Co-funded by
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Northern EU Gateways project
Science Opportunities on Polar Connect
Workshop Report - October 2023

Executive Summary

The NORDUnet organised workshop "Science Opportunities on Polar Connect" convened experts and stakeholders from both technical and scientific backgrounds to deliberate on an ambitious endeavour — creating opportunities for highly needed Arctic research using fibre sensing and SMART cable technologies in the Polar Connect submarine cable system. This initiative, supported by the European Union's Connecting Europe Facility (CEF Digital) under the 'Northern EU Gateways' project, presented an unprecedented opportunity to address complex scientific challenges in the Arctic region while fostering collaboration between the fibre technology experts and international scientific communities in the field of Arctic research.

The focus of this workshop was a dialogue between researchers about application of fibre sensing capabilities and SMART cables equipped with sensors and branching points to enable real-time observations and data collection across the Arctic Ocean. This transformative approach offers profound opportunities for the science community, particularly in the context of Arctic exploration, where traditional methods often face logistical and technical limitations and, due to that, knowledge has been limited thus far.

Benefits of Fibre Sensing for Arctic Science

The availability of fibre sensing technology on the Polar Connect submarine cable system presents a major shift in how we can observe, understand, and interact with the Arctic region. This innovative approach offers numerous benefits to the research community:

- *Access to real-time data.* Fibre sensing technology enables the continuous collection of spatial data from the Arctic Ocean, allowing scientists to monitor environmental, geophysical, and climatic conditions with much higher level of precision.
- *Enhanced scientific understanding.* With sensors deployed e.g. every 100 kilometres and branching points facilitating complex observation systems, the SMART cable concept will offer new insights into the dynamics of the Arctic region. It will enable comprehensive studies of seismology, geophysics, climate, oceanography, marine biology, and geology.
- *Unique Research Instrument*. Submarine fibre cables will provide power and communication capability to the various sensing devices along the cable. This unique fusion of the telecommunication cable and scientific applications will create a research instrument in the largely unexplored Arctic areas.

- *Cost-benefit Analysis*. While integrating sensors into the cable system and the possibility to attach sensors to the cable system involve initial investment, and continuous operational and maintenance costs, the long-term benefits in terms of scientific discoveries, resource management, and disaster prevention can justify these expenses.
- *Resilience and Security*. The ability to utilise fibre sensing and SMART cable monitoring capabilities will enhance the resilience of digital connections between Europe, Canada, USA and Asia, while maintaining the security.
- *Innovation.* Fibre sensing is a fast-evolving technology that is already being used and will be even more widely spread in 10 years. By making it available to researchers, Polar Connect will be contributing to the advancement of science and collaboration, and will become a research instrument.

Arctic Exploration and Complex Scientific Challenges

The Arctic region presents unique scientific challenges due to its extreme climate, remote locations, and dynamic natural processes, also when using scientific equipment for monitoring purposes. The sensor-equipped submarine cable infrastructure addresses these challenges by offering:

- *Real-time data about environmental changes*. Fibre sensing technology enable scientists to monitor climate change, sea-level variations, and seismic activity in real-time, feeding into climate modelling and facilitating proactive responses to environmental shifts.
- *Research instrument*. By providing an interconnected network of sensors, utilising the benefit of various fibre sensing technologies and data-sharing capabilities, the submarine cable infrastructure transforms into the unique sensing instrument.
- *Collaboration*. The mentioned submarine cable infrastructure not only represents major advancement in global connectivity, it also serves as basis for increased international collaboration and knowledge exchange in the field of Arctic science.
- *Interdisciplinary research*. The fibre sensing and SMART cable technology encourages interdisciplinary research by offering data from the Arctic Ocean, that can be utilised by seismologists, geophysicists, climate scientists, oceanographers, marine biologists, geologists, and other experts, fostering a holistic understanding of the sensitive Arctic ecosystem.

In conclusion, the incorporation of fibre sensing and SMART cable technology in the Polar Connect submarine cable system opens new horizons for the scientific community. It not only helps to overcome the challenges of Arctic exploration in harsh conditions but also promotes collaboration and fosters innovation. This workshop served as an important milestone in exploring the future opportunities of Arctic science and reinforces the commitment of NORDUnet and its partners to the advancement of knowledge in this barely explored, but extremely interesting and important region. The Polar Connect initiative has the potential to contribute to the revolutionary advancement in Arctic research and to the global understanding of our changing planet.

Introduction

On the 3rd and 4th of October 2023, a science engagement workshop titled "Science Opportunities on Polar Connect" was held in Oslo, Norway, as part of the Northern EU Gateways project. It was the first ever science engagement event organised by NORDUnet, where leading scientists were directly invited to a dialogue about novel possibilities that submarine cable technology can offer for the advancement of research and stimulate visionary thinking. The choice of location was made to ensure easy access and travel for scientists from the Nordics, who are active in research of the Arctic region.

The primary objective of this event was to facilitate the exchange of knowledge regarding the technology and scientific applications of optical fibre sensing and SMART cables across various Arctic research domains.

It was crucial to communicate the unique potential that the Polar Connect cable holds for scientific communities as it traverses the Arctic Ocean while at the same time defining the scientific requirements for utilising the data it collects.

The Northern EU Gateways project warmly welcomed scientists from diverse Arctic research disciplines. Together with experts working on fibre sensing technologies and development of SMART sensors for submarine cables, the attendees explored a wide range of possibilities that sensing cable technology offers. Scientists were asked to imagine near-real-time data streaming directly from the depths of the ocean, benefiting fields such as oceanography, geophysics, marine biology, environmental studies, climate change research, and even disaster mitigation for society.

This workshop brought together brilliant minds and technology experts from Norway, Sweden, Denmark, Finland, the Netherlands, Canada, and – via virtual participation – from the USA.

Day 1: Tuesday, 3 October 2023

Introduction to Polar Connect and the Aim of the Workshop

Ieva Muraskiene (NORDUnet) and Magnus Friberg (VR/SUNET) provided an introduction to the Polar Connect initiative, which aims to obtain secure and resilient connectivity through the Arctic to Asia and North America for Research, Development, Innovation and Education. The speakers focused on the unique aspects of the route that has never been explored before in the market of submarine cables. It is foreseen to be the shortest route possible between Europe and East Asia, bringing high performance and safeguarding minimum delay time. A route that brings broader collaboration opportunities to connect strategic partners in the USA, Canada, Japan and even beyond to South-East Asia. The Polar Connect submarine cable will create the digital infrastructure that brings not only economical and societal benefits, it will also serve as scientific instruments for Earth observation, marine, and seismic research.

The planning of the route takes into account current geopolitical situation and the fact that 90% of traffic between Europe and Asia goes through geographically congested Suez Canal area, with additional challenges arising from intense shipping activity (see Figure 1).

Figure 1. Suez Canal submarine cables. Source: https://www.submarinecablemap.com

The Northern EU Gateways project was introduced, funded by the European Union's Connecting Europe Facility (CEF Digital), which created the opportunity to organise this workshop. The project, which is a collaboration between the Finnish company Cinia and the Nordic research and education infrastructure NORDUnet, focuses on planning and development of the autonomous digital backbone and connecting Europe with global strategic partners. At the end of the project, the partners will have produced a high–level plan for new submarine and terrestrial cable systems interconnecting EU member states, overseas territories and third countries with whom the EU has strong ties and interests. Additionally, this project is also contributing to gain an understanding of the needs of the users and collaborators, and overall development in the surrounding society.

The presentation introduced the Vision 2030 (see Figure 2) for the intercontinental connectivity between Europe and Asia and how it will be strengthened through two complementing submarine cable systems – Far North Fiber and Polar Connect. The two submarine cables currently in development will greatly increase diversity and resilience for connectivity between Europe and Asia, while also increasing capacity and reducing latency.

As response to the introductory talks, it was asked if and where the cable system would land in Canada. From the project it was responded that several places in Canada, the high north of Canada and Vancouver are potential landing sites.

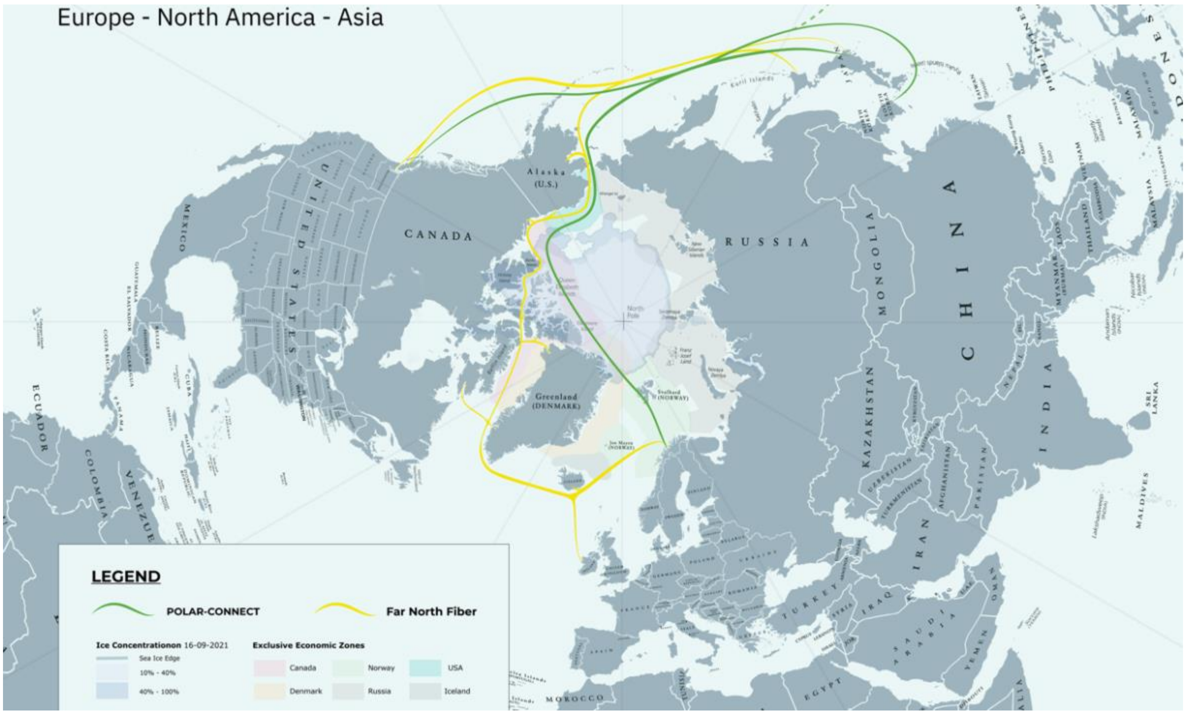

Figure 2. Vision 2030 for Arctic connectivity. Source: NORDUnet.

Cable Technology and Innovation

This part of the agenda was aimed to provide insights to the fibre sensing technologies, current developments of various sensing applications and SMART cable developments for future use.

Mads Vandborg (DTU) gave an introduction to optical fibre sensors. When explaining the principles of optical fibre sensors, the presentation delved into the general overview of sensing technologies, and types of optical sensors. The presentation concluded with comparison of the fibre sensing principles (see Table 1).

	OTDR	Transmission sensing	Alcatel SMART sensor
Range	<200 km (Coastal monitoring)	>10,000 km (Deep sea monitoring)	>10,000 km (Deep sea monitoring)
Sensitivity	Medium	Low	High
Spatial resolution	~10 m	~50-100 km	Point sensor
Hardware requirements	• Dark fiber • Interrogator unit	• Works with standard te-lecom optical fiber links. • Ultra stable laser source.	??
Sensor maturity	Commercially available	Early research stage	In development phase
Applications	• Seismic detection • Swell detection • Sea vessel detection • Temperature monitoring • Storm detection • Whale sound detection	• Seismic detection	• Seismometer/accelerometer • Thermometer • Pressure sensor

Table 1. Comparison of sensing principles.

Jan Kristoffer Brenne (ASN) delved into the SMART cable concept and the future development of sensors. The presentation outlined various acoustic sensing interrogator techniques, which focused on DAS applications on submarine cable networks (see Figure 3). The SMART cable concept and their key features served as an introduction to the latest development of the solution for climate change monitoring and other types of underwater monitoring.

Traditional DAS solutions span up to 150 km from the cable landing site, however, Jan Kristoffer presented novel potential solutions, which could extend the DAS reach while keeping the resolution for ranges up to 2,500 km. Such a distance would cover the full path from Svalbard to Canada and/or Alaska.

The following discussions focused on the options for calibrating the sensors in the ASN SMART cable concept.

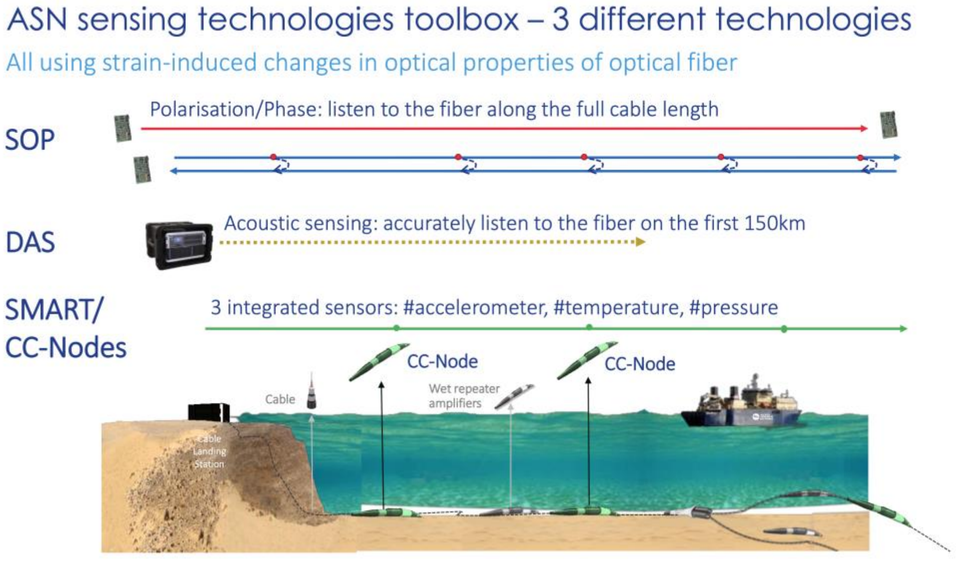

Figure 3. ASN submarine cable sensing technologies. Source: Alcatel Submarine Networks.

Cecilia Lund (SPRS) shared their experience in executing Arctic expeditions, thus confirming the viability of crossing the North Pole with a submarine cable. In this case offering the three-vessel approach, which was previously implemented with success during the Arctic coring expedition. The approach suggests, that navigating the ice would be performed by two polar class icebreakers, ensuring that the cable laying vessel is safe behind them.

The Arctic's environment is fragile, therefore, it is necessary to create a balance between conducting scientific research and protecting the region's ecosystems. Researchers must minimise their ecological footprint while conducting studies, requiring innovative solutions and methods for data collection.

SPRS are working on the vision for their new climate neutral research ice breaker with the highest Polar Class (see Figure 4). According to the plans, the icebreaker can be available by 2030 and can be equipped with the needed tools for maintenance of submarine cables in the Arctic.

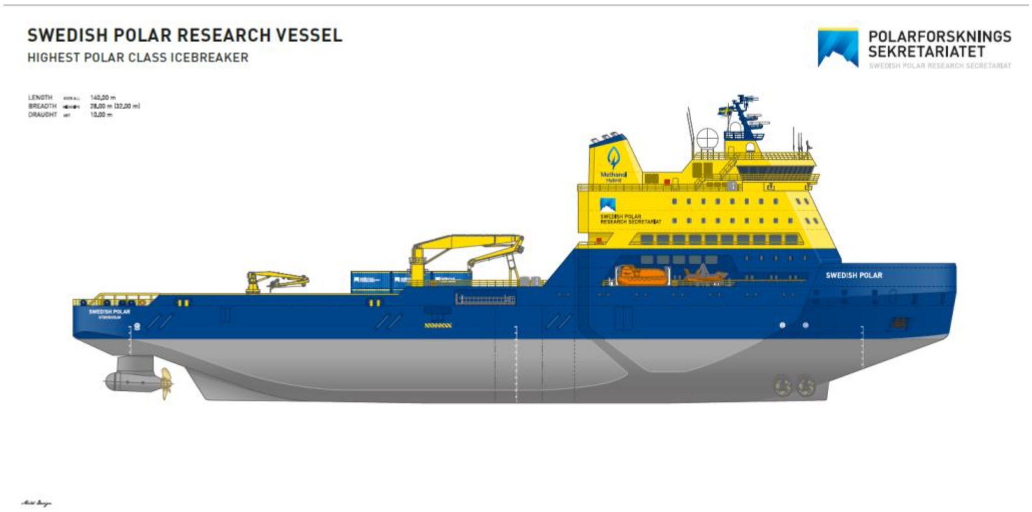

Figure 4. SPRS Vision for the icebreaker. Source: SPRS.

Environmental and Geophysical Scientific Opportunities

Martin Landrø (NTNU) highlighted the use cases of the Norwegian NREN owned submarine fibre cables on Svalbard for environmental and geophysical research. The presentation covered various ocean floor DAS technologies that proved to be an efficient tool for whale tracking, oceanography for monitoring storms, tides, currents, seismology for monitoring earthquakes, and even mapping of sediment thickness from resonance effects (see Figure 5). Yet, these systems generate huge amounts of data and present the need to develop efficient and fast data analysis algorithms. While temperature measurements are difficult with DAS, it is possible to measure temperature variations to a certain level with DAS.

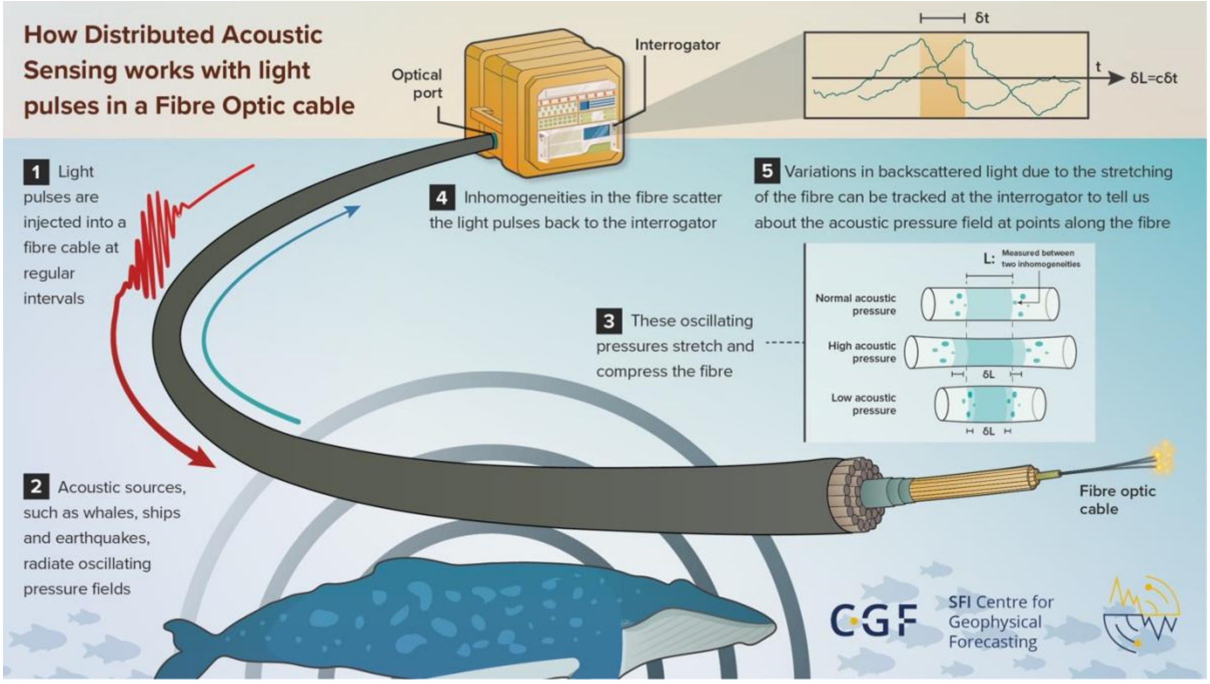

Figure 5. Distributed Acoustic Sensing on Fibre Optic cable explained. Source: SFI CGF.

Data Management and Security

Hannah Mihai (DeiC) presented the challenges and opportunities related to data management. After highlighting the FAIR data principles, the presentation focused on the important challenges arising from data collection on fibre cables. The research community, utilising the sensing infrastructure, needs to agree on certain data management policies and procedures, including but not limited to data scrubbing and filtering workflows, policies for data storage, policies for assigning the metadata, and policies for research communities getting access to the data (see Figure 6).

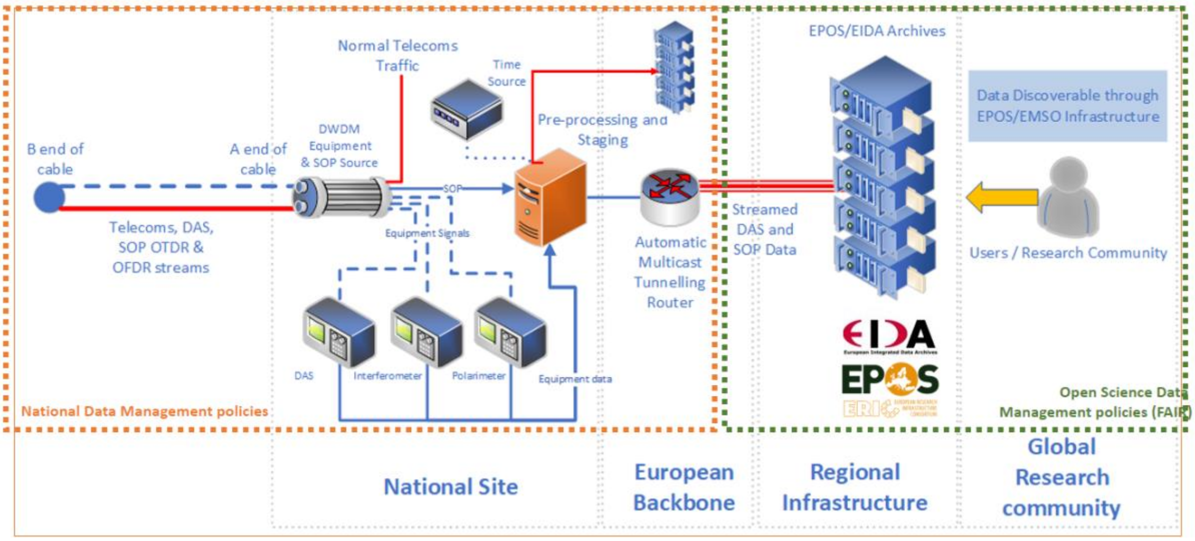

Figure 6. Data collection on fibre cables (SUBMERSE project). Source: SUBMERSE.

Olaf Schjelderup (Sikt) shared his reflections on security and data management, based on Sikt's experience using the Svalbard submarine fibre cable for sensing. While sensing can provide tremendous value to many different stakeholders, it can also capture potentially sensitive information. Currently, there are no data management policies in place to regulate access and management of data from fibre sensing. This creates the need to work closely with governments and other policymakers to ensure access to the data for the benefit of research while at the same time respecting the fact that certain data may have access restrictions associated. Fibre sensing is a technology soon to be used everywhere. With this knowledge we are to adopt the best security and access management practices, together with data scrubbing and sharing policies. We should not underestimate the sensitivity of data from the seabed of Arctic Ocean and surrounding environment, and hence work with governmental agencies to develop best current practices.

Conclusion

The first day of the workshop focused on introducing the fibre sensing technologies and the concept of SMART cables to the researchers, together with the multitude of use cases for research in the Arctic. As fibre sensing is a fast-evolving technology that is used not only for research but also by telecommunications, oil industry, and other fields, we need to be aware of data management and security challenges that arise from creating the sensing infrastructure and gathering the data from the sea, but also creating policies in place for getting access to that data.

The important takeaway from the technology session was the importance of deploying a SMART cable equipped with sensors for the measurement of various parameters as a major shift in observing the Arctic Ocean.

Day 2: Wednesday, 4 October 2023

Introduction to scientific challenges in the Arctic

The main focus of the second day was to get an understanding on the key challenges in different areas of research in the Arctic region.

Key Challenges in Arctic Sciences

The Arctic region, with its icy landscapes and remote, harsh conditions, presents a unique and challenging environment for the fields of seismology, geophysics, and geodesy. Understanding the Earth's dynamics in the Arctic is of great importance, as it is a region where the effects of climate change and natural geological processes are particularly interesting, due to the relatively big impact from the Arctic region on our climate. In this part of the workshop, we delved into the key challenges faced by scientists in these disciplines as they explore the mysteries of the Arctic.

Stein Sandven (NERSC) provided a comprehensive summary of observation systems for climate change in the Arctic Ocean. The Arctic observing network monitors the sea ice, the ocean, the atmosphere, the glaciers and many other parts of the environment. One of the main challenges is that it is very hard to find out what is happening with the ocean under the ice. Climate models cannot represent the ocean under the sea ice well as there is no consistent and validated data from the waters under the ice (see Figure 7).

While sea level can be measured from satellites, it would be a beneficial supplement with bottom-based pressure measurements, as this could also reveal seasonal variations. Thus, long time series of bottom pressure data are important for monitoring sea level change.

The talk initiated a discussion whether a submarine cable system can act as a more generic platform for supporting scientific AUVs, regularly connecting to the cable by means of a docking station for power and data offload. If data offload should happen via acoustic communication, it would be hard to provide data rates of more than approximately 200 kbit/s.

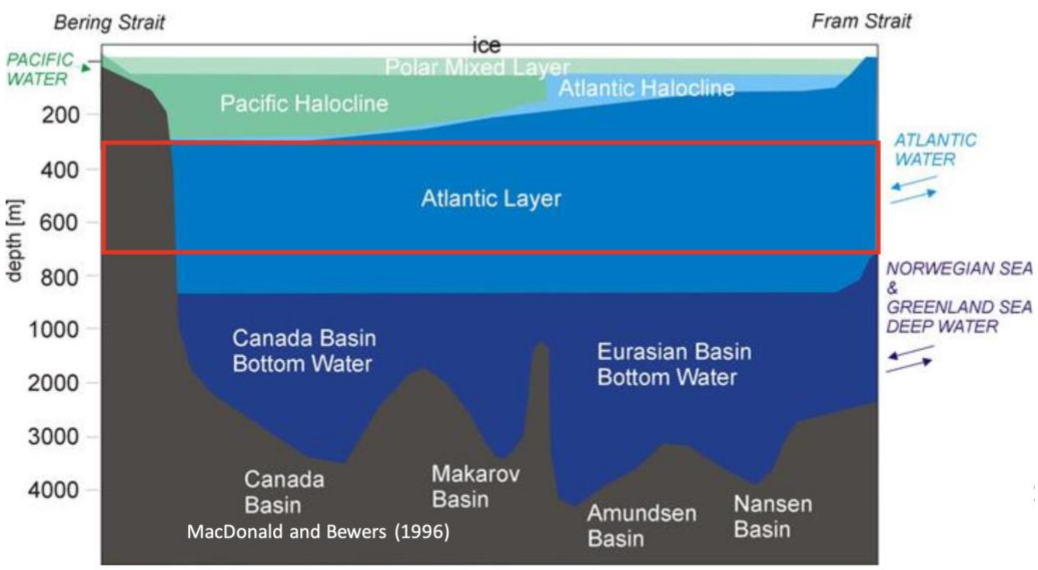

Figure 7. Arctic Ocean layer complexity. Source: MacDonald and Bewers (1996).

NERSC coordinates a HORIZON Europe project High Arctic Ocean Observing System (HiAOOS) (https://hiaoos.eu). HiAOOSwill install a network of multipurpose moorings that will provide point measurements of the ocean and the sea ice and active and passive acoustic data for several applications, including acoustic thermometry, geo-positioning of underwater floats, detection of marine mammals, geohazards, and human generated noise. However, the data will not be available in real-time, rather show recorded data of past 2 years, as it can only be extracted when the moorings are picked up. Polar Connect presents an attractive solution by providing both continuous power feed and real-time data transfer capabilities to “super sites” for observing the full water column.

Geodesy in the Arctic faces unique challenges due to the combination of rapid ice melt and the inherently complex relationship between the Earth's crust and ice sheets. Measuring and understanding the changes in the Earth's shape and the associated risks, such as land uplift and subsidence, are of utmost importance. Interpreting geodetic data in the Arctic is intricate, requiring advanced modelling and a comprehensive understanding of the complex interactions between the cryosphere, geosphere, and hydrosphere.

Per Erik Opseth (Kartverket, Norwegian Mapping Authority) introduced the unique perspective on Very-Long-Baseline Interferometry (VLBI) and the services they provide for geodesy and astrometry. VLBI stations are strategically placed on different continents to create extremely long baselines, allowing for unparalleled precision in astronomical observations. The data collected from multiple VLBI stations can produce highly accurate measurements crucial for operating satellites in space, track earth rotation, monitor global ice melt, sea level changes, tectonic plate movement and etc (see Figure 8).

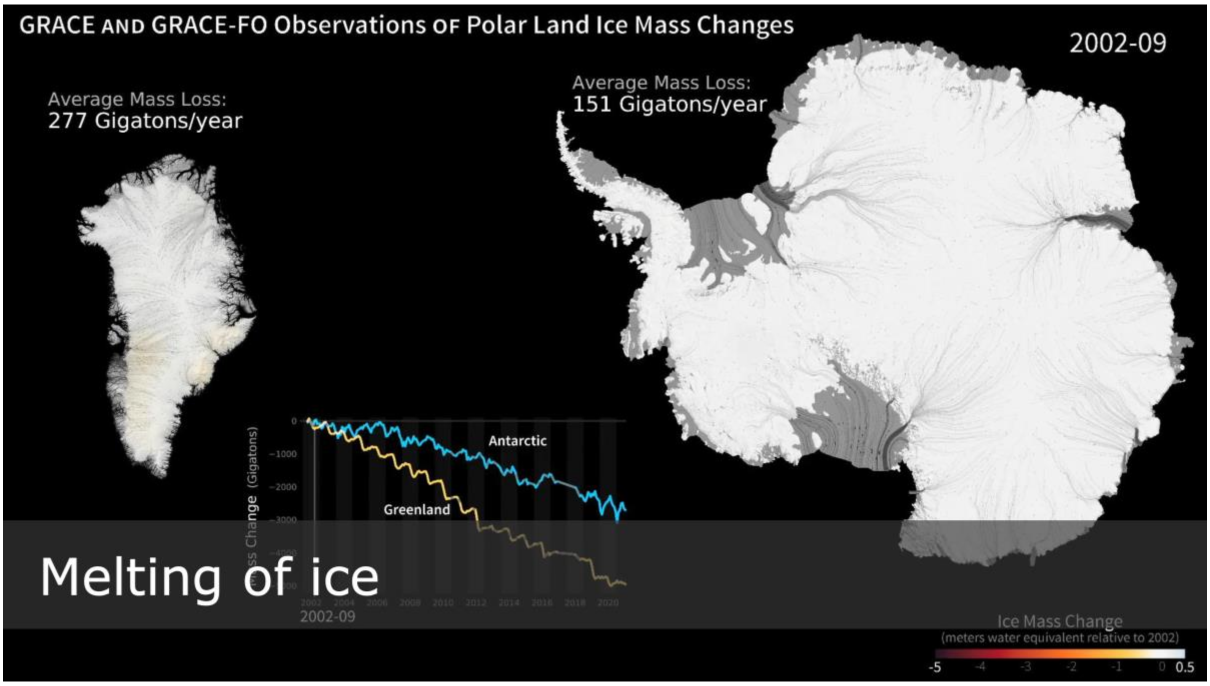

Figure 8. Observation of ice mass loss from space. Source: Kartverket.

VLBI stations could benefit from real-time data transfers to Germany, the United States, and Japan, as each radio telescope can generate up to 50 terabyte of data per day. The near real-time processing of data would create an opportunity to improve Earth observation. Moreover, the use of VLBI data for defining the satellites’ positions relative to the ground are of uttermost importance for applications such as Earth observation and satellite-based geolocation, since the Earth's rotation and its rotational axis are not constant. Being able to correct for these variations in near real-time would bring large societal benefits. Today, these corrections are made with a time lag of weeks.

Key Challenges in Arctic Climate Sciences and Services

The Arctic region is a vital area of study for climate scientists. It serves as both a barometer of global environmental changes and a focal point for understanding complex feedback mechanisms. Scientists from Stockholm University and Nansen Environmental and Remote Sensing Center explored the key challenges faced by scientists in the realm of Arctic climate sciences and services based on scientific research and information.

The Arctic is experiencing climate change at an accelerated rate compared to the rest of the planet. This phenomenon, known as Arctic amplification, results in a myriad of challenges and research questions. Rising temperatures lead to the rapid retreat of sea ice, permafrost thaw, and shifts in ecosystems. The Arctic is sparsely populated and the central Arctic Ocean is challenging to access, which means that climate observations are limited both in frequency and spatial coverage. A lack of continuous data points in this vast expanse makes it challenging to create accurate climate models and predictions, especially for local and short-term phenomena.

Léon Chafik's (Stockholm University) presentation focused on water mass exchange in the Arctic region, monitoring the impact of water flows from the Pacific Ocean to the Labrador Sea. Measuring the Atlantic Meridional Overturning Circulation (AMOC) extension into the Arctic Ocean is currently not possible (see Figure 9).

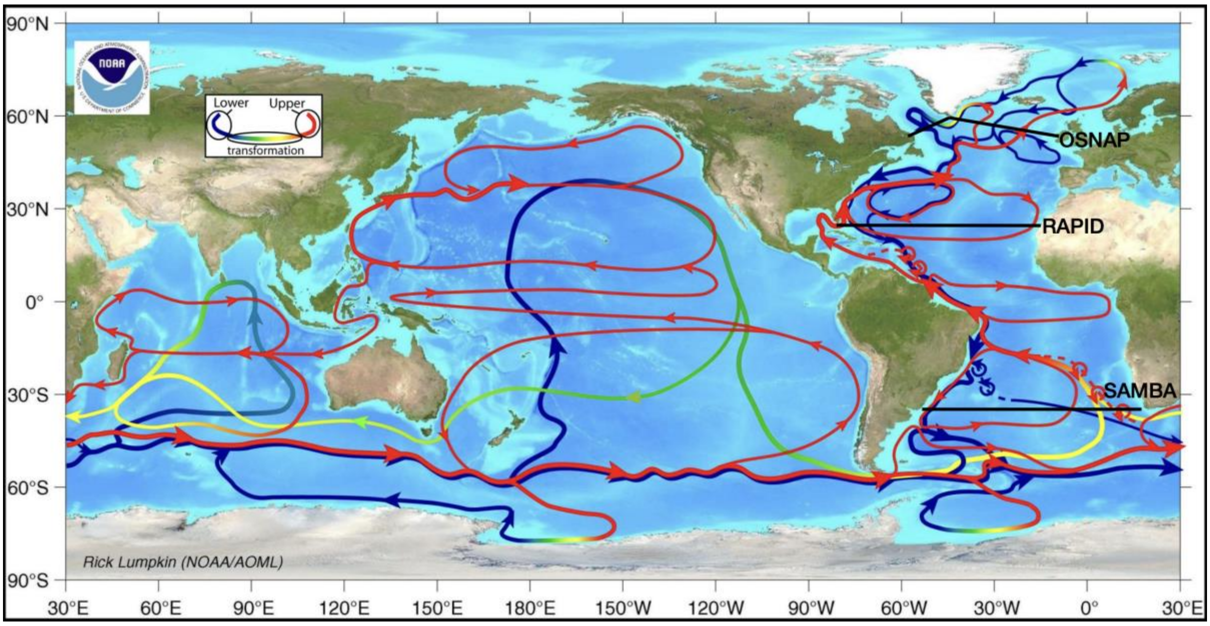

Figure 9. Global ocean circulation and Atlantic Meridional Overturning Circulation. Source: NOAA.

The monitoring of these currents would be most beneficial and impactful to climate modelling if it was done from top to bottom, coast to coast. In a case where the submarine cable was to be situated where strong currents that move southwards are, it can be used to monitor the stability and health of the currents in the Arctic Ocean and its connection to the North Atlantic Ocean. Continuous high precision measuring of temperature and salinity is essential to reduce the level of wrong assumptions and projections (see Figure 10).

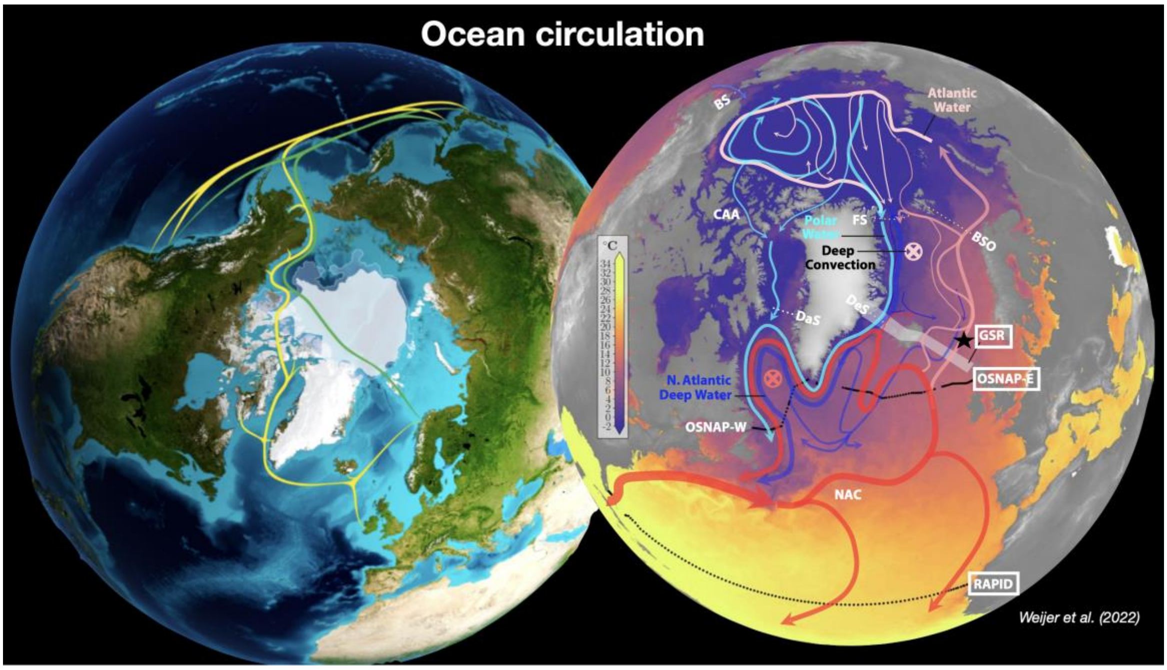

Figure 10. Potential continuous monitoring of ocean circulation in the Arctic. Source: NORDUnet, Weijer et al. (2002).

Yiguo Wang (NERSC) introduced his research focusing on climate system reconstruction all the way back from 1850, with the aim to understand anthropologically driven climate change, to study climate variability monitoring and to initialise climate predictions. Sea ice predictions are needed by shipping industries, local communities, fisheries, wildlife conservation, tourism, oil and gas industries, and scientific logistics. Continuous observations from submarine cable systems on the bottom of the Arctic Ocean delivering pressure measurement is crucial to understand boundary currents (Figure 11), both for climate reconstruction and predictions. Climate models are very dependent on the initial data parameters fed into the model and currently the average spatial gap between direct cable observations is in the order of 2,000 km and mostly only from summer seasons. Reducing the data spacing to the 80-100 km currently possible with SMART cables and to also have data from all year around would be a big leap forward.

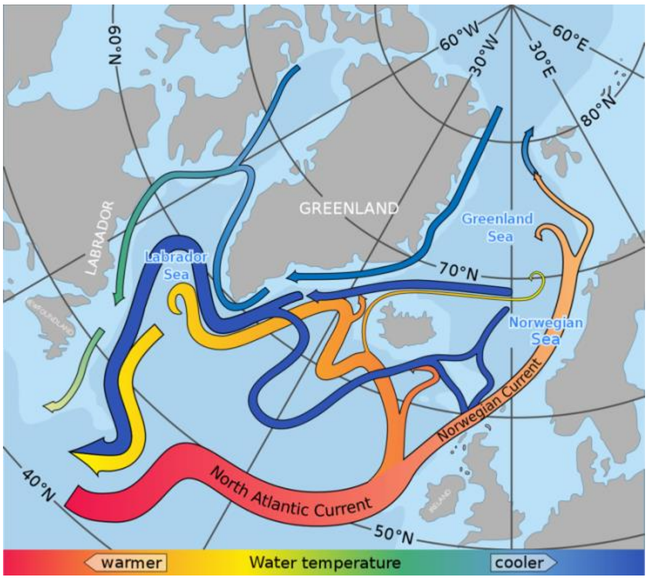

Figure 11. Understanding boundary currents for climate reconstruction and predictions. Source: NERSC.

Arctic climate sciences and services are vital for understanding and addressing the challenges presented by climate change in the region. Scientists in these fields face a variety of obstacles, from collecting data in harsh conditions to unravelling the intricacies of feedback mechanisms. By helping to overcome these challenges, researchers can contribute to our understanding of global climate dynamics and help communities and ecosystems adapt to a rapidly changing environment.

Key Challenges in Ocean Sciences

Oceanographers studying this remote region encounter numerous challenges in their quest to understand its complexities. This part of the agenda focused on the key challenges faced by ocean scientists.

Arctic Ocean researchers are operating in a remote environment characterised by extreme cold, sea ice cover, and stormy waters. These conditions make accessing the region challenging, requiring specialised equipment and expertise. There is no room for mistakes. The logistical challenges of working in such an unforgiving environment are substantial.

Anna Wåhlin and Céline Heuzé (Gothenburg University) focused on identifying the challenges in Arctic oceanography. The main challenge identified was the missing continuous high spatial resolution data from all seasons, not just the summer, to help understand climate tipping points (see Figure 12). Currently available measurements of temperature and salinity are limited geographically, seasonally, and are taken only once. Additional parameters, like gas or nutrient concentrations, are also needed to bring value to analysing shelf and deep-water interactions.

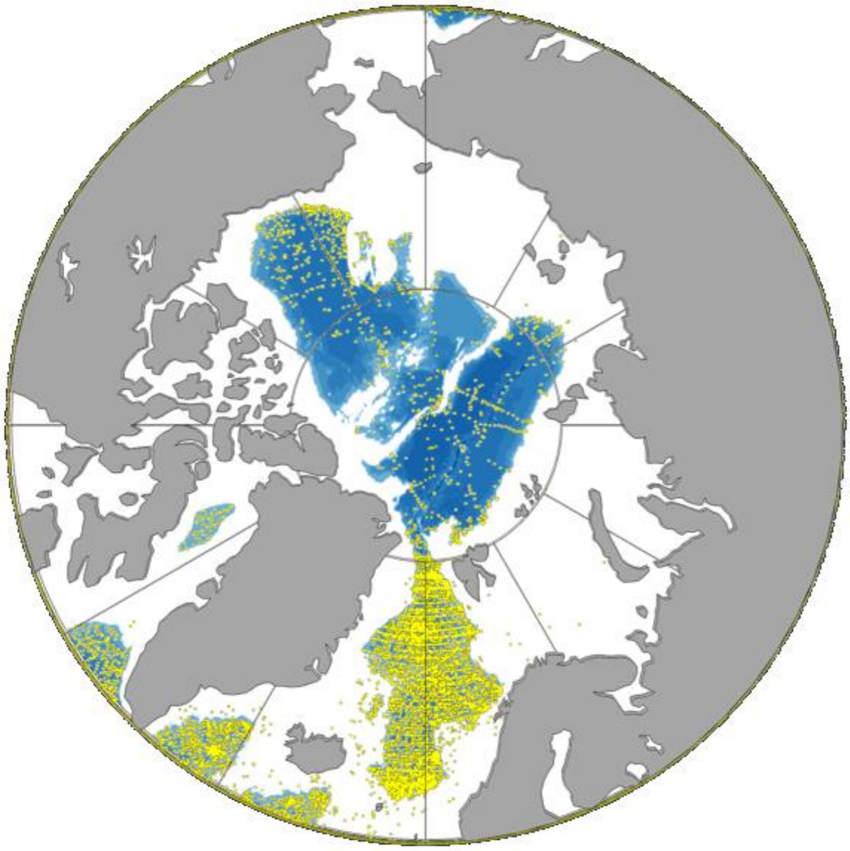

Figure 12. Yellow mark the deep water (> 2000m) casts ever made. Source: Céline Heuzé et al *2022* Environ. Res. Lett.

Oceanography scientists made a notion of the importance of sensor calibration since a small change in water temperature has a large impact when converted to energy, e.g. a 0.01 degrees change in water temperature corresponds to 10 degrees in air temperature. Hence, the issues of sensor drift, sedimentation, and biofouling are major challenges to submarine sensors. Also, sensors deployed in the Arctic Ocean over a long period of time must have a very high reliability, and preferably redundancy, since they will not be easy to repair or replace. Salinity is the most important parameter for Arctic oceanography; salinity sensors however have only become reliable and accurate enough over the last 30 years. Therefore, the oceanographers would prefer a solution that allows them to plug these already existing. finally-trustworthy sensors to a solution with a new type of sensors.

Sea ice in the Arctic is in constant motion, making it challenging to predict its behaviour when scientists are deploying instruments. Oceanographers must contend with ice that can obstruct research vessels, damage equipment, and alter ocean circulation patterns. Understanding the relationship between the sea ice and the underlying ocean is one of the significant scientific challenges of the region.

Compared to more temperate oceans, the Arctic has a sparse network of monitoring infrastructure, including buoys, research vessels, and underwater observatories. This limits the availability of real-time data, hindering the comprehensive study of the region.

The Arctic Ocean covers vast areas that are far from the established research facilities. This means that conducting fieldwork in the Arctic is logistically complex and costly. Researchers often face challenges in deploying and maintaining equipment in such distant and challenging areas, hence the need for reliable sensors that need no maintenance.

The Arctic Ocean is experiencing dramatic environmental changes due to climate change. Understanding the implications of these changes on marine ecosystems, ocean circulation, and nutrient cycles is a pressing scientific challenge.

Hence, sensing cables installed under the ice is the most viable way to overcome many of the obstacles above.

Key Challenges in Arctic Marine Biology

This extremely cold region hosts a unique marine ecosystem that is both highly adapted but also exceptionally vulnerable. Marine biologists are facing a myriad of challenges when studying life in this hostile region. The presentation by Lise Doksæter Sivle (IMR) explored some of the key challenges in Arctic marine biology based on research on the impact of sound on marine animals. There is a general lack of knowledge how the different species of animals are affected by various noise disturbances such as seismic air gun surveys, shipping and naval sonars. Exposure experiments have shown that both fish and marine mammals may stop feeding and/or swim away from the disturbance. However, the duration of the response, and its potential implications for reduced fecundity and reproduction is largely unknown, and a large knowledge gap is therefore how populations or stocks are affected. Arctic ecosystems are under stress, impacting biodiversity and potentially further altering global climate dynamics.

The immediate benefit using submarine fibres for acoustic sensing would be to monitor the presence of vocal marine species at different locations and periods with a temporal and spatial resolution that is not possible by other means (see **Error! Reference source not found.**). Such acoustic sensing will also allow getting a real time and long-term monitoring of the anthropogenic noise, that could be correlated with animal presence. Getting a high-resolution picture of the soundscape in the Arctic, and in particular with long term continuous monitoring, will greatly help monitoring changes over time. This is particularly important as human development in the Arctic is likely to increase in the coming years, thus creating more disturbance to animals.

The Arctic is undergoing profound environmental shifts due to climate change. Rising temperatures, melting ice, and altered ocean currents are impacting marine life and ecosystems. Understanding how these changes affect Arctic marine biology is yet another challenge for researchers. It involves predicting how species will respond to altered food webs, habitats, and ecosystem dynamics.

Key Challenges in Arctic Seismology

The Arctic, with its frozen landscapes and unique geological formations, presents a frontier for geologists, offering insights into the Earth's ancient history and its ongoing transformation. Seismology is a discipline for monitoring geological activity such as earthquakes and volcanic eruptions. Establishing and maintaining seismic networks in the remote and extreme conditions of the Arctic is a challenge. It involves deploying sensitive seismometers on harsh and icy terrains where access can be limited due to extreme cold conditions, moving sea ice, and remote locations. Maintaining and servicing equipment in such conditions is logistically complex and costly.

Ari Tryggvason from Uppsala University presented the seismological research in the Arctic, providing the audience with an adept overview of possible opportunities by utilising submarine fibre as an instrument for monitoring seismic activity around the Gakkel Ridge (see Figure 13). The sensing capabilities can contribute to monitoring tectonic plate movements between the North American Plate and the Eurasian Plate, increased seismic monitoring in this area will likely reveal hitherto unknown seismic lineaments and seismic “hotspots”.

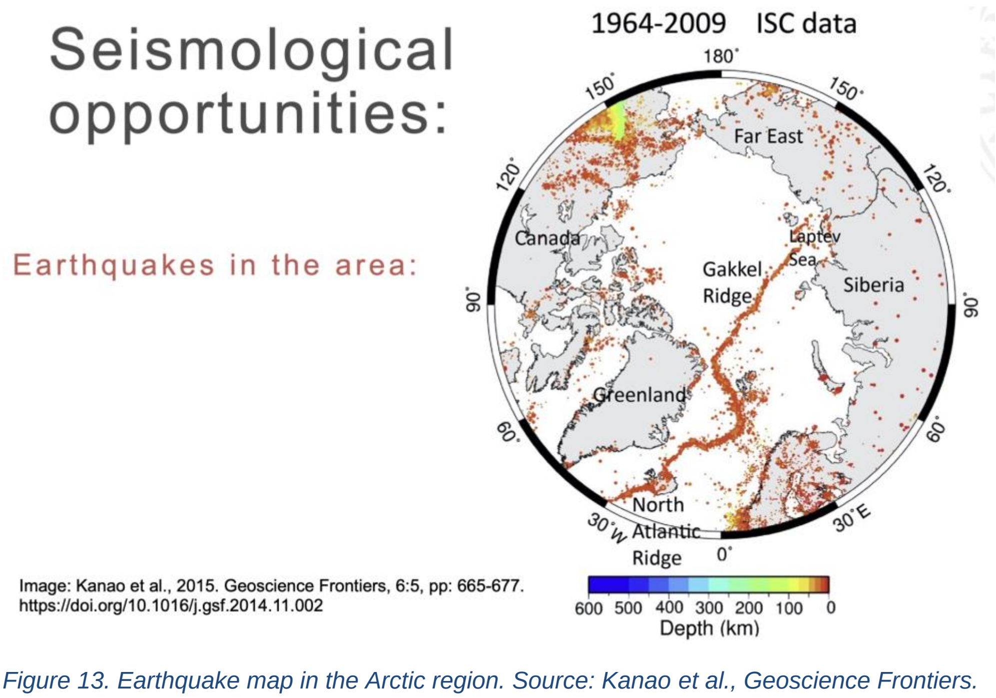

Figure 13. Earthquake map in the Arctic region. Source: Kanao et al., Geoscience Frontiers.

The Arctic Ocean's seafloor is a geologically significant yet underexplored area. Submarine mountain ranges, hydrothermal vents, and fossil-rich sediments hold clues to Earth's past and the dynamics of the ocean basin. Researching these sites is challenging due to the Arctic's harsh marine conditions, including a thick ice cover and the need for specialised equipment.

The vast and varied Arctic terrain requires extensive geological mapping and surveying. Creating detailed maps of the region's active volcanoes, also known as black smokers, moving plates, and other interesting processes is a significant challenge given the scale and inaccessibility of many areas. The Arctic's geological wealth, including mineral and energy resources, has attracted significant industrial and economic interest. Balancing resource exploration with environmental and ecological protection is a key challenge for geologists and policymakers alike.

Wrap-up and Next Steps

The closing remarks of the workshop highlighted the importance of this event, that helped understand various scientific challenges in the Arctic better. The rich exchange of knowledge, the depth of discussions, and the interdisciplinary collaborations proved the dialogue with the researchers is essential to ensure fibre sensing and SMART cable technology is developed with the aim to offer access to continuous observation data from the Arctic Ocean. Additionally, it was beneficial to hear general agreement from the researchers to continue the dialogue and stay involved in future engagement events to communicate their needs and requirements for the development of Arctic monitoring applications using submarine cable systems and fibre sensing technologies. This workshop served as a starting point paving the way for continued collaboration, innovation, and a deeper understanding of the complex dynamics of the Arctic region.

Conclusions

The Arctic is a region of great complexity due to the harsh conditions and moving ice. The effects of climate change are causing shifts that are not yet fully integrated into the climate modelling due to lack of data from the Arctic. Researchers go to extreme lengths for deploying scientific instruments only to be able to collect data from the Arctic over the summer period. This requires flexibility in research approaches and extremely accurate planning, as well as the ability to adapt to the rapidly changing conditions of the Arctic environment.

The "Science Opportunities on Polar Connect" workshop has shown the high value of using submarine fibre cables equipped with sensing technology crossing the Arctic region for a variety of Arctic research areas. This ambitious initiative, driven by NORDUnet and supported by the EU co-funded CEF Digital 'Northern EU Gateways' project, opens new opportunities for collaboration between technology developers and researchers in the Arctic region to work closely together in understanding the needs and tailoring the requirements for the development of the sensing technologies. The challenges and expectations discussed throughout this workshop emphasise the critical need for fibre sensing in the Arctic, with a focus on observing the cross-disciplinary parameters, like temperature, salinity, velocity, and pressure.

The Arctic Ocean is an uncharted region that defies simple explanations and demands innovative approaches to understanding its dynamics. The deployment of fibre sensing technology will offer a major shift in the way we observe and comprehend the Arctic. Real-time data streams of temperature, pressure, salinity, acoustics, and seismicity, as well as connecting together observation systems across the Arctic in real-time will allow us to monitor and analyse the subtle changes of this dynamic environment in far more detail than has ever been possible before. These parameters are key elements of scientific modelling for Arctic climate studies, oceanography, ecology, and geophysics. They hold the key to understanding the effects of the global climate change, ocean circulation, biodiversity, and the profound geological processes that shape this region and impact the surrounding continents.

Submarine cables are being enhanced with sensors for new applications that contribute to a better understanding of the Earth and its natural processes. Apart from usual telecommunications traffic, submarines cables can be used to monitor and detect:

- Seismic activity and geophysics for enhanced monitoring of tectonic movements and earthquakes.
- Tsunamis, leading to improved warning systems for society, living in the close proximity of seismic activity.
- Global warming, with continuous tracking of ocean warming trends.
- Parameters for improved weather forecasting and climate change modelling.
- Accurate sea level rise over a long period of time.
- Marine mammal communication and other oceanic sounds impacting the sensitive Arctic ecosystem.

A range of fibre sensing technologies are already available, and more are under development. The aim is to provide researchers with appropriate trustworthy instruments that can be selected based on key parameters to be monitored, with required range, sensitivity, and longevity.

The Arctic Ocean presents particular challenges to the submarine sensors on the seabed, particularly with regard to sedimentation. The deposition of sediments on the seafloor can obstruct sensors and impede data collection. Researchers and engineers are tasked with developing innovative solutions to mitigate these challenges and ensure the reliable operation of fiber sensing technology in the deep Arctic waters. Also, the sensors can become part of the ocean floor, and thus provide a habitat for small marine life, while obstructing the sensing.

Moreover, the essential regular calibration of sensors in the depths of the Arctic Ocean is a complex endeavour. The extreme conditions and remote locations make sensor maintenance and calibration a formidable challenge. These sensors must operate autonomously and continuously, providing data accuracy and reliability over extended periods. The calibration process is essential for data accuracy and validity.

Fibre sensing technology integrated into the Arctic digital infrastructure promises to revolutionise our understanding of this region. It will also empower researchers to make informed decisions, respond to environmental changes, and provide valuable insights for global climate studies. The fibre sensing technology ensures an innovative approach in understanding the complex dynamics in the Arctic with minimal intervention and little to no impact to the surrounding environment, once the scientific instruments have been installed.

The "Science Opportunities on Polar Connect" workshop has set the ground for emphasising the importance of collaboration between the research and technical community for the successful development of fibre sensing in the Arctic - creating high value both for science, our planet and global society. As this is an ambitious path, it is crucial to harness our collective skills, knowledge, and resources, foster international collaboration, and push for innovation to create a sustainable way of continuous exploration and understanding of the Arctic region and its global significance. With fibre sensing technology and SMART cables, the secrets of the Arctic will be much easier to unveil and share with the world.

In all the Arctic research fields, a significant challenge is the collection and integration of data. Researchers need comprehensive, continuous, and precise datasets from a region that is remote, vast, and often inaccessible due to its extreme conditions. Moreover, the integration of multi-disciplinary data, including seismic, geophysical, and geodetic information, is essential for understanding of the Arctic environment dynamics.

Summarising the thoughts from the workshop, the requirement from the researchers is to have a mature and long-lived plug-and-play Arctic observation system with calibrated sensors and constant monitoring opportunities for various parameters. The maturity of such a system would ensure trust and integrity of data collected by the sensors. Trustworthy technology is an absolutely necessary element for researchers to be able to use the data for scientific modelling and as a basis of their research. Redundancy of sensors can be ensured by installing sensors in fewer locations, but duplicating the installation.

Appendices

- Appendix 1 – Agenda of the event.
- Appendix 2 – Participants list at the venue.
- Appendix 3 – Remote participants list.