Polar Connect: Opportunities for a long-term Arctic Observatory

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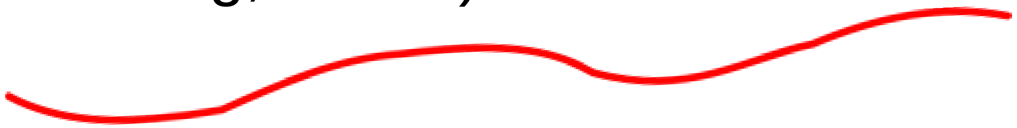
22-EU-DIG-NPF
Co-funded by the European Union

Science Opportunities on Polar Connect

- Sensors permanently embedded into the cable (SMART cables)

- A fiber inside the cable as a sensor (Distributed Optical Fiber Sensing, DOFS)



Rapid development in sensing on submarine fiber cables!

Co-funded by
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22-EU-DIG-NPF

SMART cables

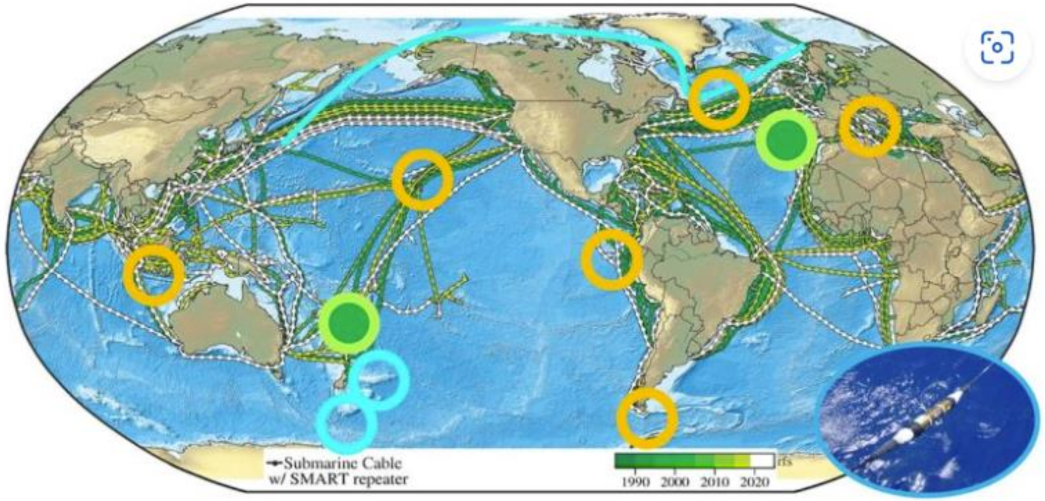
…recently became an Emerging Ocean Observing Network of the Global Ocean Observing System (GOOS)

Goal of UN Ocean Decade: Integrate SMART Cable technology into innovative early warning systems

see also Rowe et al. 2022

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

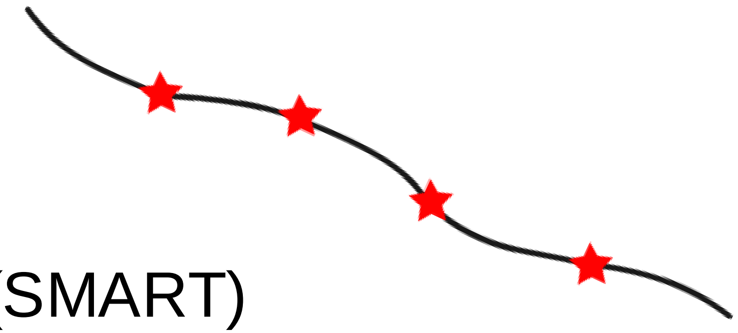
"The SMART Cables network will contribute to GOOS by **filling observing gaps** in the **deep ocean** on the **global scale** with **reliable, real-time, long-term measurements**."



The distribution of current and planned cables. Portugal's Atlantic CAM SMART Cable and the Vanuatu-New Caledonia SMART Cable (green circles) will be ready for service in 2026. Other symbols show cable systems under consideration. (Image credit: SMART Cables)

https://ecomagazine.com/news/research/three-emerging-observing-networks-join-the-global-ocean-observing-system/

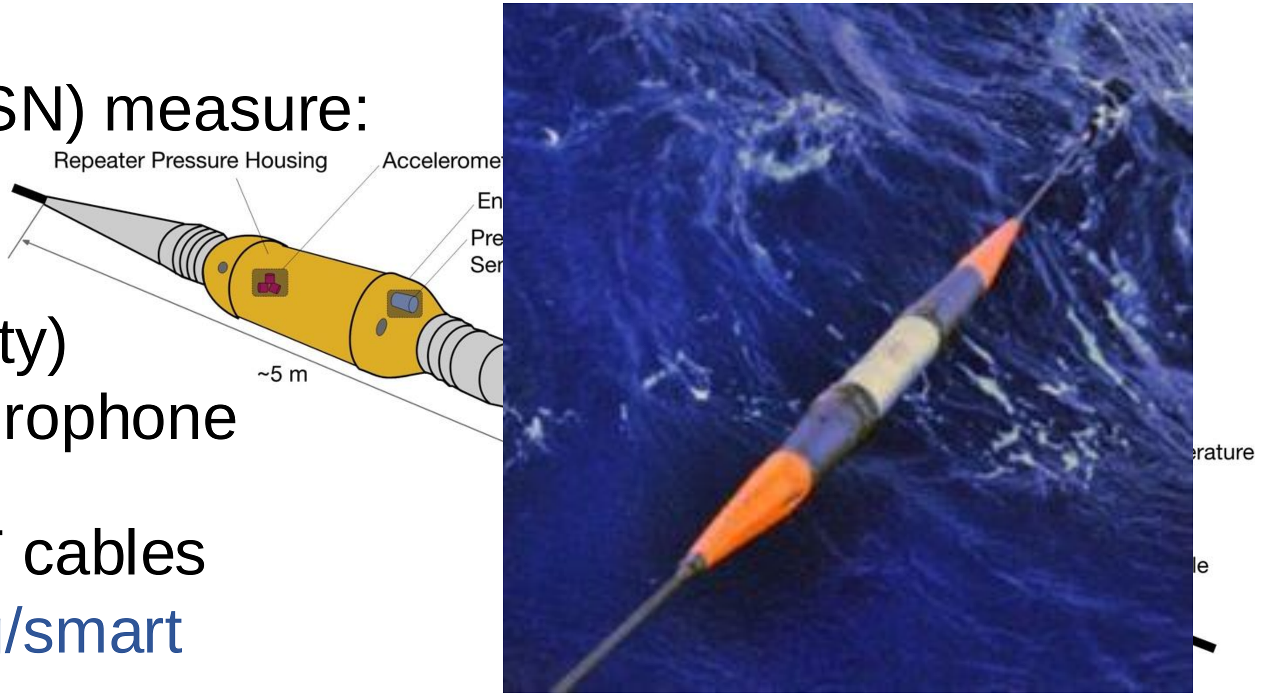
SMART cables



Science Monitoring And Reliable Telecommunications (SMART)
-- use power from cable and use cable itself to send data

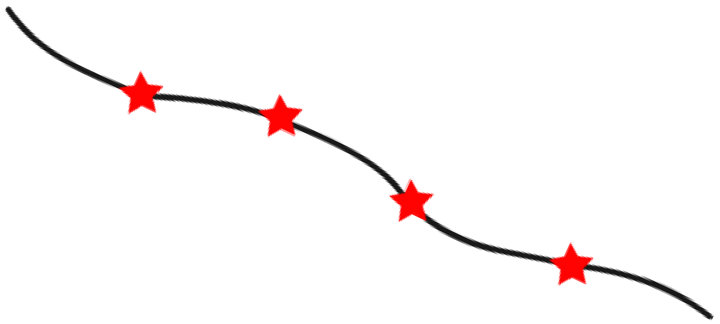
Climate Change nodes (CC-Nodes - ASN) measure:

- ocean bottom water temperature
- ocean bottom pressure
- seismic motion (acceleration & velocity)
  can be similar to a low-frequency hydrophone



Joint Task Force on SMART cables
https://www.smartcables.org/smart

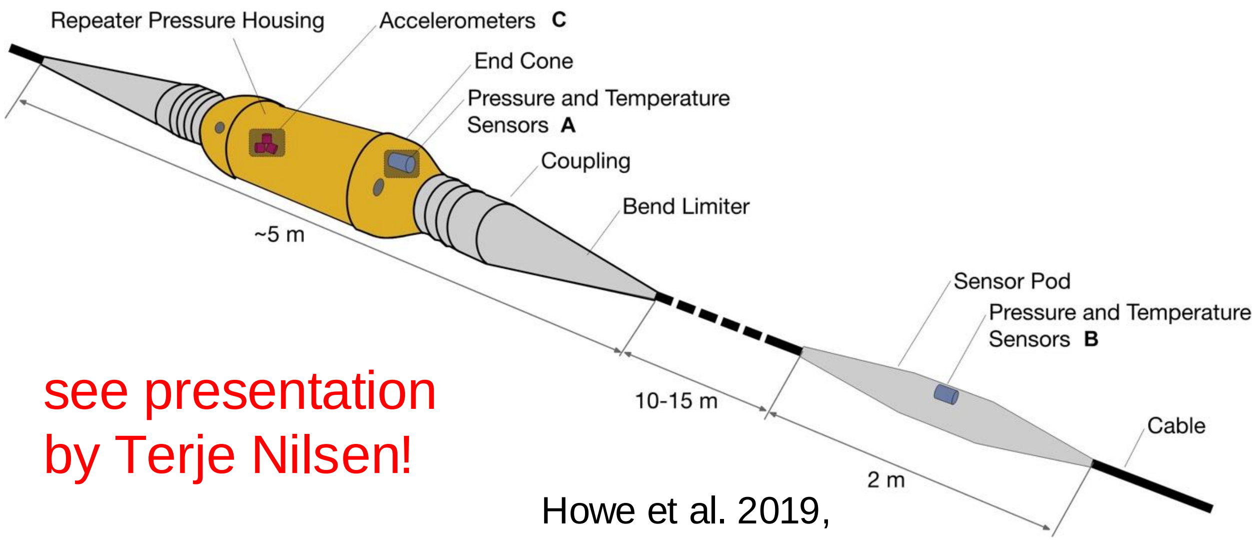
SMART cables



Advantages:
- In situ sensor data!
- Data can be directly assimilated by operational ocean models and geohazard early warning centers
- Flexible placement where needed

Current limitations:
- Power supply (long cables)
- (Not-) Maintenance of sensors
  drift in sensors, biofouling (coastal)

see presentation by Terje Nilsen!

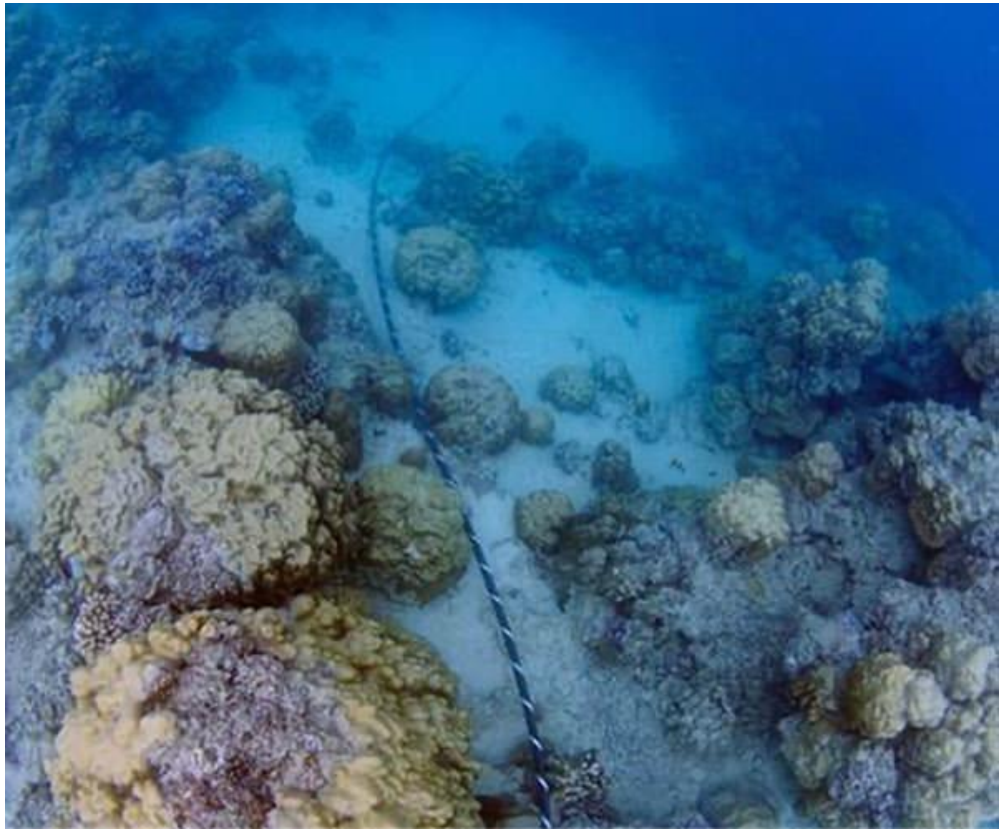


Howe et al. 2019, Frontiers in Marine Science

Distributed Optical Fiber Sensing (DOFS)

Measuring along the optical fiber

- **Scattering: Rayleigh (DAS, strain and temperature)**, Raman (DTS, temperature only), Brillouin (DSTS, strain and temperature)
- **State Of Polarization**
- **Interferometry**
  (on received signal or Fiber Bragg Gating reflected signal)



https://www.asn.com/fiber-sensing/

Rayleigh Scattering - DAS

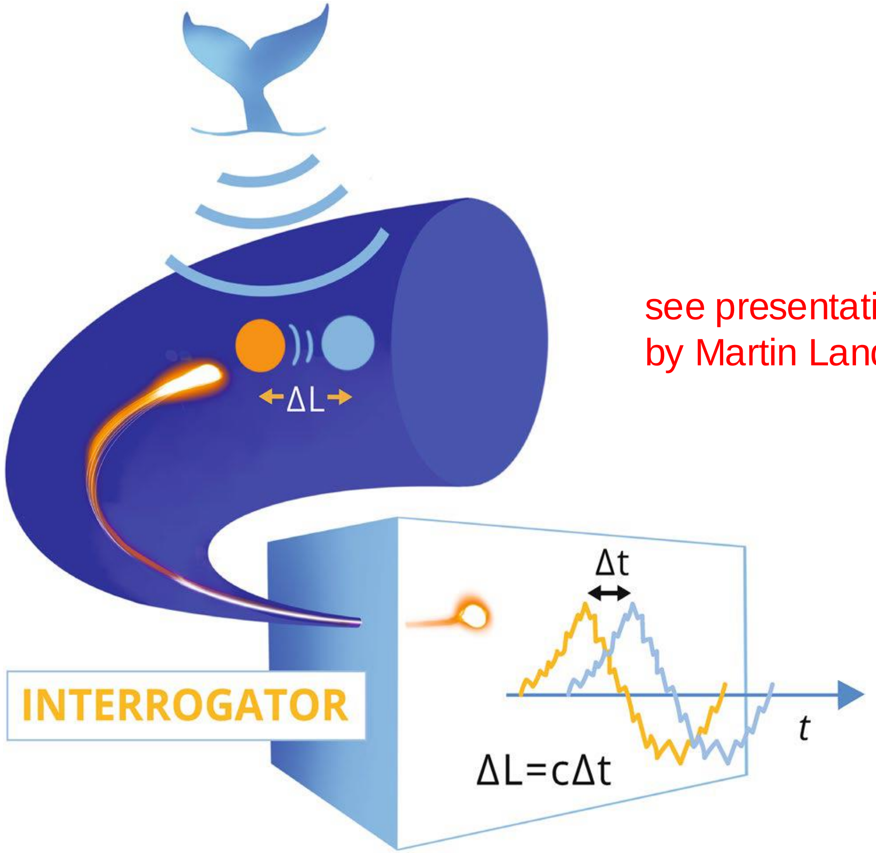
Distributed **A**coustic **S**ensing (DAS)

Primary reason for attenuation of the wave – highest scattering amplitude.

Send chirp pulse into cable and measure phase changes in the scattered signal.

- Needs equipment on shore
- High spatial resolution but limitless range is challenging
- For long ranges DAS needs its own fiber pair

Technological development is ongoing!



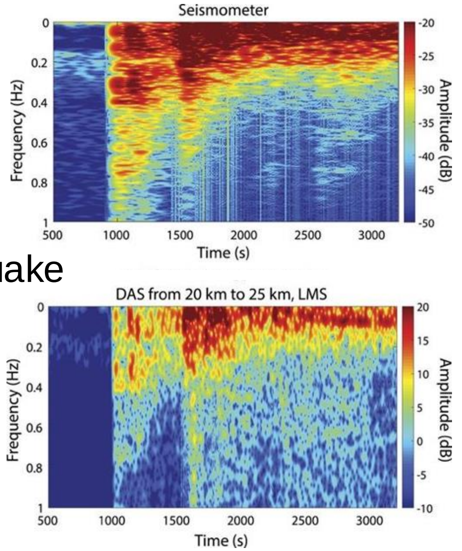
see presentation by Martin Landrø!

Landrø et al. 2022, Scientific Reports

Applications of DAS - Geophysics & Biology

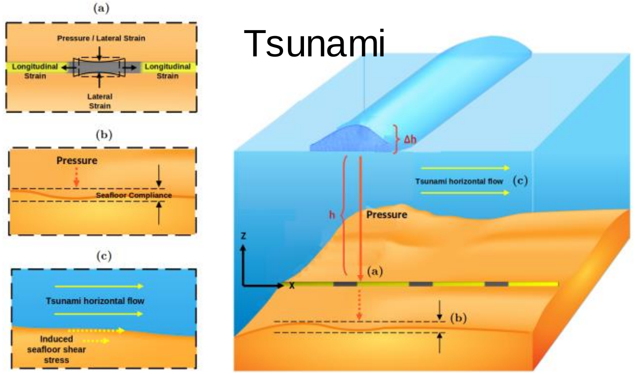
“Distributed acoustic sensing for seismic activity monitoring”

Earthquake



(Fernandez-Ruiz et al. 2020,) APL Photonics

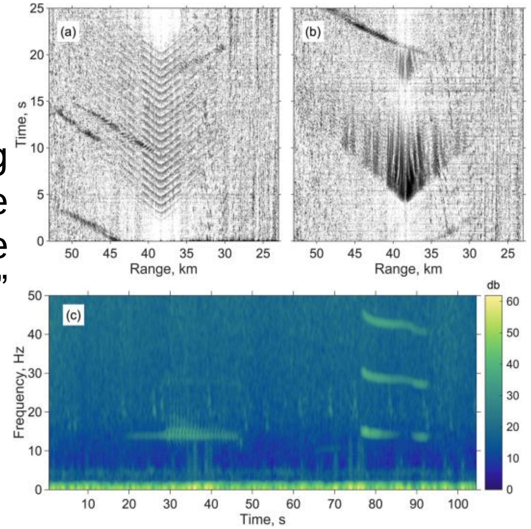
“Towards tsunami early-warning with Distributed Acoustic Sensing: Expected seafloor strains induced by tsunamis”



(preprint Becerril et al. 2024)

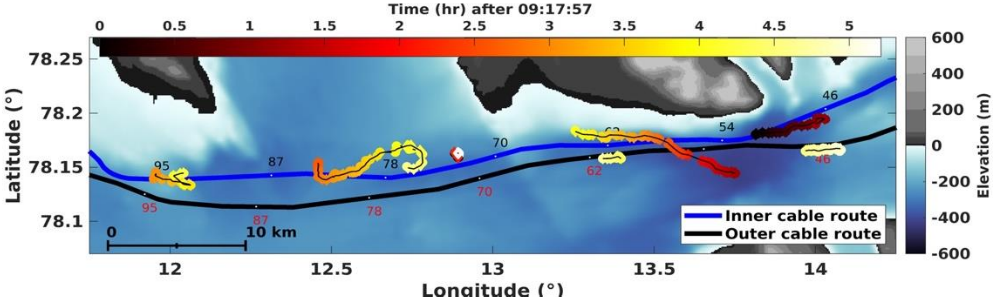
“Distributed acoustic sensing recordings of low-frequency whale calls and ship noise offshore Central Oregon”

see presentation by Martin Landrø!



(Wilcock et al. 2023, JASA Express Letters)

“Simultaneous Tracking of Multiple Whales using two Fibre-Optic cables in the Arctic”

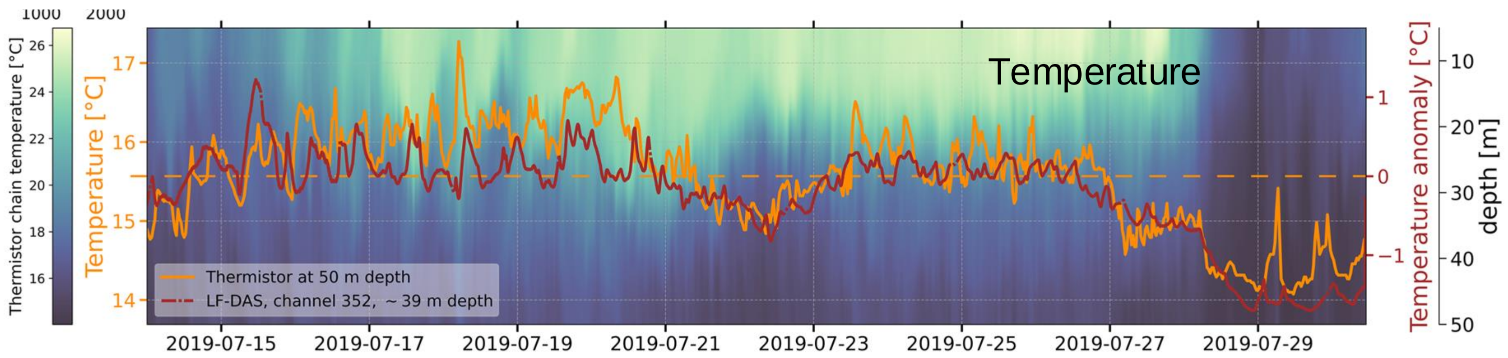


(Rørstadbotnen et al. 2022, Frontiers in Marine Science)

Co-funded by the European Union

Applications of DAS in Oceanography

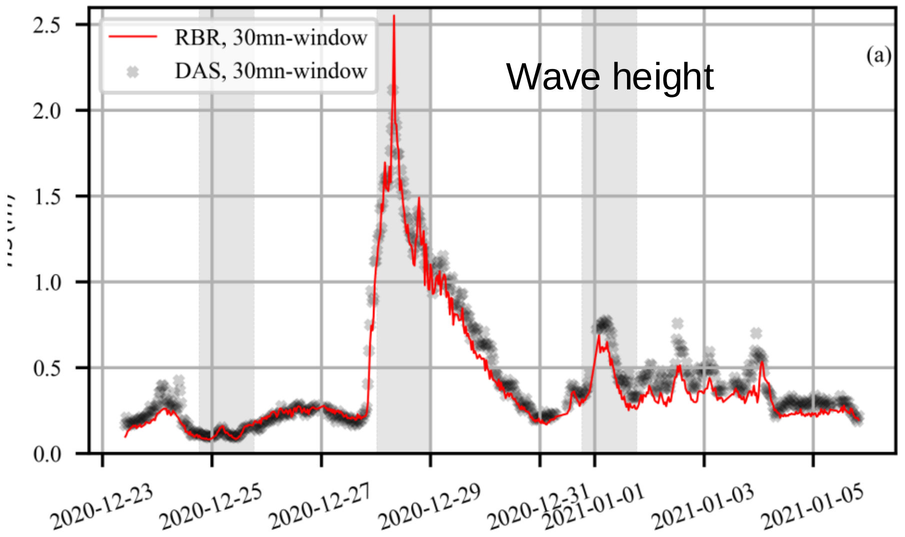
"High Resolution Seafloor Thermometry for Internal Wave and Upwelling Monitoring Using Distributed Acoustic Sensing."



(Pelaez Quiñones et al. 2023, Scientific Reports)

- Temperature anomaly sensors with millikelvin (mK) sensitivity
- Monitoring oceanic processes with unprecedented detail – capturing propagation characteristics of ocean seafloor variability
- Currently, DAS only provides temperature changes estimates, however practical solutions are outlined to obtain continuous absolute temperature measurements with DAS at the seafloor.

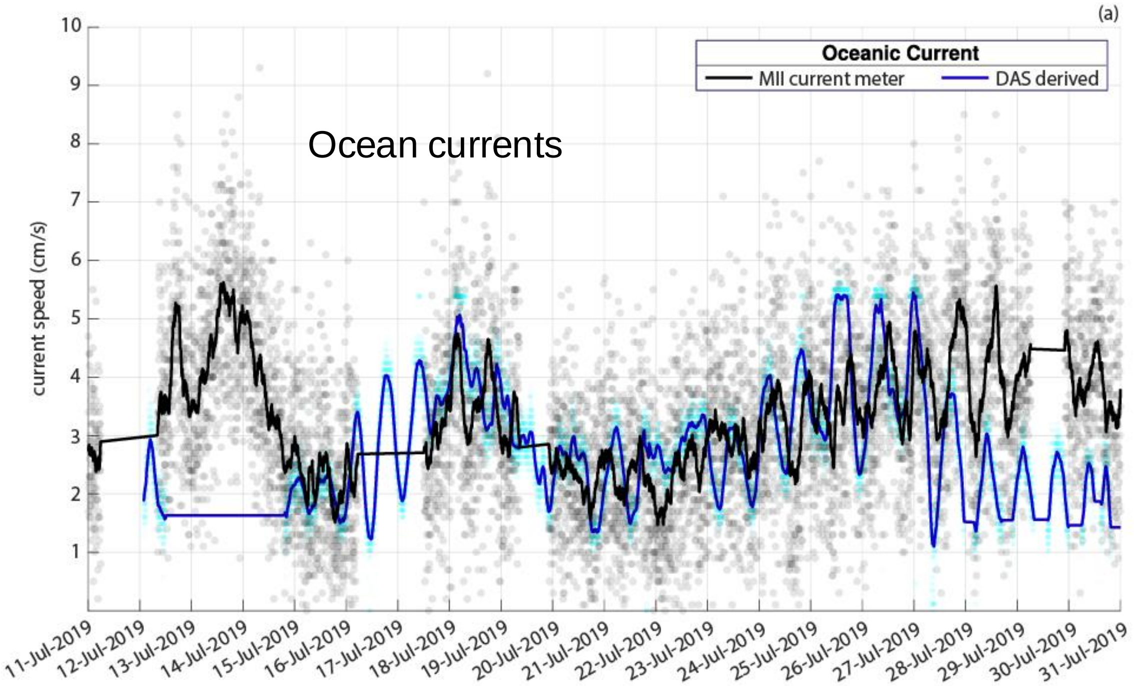
"Reconstruction of Nearshore Surface Gravity Waves from Distributed Acoustic Sensing Data"



(Meulé et al. 2024, preprint)

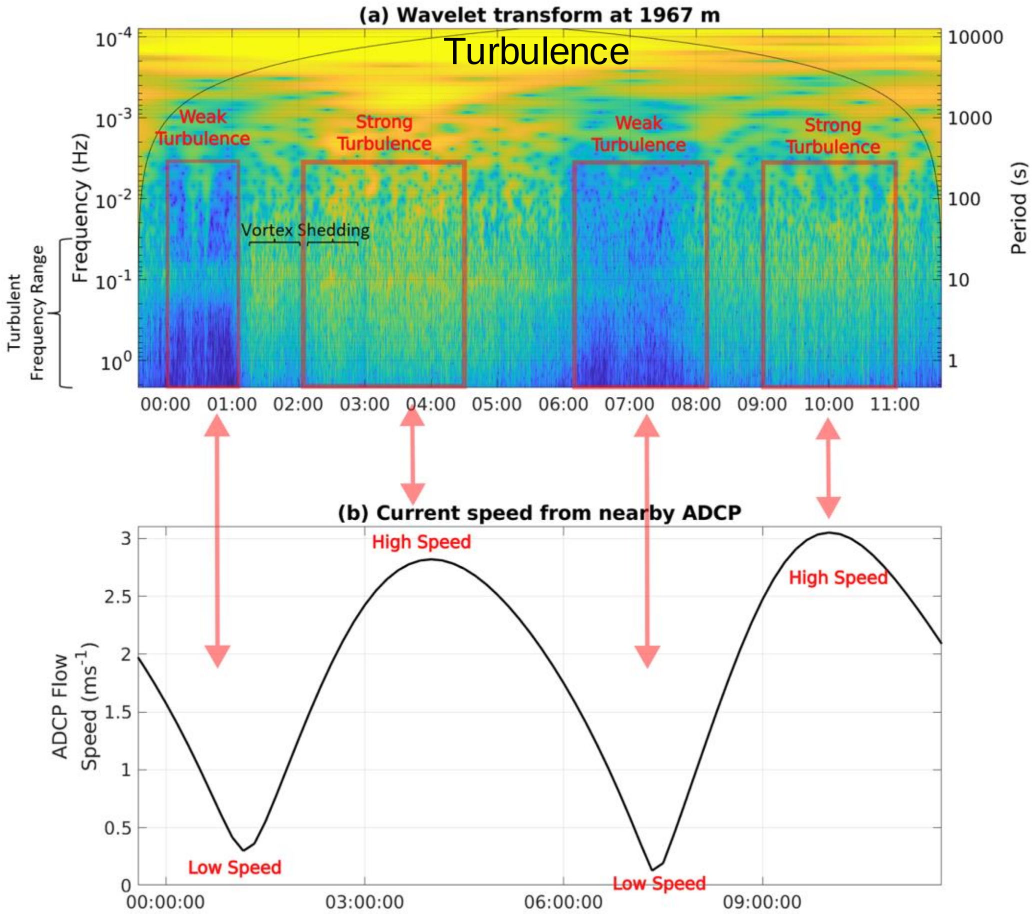
Applications of DAS

"Monitoring Deep Sea Currents with Seafloor Distributed Acoustic Sensing" (through vortex-induced vibrations)



(preprint Flores et al. 2022, published 2023, Earth and Space Science)

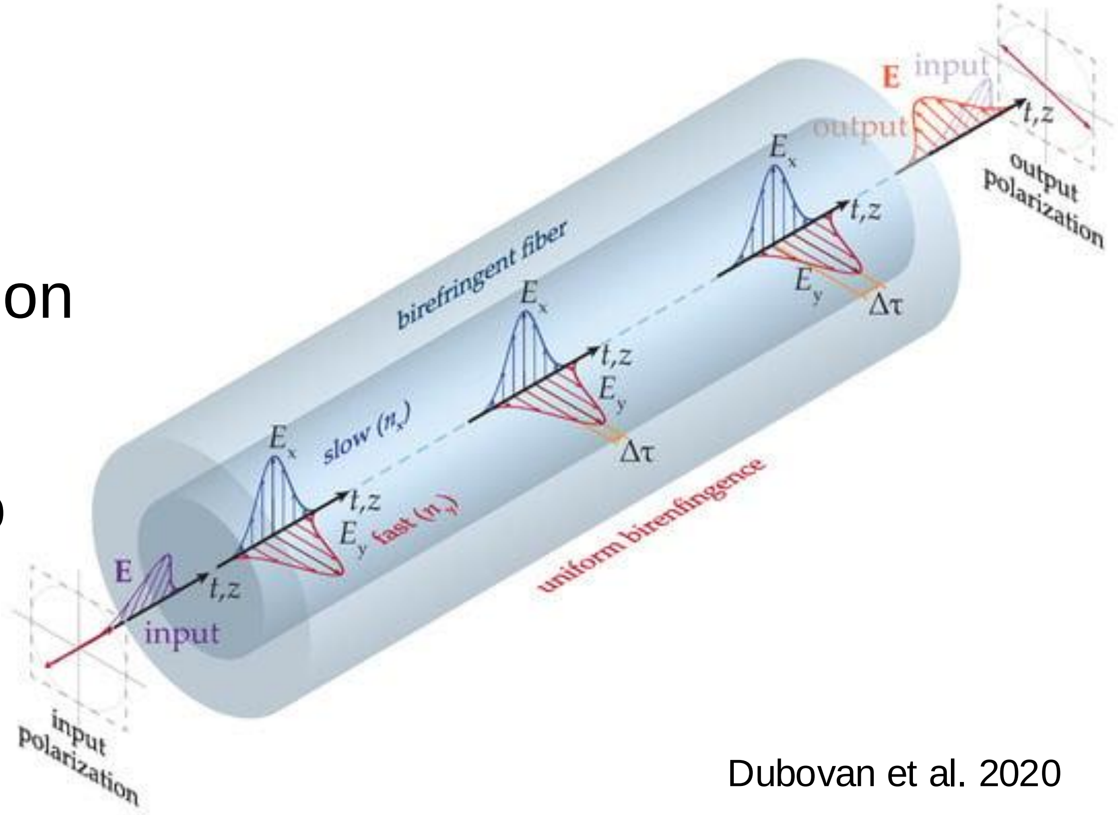
"Optical fibre sensing of turbulent-frequency motions in the oceanic environment"



(Spingys et al. 2024, Scientific Reports)

State of Polarisation (SOP) Sensing

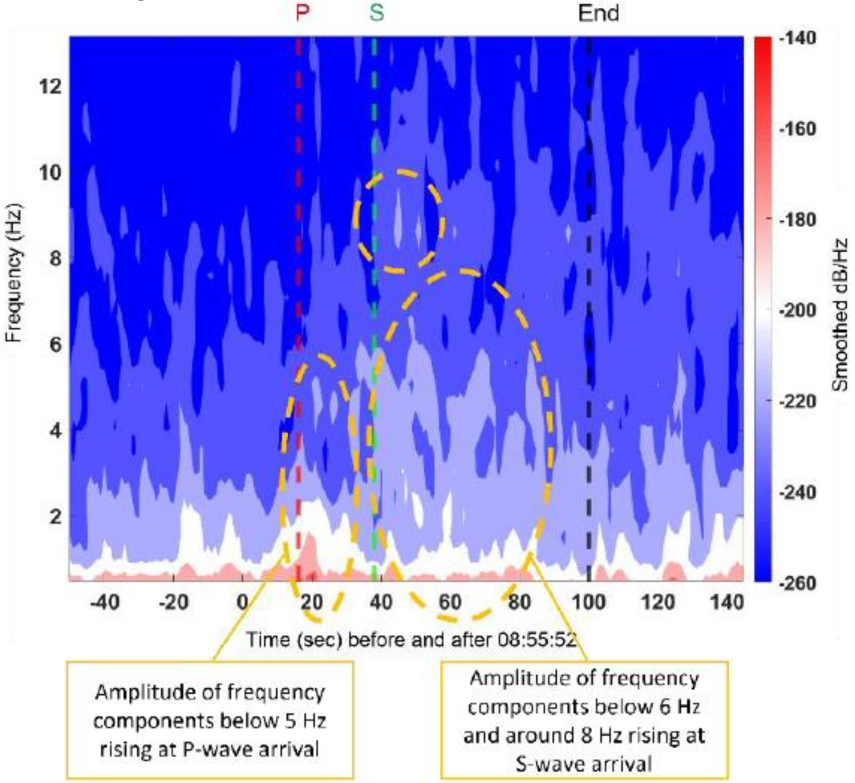
- Based on existing network equipment and regular optical telecommunication traffic
- Sensitive to changes in strain, pressure, temperature
- Measures over long distances (10 000 km)
- Measures **integrated** changes in polarisation of light caused by an external field (temperature, pressure, strain)
- Several techniques are being developed to determine the location of the disturbance (ASN, NTNU, Sikt, Tampnet, SUBMERSE project)



Dubovan et al. 2020

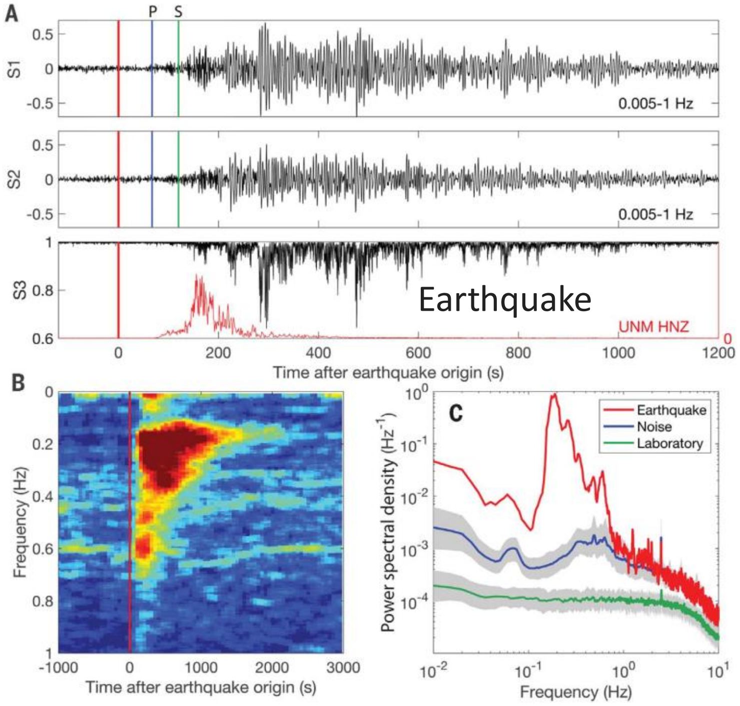
Applications of SOP

"Observation of Local Small Magnitude Earthquakes using State Of Polarization Monitoring in a 250km Passive Arctic Submarine Communication Cable"



Yamase Skarvang et al. 2023, Optica, Tampnet and Sikt

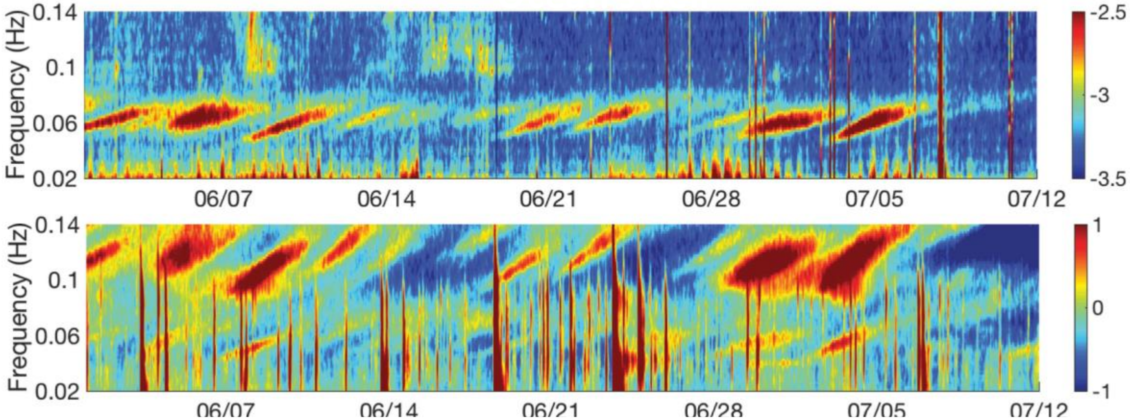
"Optical polarization–based seismic and water wave sensing on transoceanic cables"



Zhan et al. 2021, Science

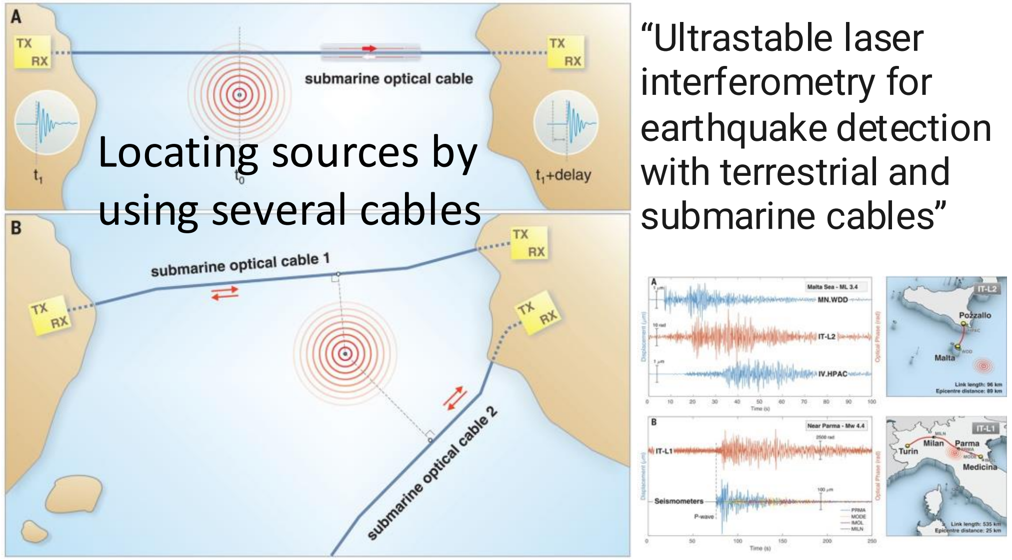
SOP

coastal seismic station



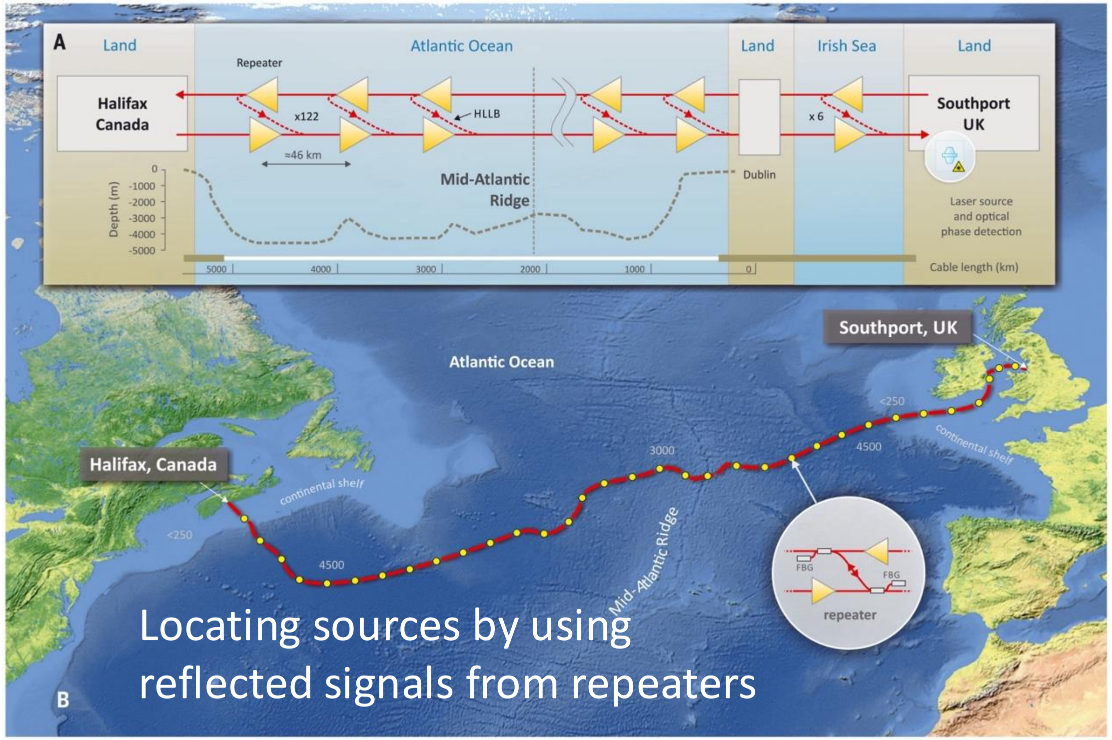
Interferometry

- Measure phase difference between injected and returned light (ULE cavity-stabilized laser)
- Measures **integrated** phase changes



"Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables"

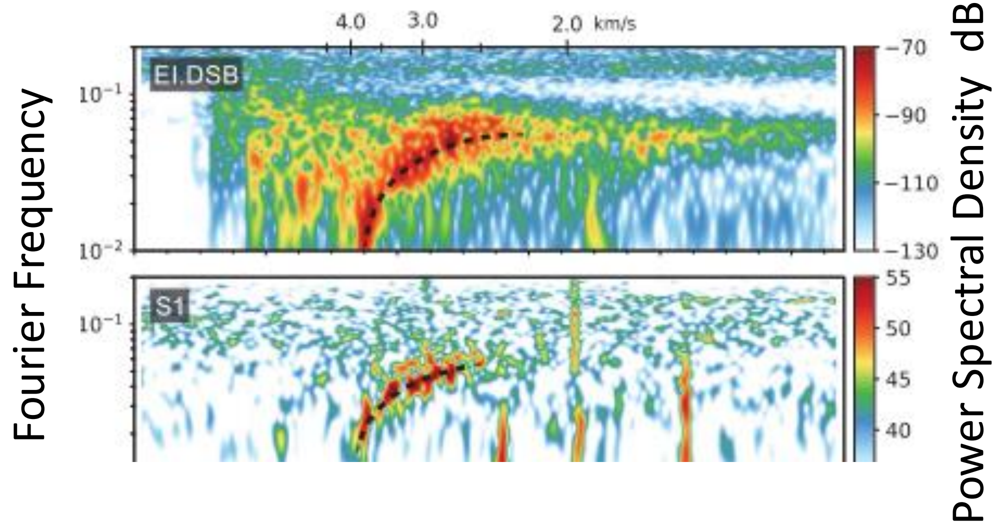
Marra et al. 2018, Science



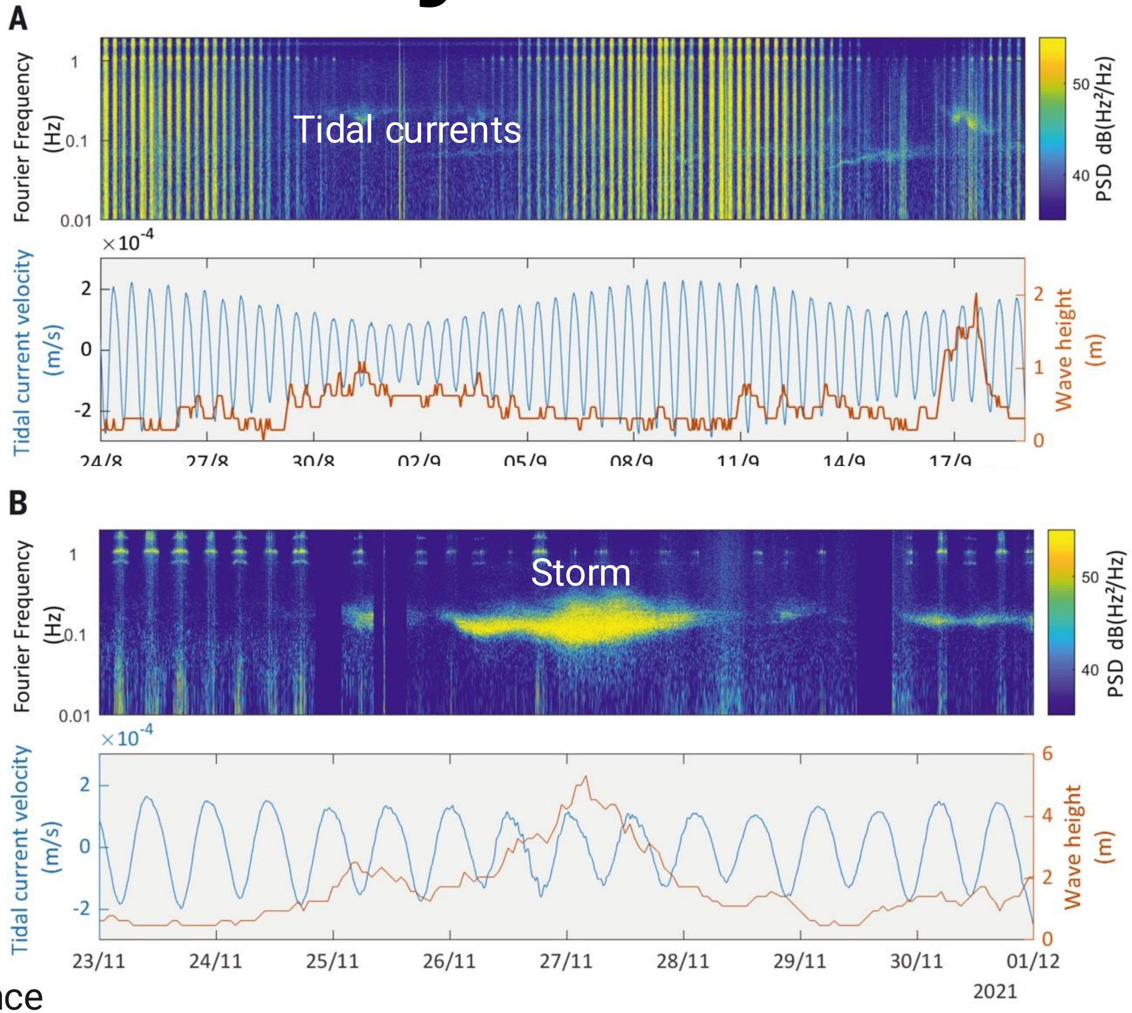
Marra et al. 2022, Science

Applications of Interferometry

“Optical interferometry–based array of seafloor environmental sensors using a transoceanic submarine cable”



- Cable from UK to Canada, length 5860 km
- Range resolution of 45-90 km

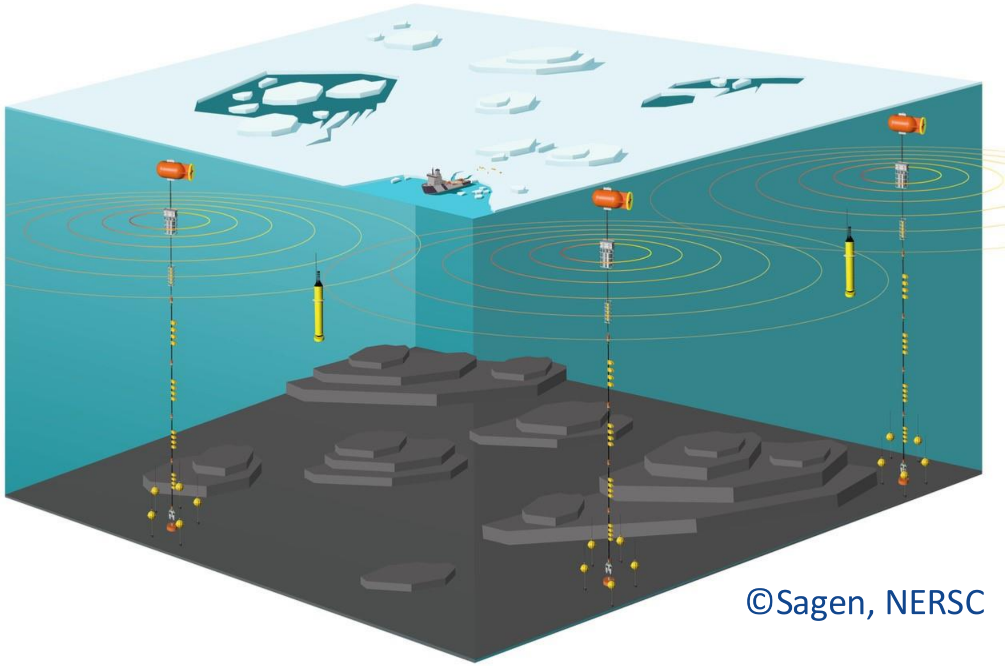


Marra et al. 2022, Science

Integrated Arctic Infrastructure

Submarine cable system + ocean mooring systems + active acoustics

- Observations near the seafloor and in the entire water column
- Additional sensors can dock/connect with the cable
- Acoustic tomography (ocean temperature)
- Underwater gps and time
- Fast data transfer
- AUVs for maintenance of sensors
- Power supply to AUVs



https://hiaoos.eu/2024/09/25/large-scale-multipurpose-ocean-observation-system-installed-in-the-central-arctic/

see HiAOOS (High Arctic Ocean Observation System), led by Hanne Sagen
and Howe et al. 2007, “Sensor Network Infrastructure: Moorings, Mobile Platforms, and Integrated Acoustics”

Science Opportunities

- Oceanography (ocean temperature, internal waves, upwelling, current velocities, turbulent mixing, wave height)
- Climate (sea level change, ocean heat content, ocean circulation)
- Geophysics / Seismology (earthquakes, underwater volcanoes, tsunamis)
- Marine biology (tracking mammals by their sound)

+ ???!

Thank you for your attention!

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