwide, underpinning the Internet and global financial trading. Ensuring it remains resilient is critical to stable and continued digital communications. The map below shows the network of submarine telecommunications cables (white lines) based on TeleGeography's Submarine Cable Map resources licensed under Creative Commons CC BY-NC-SA 3.0 (https://github.com/telegeography/www.submarinecablemap.com). Also shown is the distribution of earthquakes (coloured points) with a magnitude greater than 6 from the U.S. Geological Survey catalog since 1970 (https://earthquake.usgs.gov/earthquakes/search/). The larger the coloured point (and the hotter the colour), the larger the earthquake's magnitude. Global map data ©2015 Google.

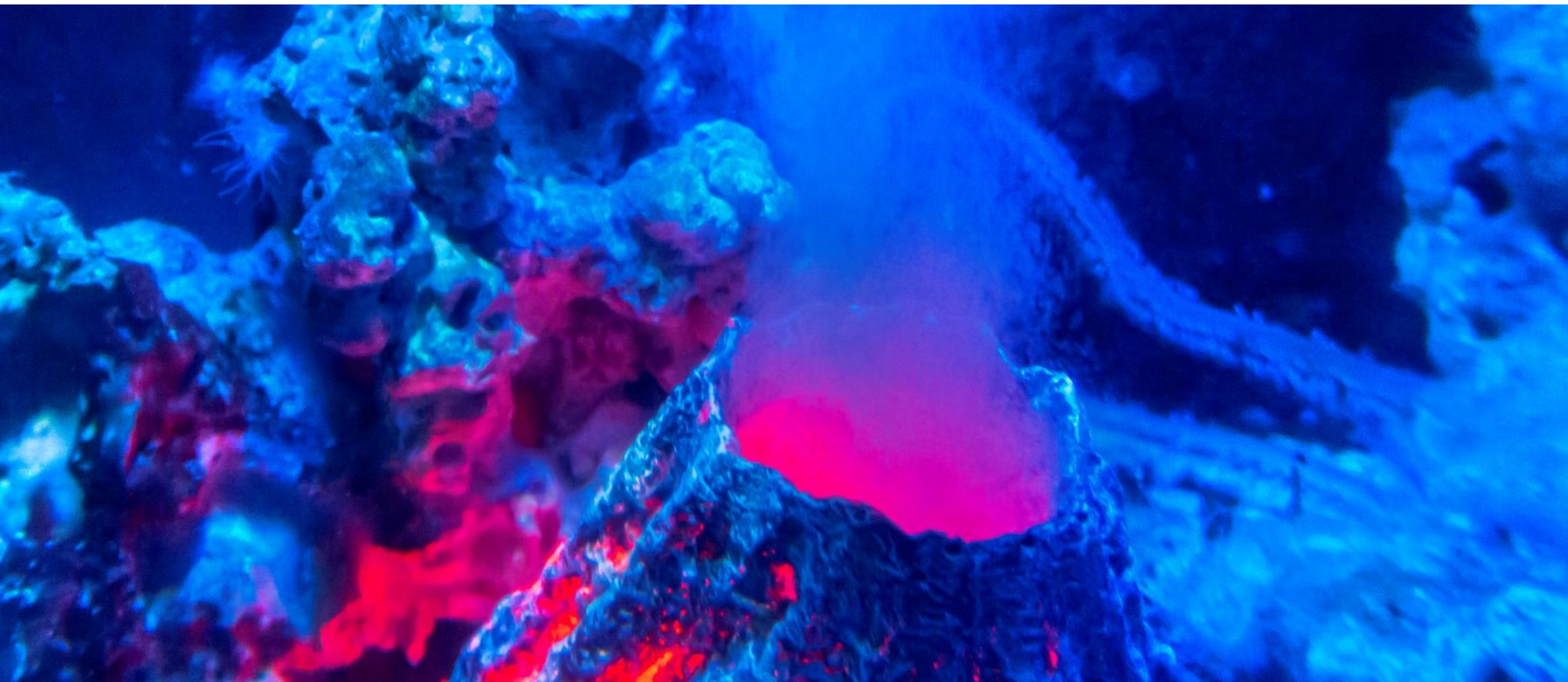


USING SEAFLOOR CABLES TO MEASURE THE WORLD AROUND US (pages 7-14)

- Seafloor telecommunication cables provide critical global connections that underpin our digital lives.
- Recent technological developments have revealed how seafloor cables can also be used to listen for and detect hazards in the ocean.
- Here, we introduce the concept of sensing along seafloor cables, highlighting recent studies that show how a range of natural and human phenomena can be detected using the optical fibres that lie at the core of standard telecommunications cables.
- On-going research is focused on developing early warning systems for earthquake or tsunami monitoring.

GAPS IN THE OCEAN

The ocean covers more than 70% of our planet's surface and plays a vital role in regulating the effects of climate change, providing food supplies and hosting sources of energy[1]. In addition to supporting our daily lives, many of the most severe natural hazards are known to initiate from offshore locations, including submarine earthquakes, volcanoes and landslides[2,3]. Despite the thousands of lives lost to tsunamis triggered by such events in recent years (e.g., 2004 Indian Ocean tsunami, 2018 Palu Bay and Anak Krakatau tsunamis), wide expanses of the global ocean remain sparsely monitored[5-7]. The limited amount of offshore monitoring is due to the challenges in installing expensive

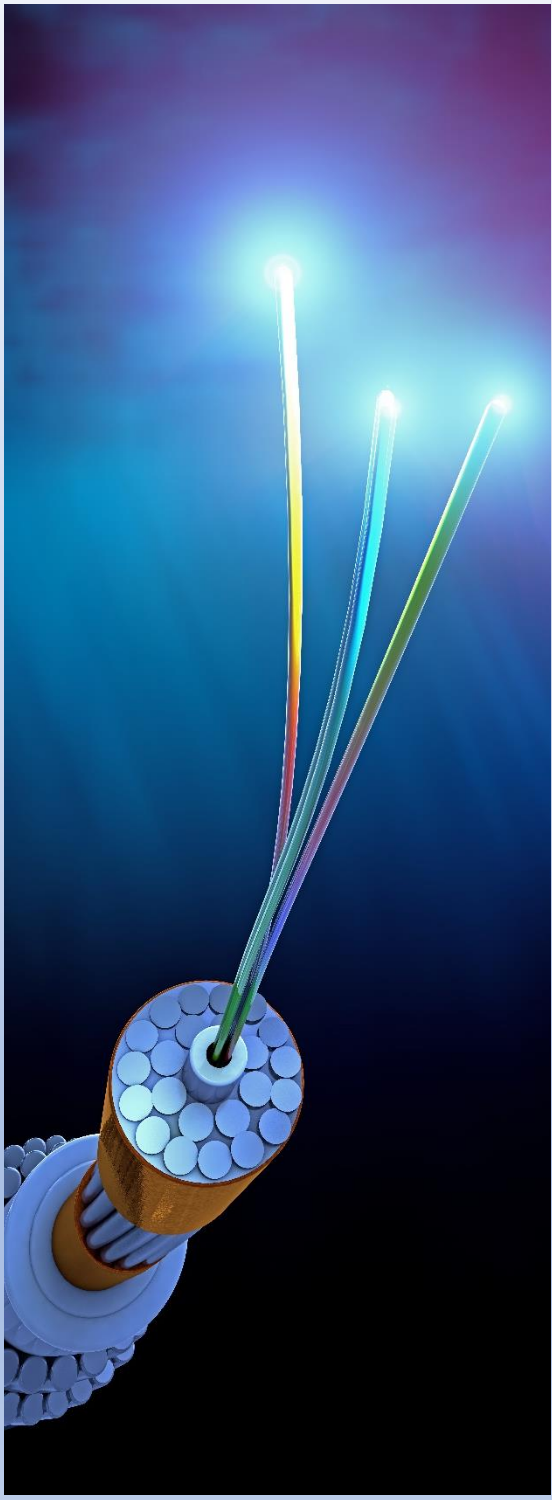


equipment in remote locations that are often far from shore, at great water depths, in difficult environmental conditions (waves, currents, high pressures), and because of limitations in long-range underwater communications and battery power[9]. These challenges, coupled with the vast scale of the ocean, means that offshore hazard monitoring typically relies upon data collected at individual locations over very short time periods, large datasets cannot be relayed in real-time, and relies upon expensive ships for data and instrument recovery[8-10]. Recent advances in sensing technology, using networks of seafloor cables rather than individual sensors, provide emerging opportunities to fill these major gaps in hazard detection, and potentially to develop the early warning systems that are needed in many regions to provide notice ahead of hazardous events.

USING CABLES TO LISTEN TO ENVIRONMENTAL NOISE

In the past few decades, the use of the optical fibre within a cable to remotely sense the surrounding environment has been extended far beyond verifying the health and performance of telecommunications cables. Fibre-optic sensing is now regularly used to monitor the health of structures such as bridges, railways, airport runways and roads, to detect local noise sources such as vehicles and mining blasts, and has even been shown to be capable of identifying noise created by parades and music concerts in urban settings[13-16]. Sensing along buried telecommunications cables in California documented the impact that recent COVID-19 lockdowns had on traffic and infrastructure use, and has potential for less invasive monitoring of population behaviour than tracking mobile phone location data[17]. Fibre-optic sensing has only recently started in the ocean, but a growing number of studies demonstrate that this technology has the potential to fill key geographic gaps in existing monitoring networks and provide key scientific insights.

OPTICAL FIBRES: THE CORE OF MODERN TELECOMMUNICATIONS



At the core of modern telecommunications cables lie bundles of optical fibres that are the same width as a human hair. Information is converted to pulses of light at one end of a cable, and can be transmitted over vast distances along an individual glass fibre. More than 1.8 million km of fibre optic cables, which are typically no wider than a garden hose, cross the global ocean; underpinning more than 99% of all global digital data transfer, including the Internet[11]. Since the start of the modern fibre-optic cable era in the 1980s, telecommunications cable companies have monitored the quality and effectiveness of communications along cables, particularly by analysing the light signals that are reflected back to the source[12]. These reflections occur where the original light pulse bounces off tiny, minor imperfections in the optical fibre, as well as occurring where a cable has been damaged or locally affected by a disturbance[13]. This allows the user to not only determine the quality of the data transfer, but also to pinpoint the location of any faults or disturbance events (such as natural hazards or human activities) along the cable, based on calculation of how long it takes light to travel back along its length[13,14].

EXTENDING LAND-BASED EARTHQUAKE MONITORING NETWORKS USING CABLES

The use of cable sensing to detect earthquakes has been the most prominent field of application in marine settings.

- **Detection of distant earthquakes:** Standard onshore and offshore telecommunications cables in the UK and Italy were used to detect the timing of earthquakes, some of which occurred as far as 18,500 kilometers away[18]. Using a technique called Laser Interferometry, an ultra-stable laser is shone down an optical fibre, while the response is monitored at the other end[18,19]. Seismic waves generated by earthquakes create changes in the phase of the light signal, enabling detection of earthquake timing, and potentially many other events not detected by existing monitoring networks[18]. This approach can make use of unused 'dark' fibres on an in-service telecommunications cable, or use a single channel on a fibre that also transmits commercial traffic; however, it requires expensive, bespoke equipment, including a laser that is far more stable than that typically used in commercial telecommunications cables, as well as requiring access to both ends of the cable[19]. While this provides opportunities to identify the timing of earthquakes, their location cannot currently be detected using this technique as measurements are made along the entire cable, rather than distributed along it[20].

- **Pin-pointing earthquake sources and mapping unknown seismic faults:** Distributed Acoustic Sensing (DAS) monitors changes in the reflected light at different locations along an optical fibre[13]. A specialist interrogator unit can detect these changes at various points along a cable arising from changes in temperature, pressure or ground motions, such as those generated during an earthquake or by a tsunami wave. A fibre-optic cable can therefore be considered like a series of many thousands of seismometers that are distributed along the seafloor when using this approach[7,13,14]. Distributed Acoustic Sensing along the 20 km Monterey Accelerated Research System (MARS) cable, offshore California, not only identified very small magnitude earthquake events, but also illuminated the location of an active tectonic fault, that was previously unknown[20]. The distance over which Distributed Acoustic Sensing can be performed is limited, however, primarily by the distance to the first repeater (a junction box needed to boost telecommunications signals over long distances); a distance that is typically much less than 200 km from shore[15,19,21].

- **Trans-oceanic earthquake and tsunami detection:** To date, the longest distance sensing along seafloor cables involved the Curie telecommunications cable that connects Los Angeles, California to Valparaiso, Chile; spanning a distance of 10,000 km, and thus far beyond the current limits of Distributed Acoustic Sensing[22]. Using a new technique known as State of Polarization, researchers analysed distortions in the light signal received at the end of the cable, identifying multiple moderate to large earthquakes as well as swells on the ocean surface; demonstrating how this approach can potentially be used for tsunami detection[7,22]. Like Laser Interferometry, this technique makes measurements over the entire cable length, and therefore cannot be used to pin-point event locations, unless several cable systems are used at the same time[19]. However, as this technique makes use of a standard telecommunications laser, and does not require any specialist equipment at either end of the cable, it has been suggested that combinations of existing or retired telecommunications cables may fill some of the geographic gaps in earthquake and tsunami monitoring networks, which would enable locating these and other hazardous events[7,15,22].

▼ **Figure 2:** Submarine cables representing good substrate to seabed flora and fauna. ATOC/Pioneer Seamount scientific cable with attached anemones (Metridium farcimen) at ~140 m depth off California, USA. Source: Monterey Bay Aquarium Research Institute.

FUTURE CHALLENGES AND OPPORTUNITIES

More research is required to refine cable sensing techniques before early warning systems can be implemented, however. The sensitivity of cable sensing depends very strongly upon how well a cable is in contact with the seafloor [13,22]. Cables laid on areas of muddy flat seafloor have been shown to accurately record small earthquakes, but when laid across rough terrain, the cable can locally be suspended above the seafloor, which compromises its ability to record clear signals[22]. Different types and magnitudes of events will have a different signal, but our understanding of ocean and earth

FOOD FOR THOUGHT

- The application of cable sensing has already been extended far beyond earthquake monitoring, including detection of volcanic activity[23], vigorous seafloor currents[20], tides and storms[10,24], and rock falls[25], to track the movement of glaciers[25-27], monitor the escape of gases from hydrocarbon reservoirs[28], and to identify shipping vessels and fishing activity[29,30].
- Sensing along submarine cables has been shown to be far more efficient at detecting earthquakes and several other phenomena than using onshore cables, due to specific properties of seawater and the seafloor substrate[15]; hence the advent of these technologies provides intriguing opportunities to apply cable sensing techniques to submarine telecommunications cables[7,31-34].
- Cable sensing can be used to measure changes in ocean temperature, and may therefore also provide valuable long -term records of the effects of future climate change, and identify areas where impacts are more pronounced than others[10].

processes is still quite limited. Therefore, calibration using more conventional monitoring sensors will be required to 'fingerprint' a wide range of events before they can be confidently interpreted when sensing along cables[34]. Finally, there are a number of logistical limitations that need to be overcome. Cable owners will not necessarily have sufficient capacity to provide a spare fibre for sensing, while there are often sensitivities about providing access to commercially important infrastructure. These issues need to be addressed before commercial cables can be utilised as sensing networks, but the use of retired cables or scientific cables provides immediate opportunities for this work to begin, offering a repurposing opportunity for these out-of-service cables. Submarine telecommunication cable routes are generally chosen to avoid hazardous areas and are routed away from some of the existing blind spots in global monitoring of natural hazards[7,10]. Some regions (e.g., Northwest Europe, Southeast Asia) have dense networks of submarine cables and may be better suited; however, others are much less well served (e.g., the Southern Ocean)[35]. The deployment of new bespoke scientific cables has therefore been proposed to try and fill some of these gaps and potentially offers valuable opportunities to discover previously unknown processes and develop new early warning systems to protect seafloor infrastructure and coastal communities[8,19]. One challenge, however, remains the high capital costs for deploying such new systems with costs ranging from tens to hundreds of millions of dollars depending on system length.

KEEPING THE INTERNET PROTECTED FROM SPACE WEATHER
(pages 15-22)

In this article we discuss how past Space Weather (i.e., solar storms) events have impacted communications networks and how improvements in design ensure the Internet keeps running.

HIGHLIGHTS:

- Previous solar storms have had significant impacts on power and communications networks.
- The likelihood of a major space weather event impacting submarine telecommunications cables is considered to be very rare.
- Modern systems are designed to be resilient, based on lessons learned from impacts of past space weather events.

WEATHER FROM SPACE

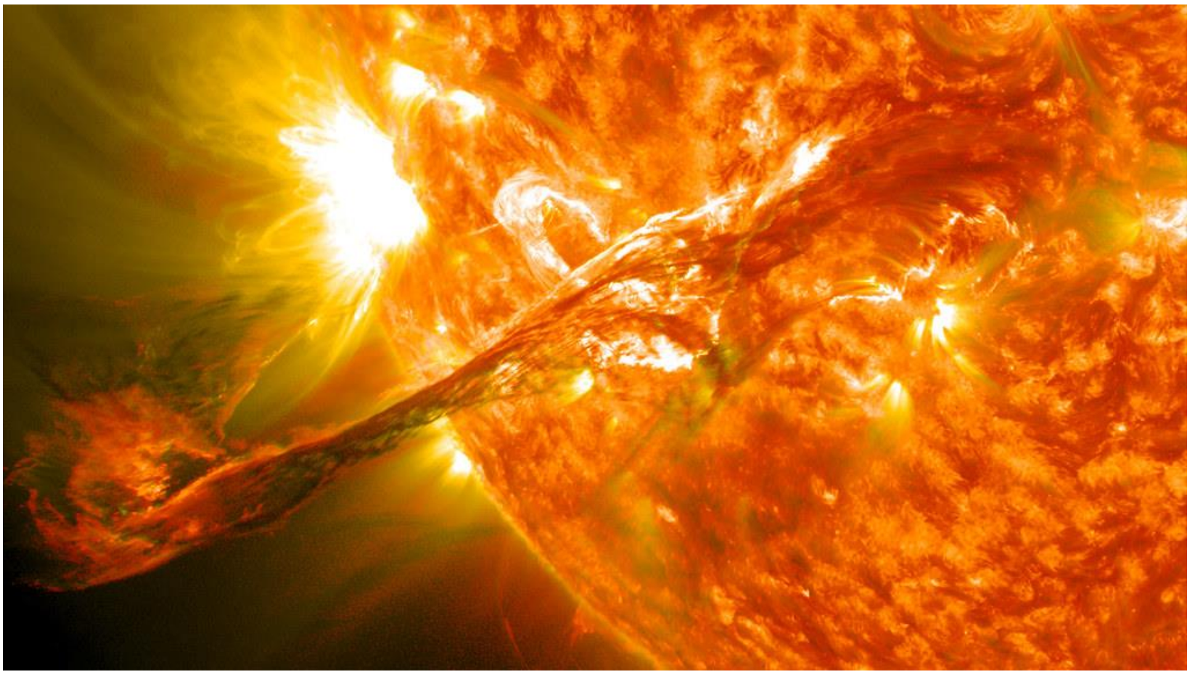
Despite being 93 million miles away, the Sun's strong influence on our planet is clear—controlling the path of Earth's orbit through space,

▼ **Figure 3:** *The Aurora Borealis, also known as the Northern Lights, above Tromsø, Norway. The result from geomagnetic disturbances caused by solar wind. Reproduced from Svein-Magne Tunli—tunliweb.no under a Creative Commons Licence.*

keeping us warm, and providing an important source of energy. Less well known, however, is how eruptions from the Sun's surface can create solar storms, carrying electricity-charged particles towards the Earth at millions of miles per hour[36,37].

- This phenomenon is known as 'space weather', the intensity of which varies over solar cycles that recur on an 11-year periodicity[37,38].
- The Earth's magnetic field and atmosphere play crucial roles in deflecting space weather events, sheltering us from the majority of solar wind blasts[36]. However, solar storms sometimes penetrate through the atmosphere, or if they are particularly strong, may become trapped by the magnetic field, creating large electrical currents that flow around the Earth[36,39].
- The interaction of these currents with the atmosphere is responsible for spectacular auroras such as the Northern

▼ **Figure 4:** A large solar filament eruption as imaged by NASA. This type of eruption from the Sun's surface creates solar winds that can be directed towards Earth. Credit: NASA/ GSFC / SDO.



and Southern Lights, but can also affect the voltage across long electrical, communication and navigation systems, sometimes leading to major disruptions[37-41].

PAST IMPACTS OF SPACE WEATHER ON POWER AND COMMUNICATION NETWORKS

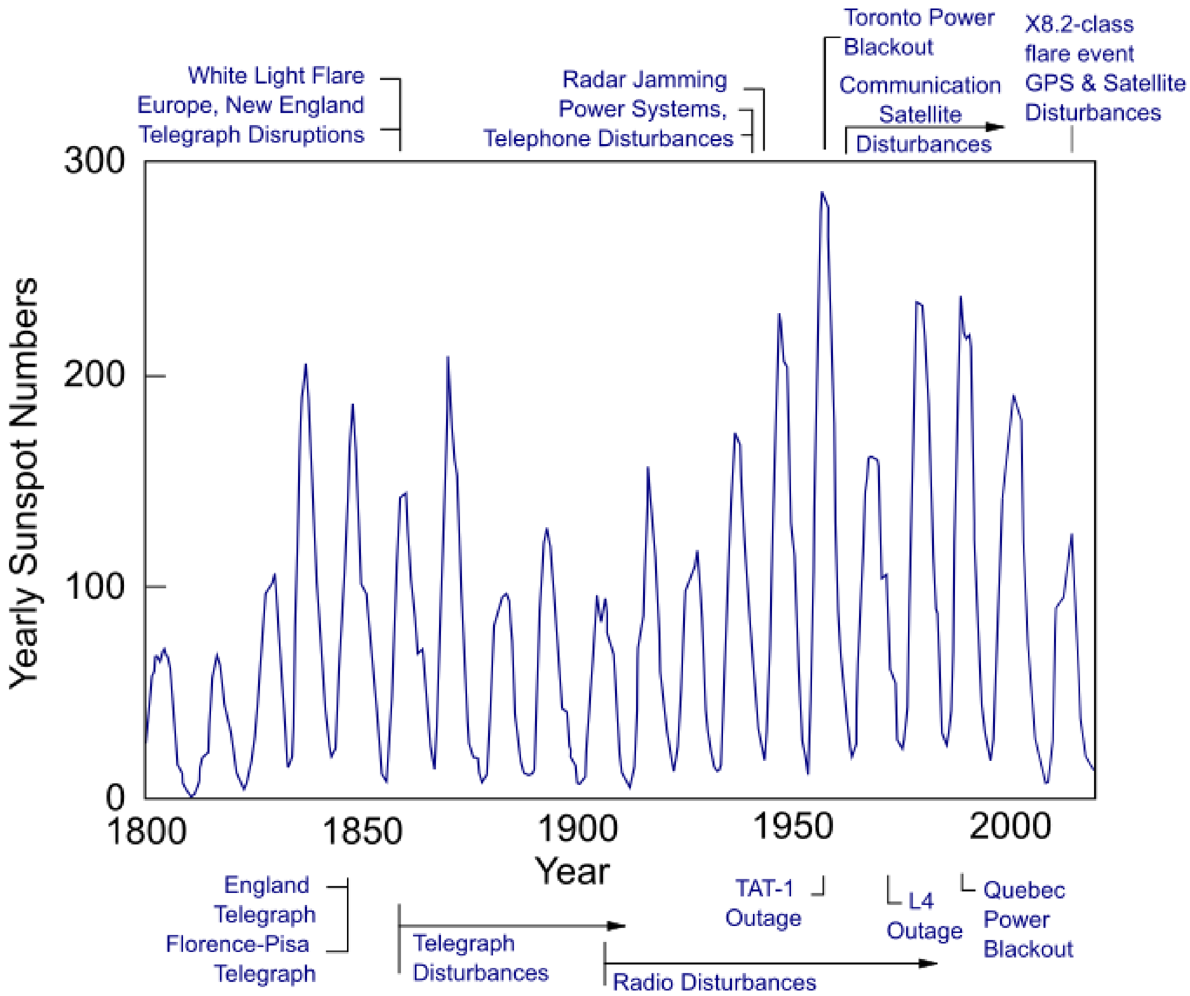
The most severe impacts of space weather on infrastructure occurred during peaks in solar activity and include:

- A solar storm in 1851 that took control of all the telegraph lines in New England, and halted business transactions along the network[39].
- An exceptionally large solar storm in 1859 (known as the 'Carrington Event' (the largest space weather event recorded to date) had widespread impacts on early telegraph systems. Telegraph operators were surprised when some systems continued to work even when disconnected from their batteries, as the voltages induced by the geomagnetic storm were sufficient to power them[37-39].
- In 1921 a large solar storm cut off Washington DC's telegraphic cable connections from the rest of the United States. This disturbance was reported as 'unprecedented' by the American Telegraph and Telephone Company[37-39].
- Voice communications were halted along the first trans-Atlantic telecommunications cable (TAT-1 that connected Canada to Scotland) during a space weather event in 1958, when a geomagnetic storm also caused temporary power cuts across the Toronto area. Apparently, the darkness was only broken by the light of the aurora overhead[43].
- A large geomagnetic storm in 1972 caused power disruptions across many

regions of North America, and disrupted communications across a long line telephone cable between Illinois and Iowa, USA for nearly an hour[44].

- Solar storms interfered with shortwave radio services throughout China for 17 hours in 2000, which also interrupted a communication satellite and some navigation systems[39].

▼ **Figure 5:** Solar activity since 1800, as revealed by the number of observed sunspots each year. Instances of disturbance to infrastructure networks annotated above and below, including impacts to early telegraph systems and the first trans-Atlantic cable, TAT-1. Modified from Lanzerotti (2007)[37].



WHAT THREAT DOES SPACE WEATHER POSE TO SUBMARINE TELECOMMUNICATIONS CABLES?

Given our increasing reliance on submarine cables for stable digital communications, data transfer and connection to clean energy supplies, it is important to understand what threat is posed by space weather to these critical networks. Far from having overlooked the impacts of space weather[45], the submarine telecommunications cable industry has learned lessons since the first trans-Atlantic fibre-optic cable (TAT-1) was impacted in 1958[44], and has continued to improve cable design to ensure the network is resilient. A geomagnetic storm in 1989 caused a day-long power blackout across the province of Quebec; however, the TAT-8 trans-Atlantic fibre-optic cable withstood this major space weather event[42]. Despite surges along its length, the TAT-8 cable was found to be resilient to unusually large fluctuations in 'earth potential' (the difference between the voltage at the cable landing points)[42]. Fluctuations as large as 700 volts were recorded along the cable, with the largest impacts focused towards the Canadian landing point.

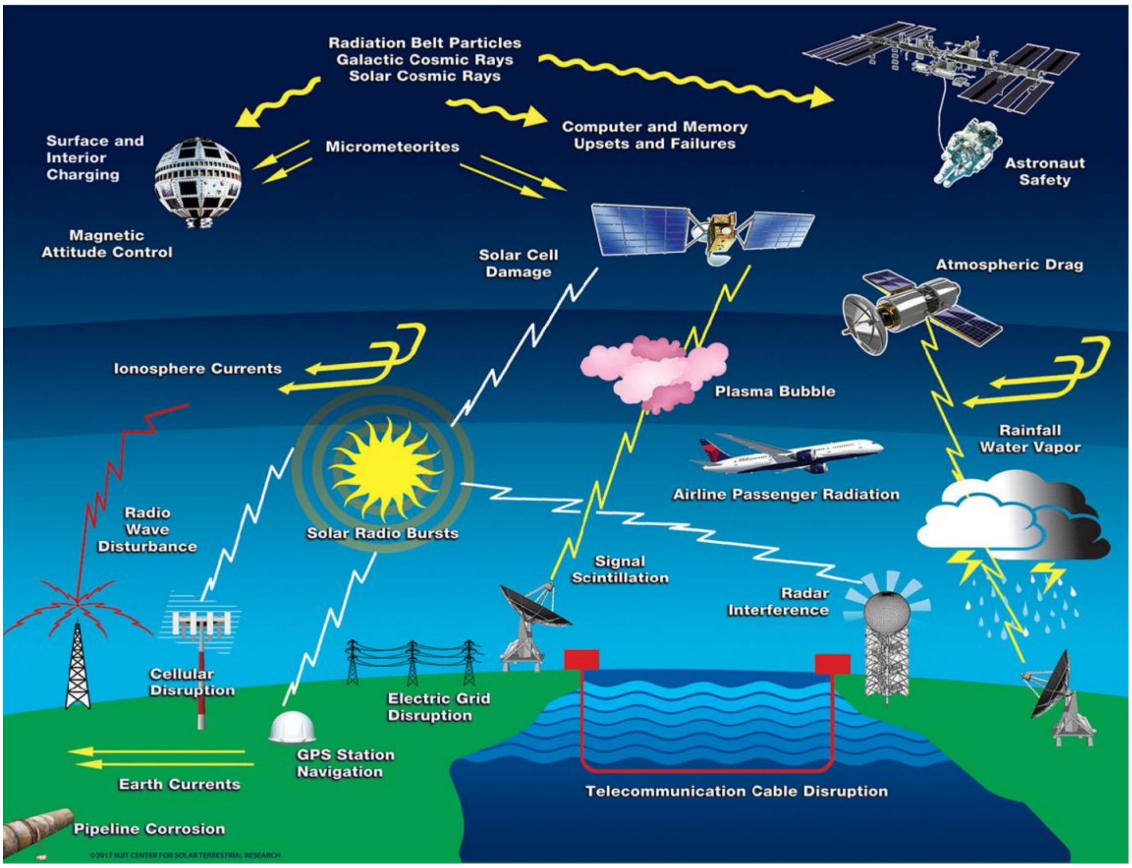
Improved design has continued to develop as part of broader cable protection strategies worldwide and the threat posed by space weather is generally considered to be of a low likelihood because:

- **Modern fibre-optic cables are resilient to impacts of a major solar storm.** A recent study of 12 submarine telecommunications cables[40] analysed the impacts of a solar storm in 2017, which included some of the strongest solar flares in a decade. Earth potential variations were found to be highest for cables that run from north to south (rather than east to west), particularly those in the Northern Hemisphere, however, the impacts were negligible on all the cables; falling well below thresholds for damage.

- **Modern telecommunications cables are designed to withstand large additional voltages.** Where fibre-optic cables are powered (typically those that exceed a few hundred kilometres in length), power is supplied from the landing station at each end to supply power to nodes along its length (known as 'repeaters'), which amplify the optical signal that would otherwise be incapable of traveling great distances along cables. Where there are two landing locations, half of the voltage is supplied from each end; however, modern cables are designed to operate with all the voltage supplied from a single end, to ensure they can continue to work should a fault occur at one end. Modern design not only ensures that cables can operate in such instances, but also includes an 'Earth Potential Allocation' (EPA) margin that can accommodate the additional voltages that may be imparted during geomagnetic events[40]. It is worth noting that the resistance of telecom cables is 10 to 1000 times greater than for power cables, hence the surge currents will be proportionally lower, and will be dealt with by surge protection circuits in the repeaters[51,52]. Furthermore, the longer the cable, the more dissipation will occur along its length; hence also reducing impacts across long routes[53].

- **Large solar events are infrequent relative to the design life of a cable.** The 1859 'Carrington event' is the largest documented space weather event, but as this occurred prior to the development of modern telecommunication networks, satellites, GPS and electrical systems, the potential impacts of a repeat event are not fully known[36,38]. Such a large event is considered to be extremely rare (although the precise likelihood cannot be exactly determined based on current data)[37,38]. Based on the eleven-year solar cycle[47], a cable is only likely to encounter a single major geomagnetic event during its c.25 year design life. The worst case scenario would probably be the coincidence of a large geomagnetic storm with a fault on a North Hemisphere transoceanic cable that results in the system being powered from one end only, thus limiting the ability of the cable to absorb the additional voltage[5]. It should be noted that this is highly unlikely, however, as the probability of such a coincidence is estimated as 1 in 2.7 million[40].

- **The distributed nature of the global network provides additional resilience.** It has long been known that submarine cables can be damaged; however, most of this damage relates to accidental human activities such as fishing and anchor drops, with a small proportion (<10%) arising from natural hazards[46]. The global network is designed to be resilient to such impacts, however, as Internet traffic can be re-routed via different cables or along local routes where faults occur. Additional and more diverse routes are planned in the future, which will contribute to strengthening this resilience.



◄ **Figure 6:** Overview of some of the observed effects of space weather on modern technology from Lanzerotti (2017)[3]. Presented under a Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/)

FOOD FOR THOUGHT

- Space weather is a growing area of research and there is much still to discover about this complex phenomenon.
- Significant efforts are now devoted to the prediction of solar activity to determine if early warnings can be made prior to Earth-impacting events[36,48-50].
- The submarine cable industry continues to consider improvements to design, including proposed designs to support larger voltages (e.g., reducing the typical 'Earth Potential Allocation', use of more expensive, low-resistance cable[40]), as part of ongoing broader assessments of threats to submarine cables that arise from changing ocean use and climate change[46].
- **There have been so few documented impacts on the global telecommunications cable network, compared to the number of space weather events that have occurred, which is perhaps the greatest testament to its resilience.**

Please visit www.iscpc.org for further information.

Sharing the seabed in harmony with others

The International Cable Protection Committee (ICPC) was formed in 1958 and its primary goal is to promote the safeguarding of international submarine cables against human made and natural hazards. The organisation provides a forum for the exchange of technical, legal and environmental information about submarine cables and, with more than **170 MEMBERS** from over **60 NATIONS,** including cable operators, owners, manufacturers, industry service providers, and governments, it is the world's premier submarine cable organisation. The ICPC comprises of an 18 Member Executive Committee (EC)-led organisation voted in by its Full Members. In addition to the Marine Environmental Adviser (MEA), General Manager (GM) and Secretariat team, the ICPC also has an appointed International Cable Law Adviser (ICLA) as well as a United Nations Observer Representative (UNOR).

Prime Activities of the ICPC:

- Promote awareness of submarine cables as critical infrastructure to governments and other users of the seabed.
- Establish internationally agreed recommendations for cable installation, protection, and maintenance.
- Monitor the evolution of international treaties and national legislation and help to ensure that submarine cable interests are fully protected.
- Liaison with UN Bodies.

Recommendations:

- Taking into account the marine environment, the ICPC authors Recommendations which provides guidance to all seabed users ensuring best practices are in place.
- Educating the undersea community as well as defining the minimum recommendations for cable route planning, installation, operation, maintenance and protection as well as survey operations.
- Facilitating access to new cable technologies.

Advancing Regulatory Guidance:

- Promoting United Nations Convention for the Law of the Sea (UNCLOS) compliance.
- Championing uniform and practical local legislation and permitting
- Protecting cable systems and ships.
- Aiding education of government regulators and diplomats.

Working with Science:

- Supporting independent research into cables.
- Publishing reviews for governments and policy makers.
- Working with environmental organisations.
- Effective public education via various media.

To learn how to become of Member organisation of the ICPC, please click on join here.

EDITORIAL STAFF

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Mike is the Marine Environmental Adviser for the International Cable Protection Committee (ICPC) and is a Principal Researcher at the National Oceanography Centre, UK, where he works as part of the Ocean BioGeoscience Research Group. His research focuses on better understanding the dynamic seafloor, the implications of past and future climate change, impacts of human activities, and quantifying risks to critical infrastructure. Prior to his research role at NOC, he worked for ten years as a geohazard consultant to a range of offshore industries.

Editor: Ryan Wopschall

Ryan is the General Manager for the ICPC. He has spent the last 15 years in the telecommunications industry with a focus on inter-national undersea and terrestrial backhaul telecommunications.

Design & Layout: Christine Schinella

As part of her Secretariat role, Christine coordinates marketing activities for ICPC. With a background in graphic design and publishing, Christine has been working in the telecommunications industry since 2000.

FURTHER READING & REFERENCES

Further information on submarine cables and the marine environment can be found in the references and text within the peer-reviewed UNEP-WCMC report via: **'Submarine Cables and the Oceans: Connecting the World'** as well as other resources via: https://iscpc.org/publications.

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