Optical Fiber based sensing technologies and field test sensing activities at Sikt

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Sikt, Norwegian Agency for Shared Services in Education and Research

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Helsinki, Finland

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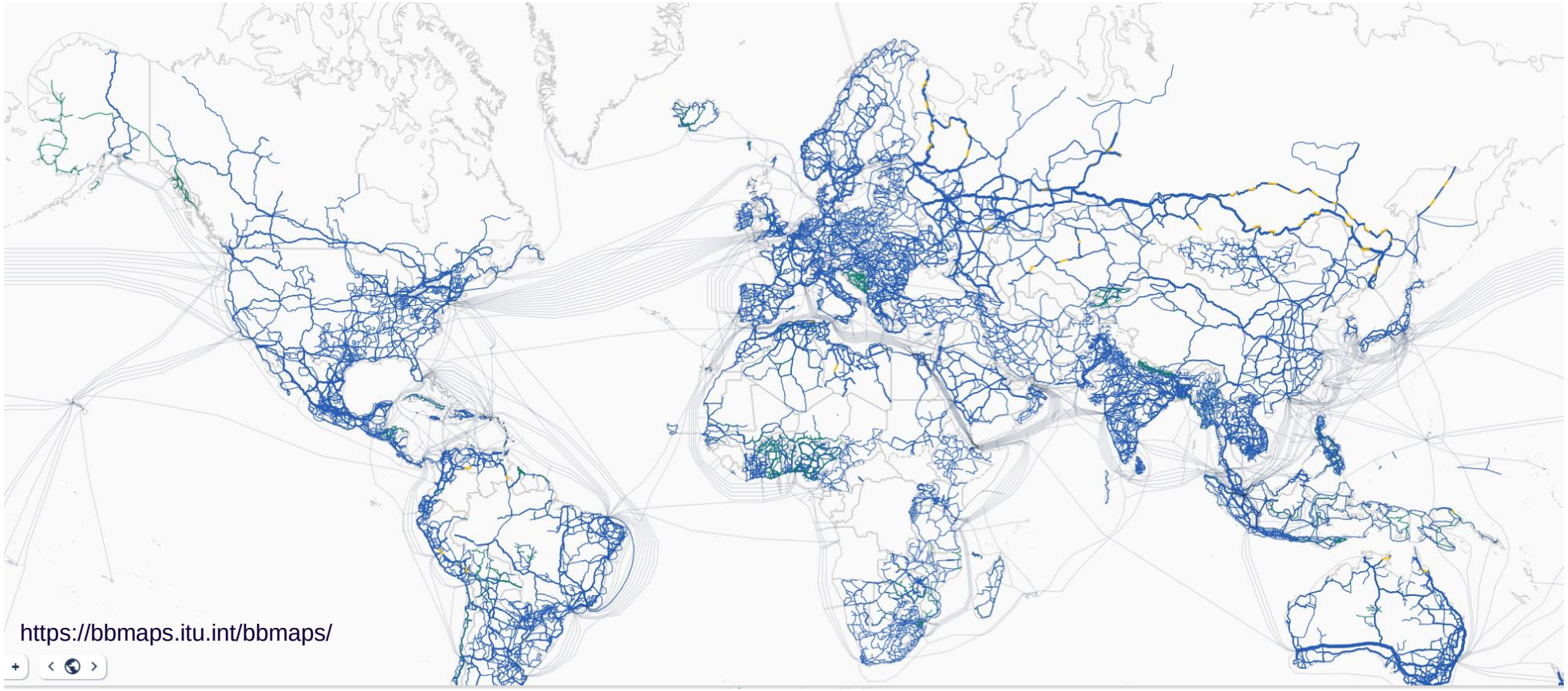
Outline

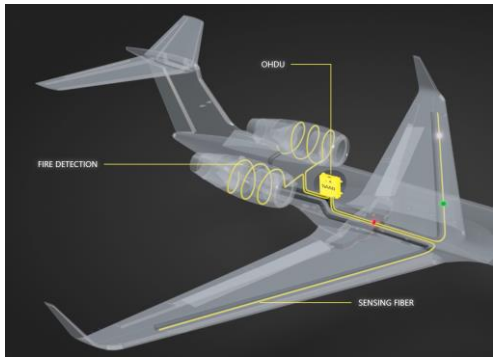
- Worldwide fiber sensing network
- Optical Sensing techniques
- Sikt’s activities on Optical Fiber sensing
  - Distributed Acoustic Sensing field test
  - State of polarization field test
    - Event detection
    - Event localization
  - Coexistence between DWDM and DAS (lab-*test*)
    - Impact on DWDM channels
    - Compering DAS sensitivity over dark fiber vs DWDM

Deployed fiber optic cables

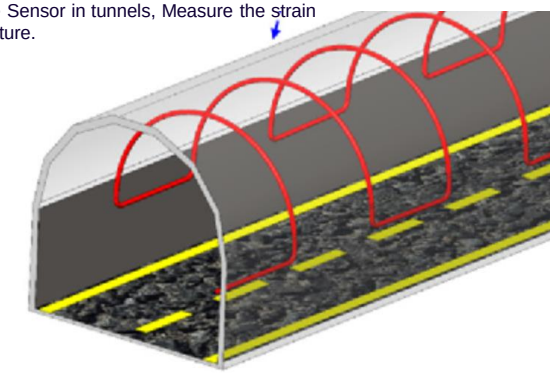


- The total length of submarine fiber optic cables laid worldwide was estimated to be over 1.3 million kilometers.
- Terrestrial deployment is 100s times higher

Fiber Optic Sensing

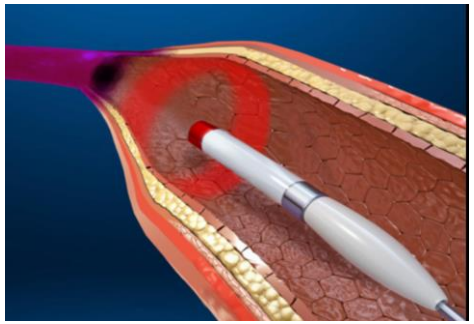


Civil engineering:. E.g. Raman Distributed Temperature Sensor in tunnels, Measure the strain and temperature.



- Sensing strain, temperature, pressure, acoustic waves …
- By detecting changes on lights parameters like phase, amplitude, polarization, backscattered light …

fiber-optic gyroscopes at Boeing 737



Health care: surgeons to repair organs, diagnose joint problems, and remove diseased tissues

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Merging two worlds: fiber-optic communication and fiber-optic sensing

Creating a worldwide sensing network

Optical sensing techniques

in Miro

Sikt and fiber optic sensing acti

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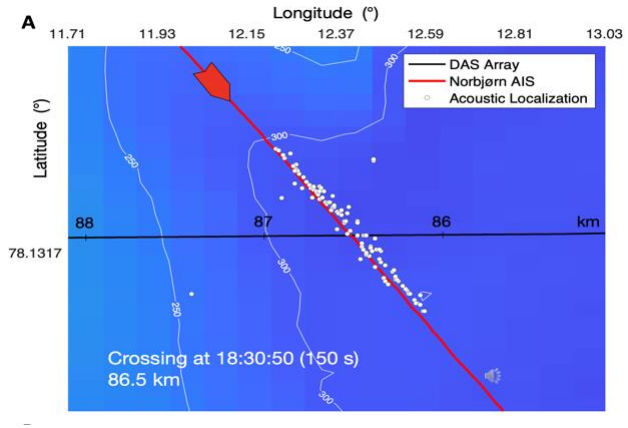
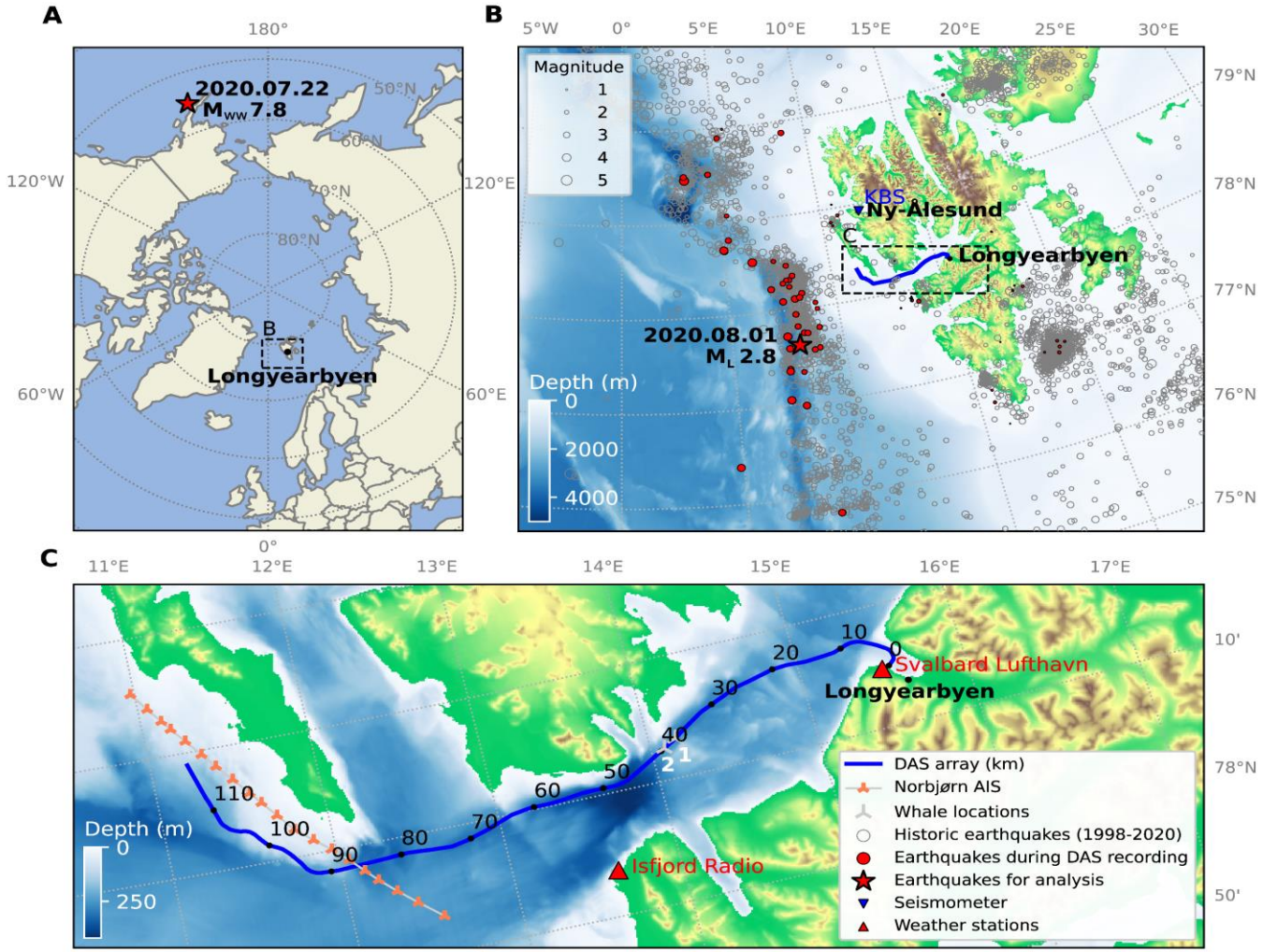
Field test 2020: Svalbard





Source: Martin Landrø et al., Sensing whales, storms, ships
and earthquakes using an Arctic fibre optic cable, Nature Published: 10 November 2022, https://www.nature.com/articles/s41598-022-23606-x

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Data streaming

We live-streamed 250 TB of DAS data from Svalbard to mid-Norway over 40 days of test period (7TB per day)

This technique make it possible for researcher to study whales and their sound production, their calls and their vocalizations from everywhere almost instantly.

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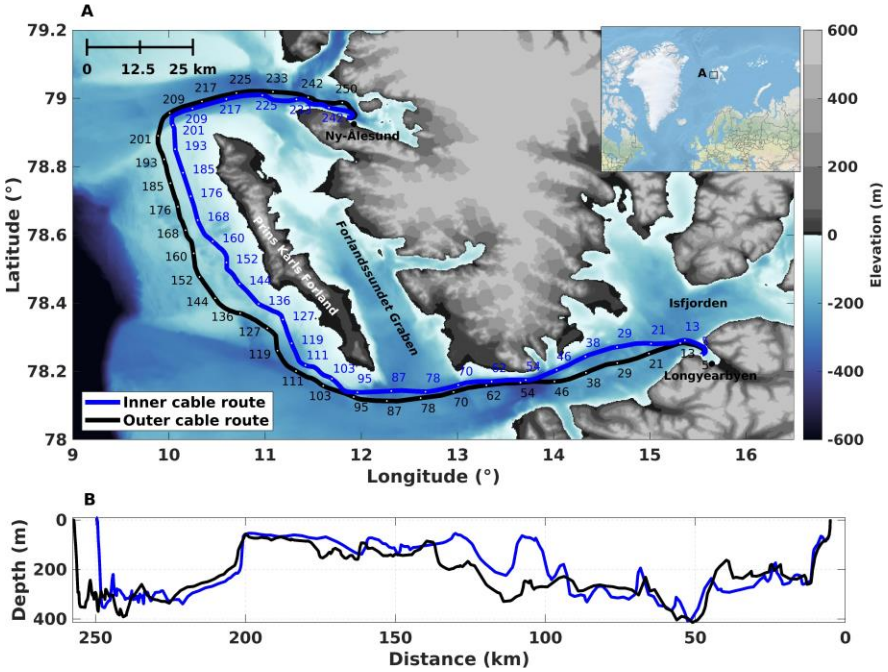
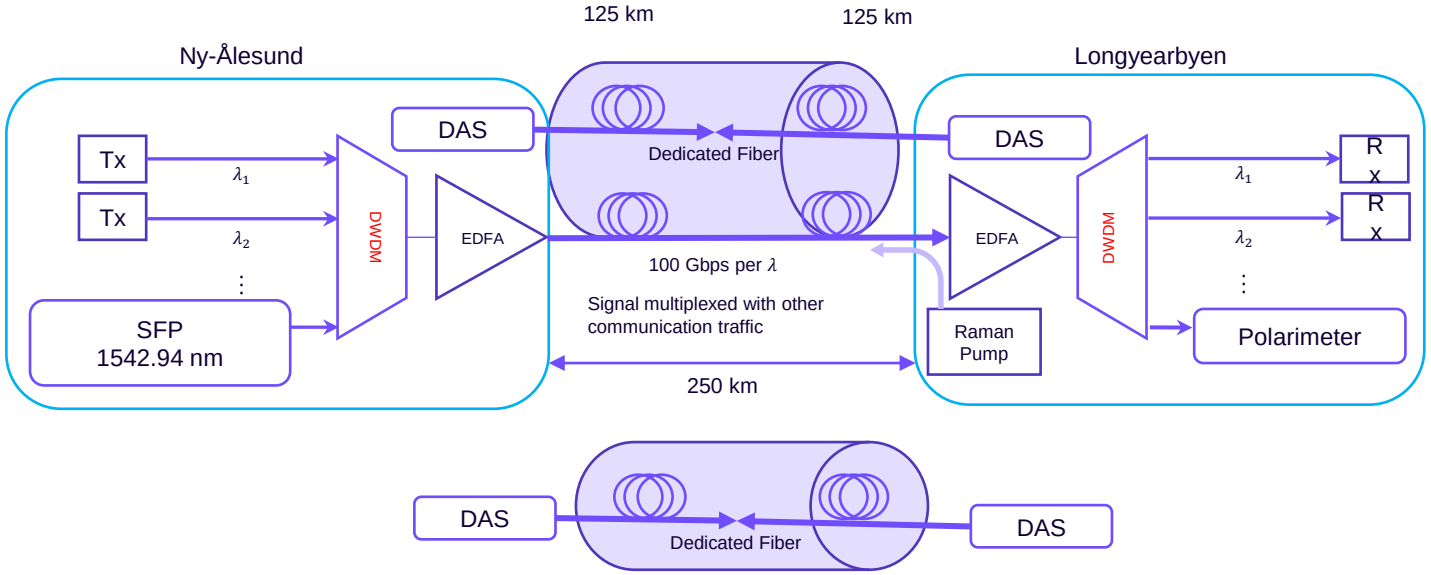
Field test 2022: Svalbard

- Polarimeter (PM1000, Novoptel) connected to a live DWDM link
- DAS (OptoDAS, ASN) interrogators connected to two dedicated fibers in each cable





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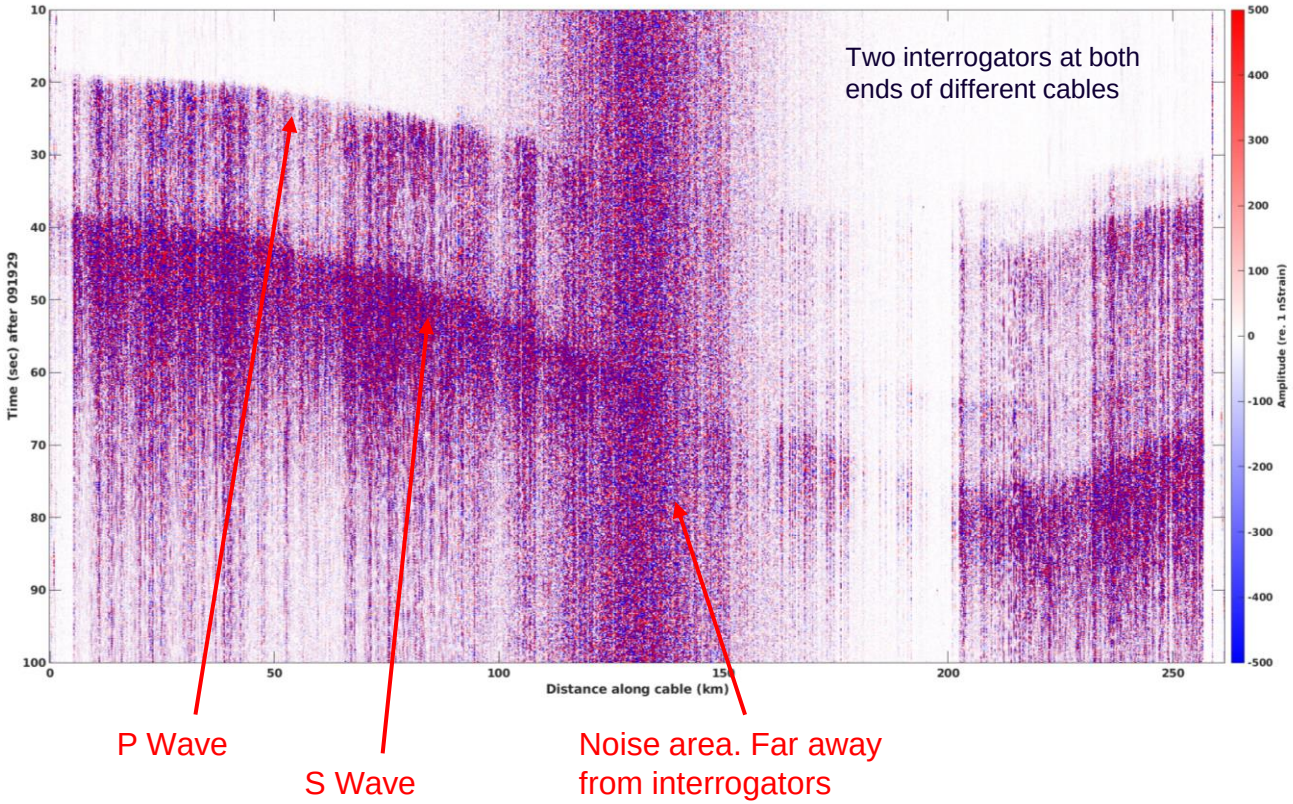
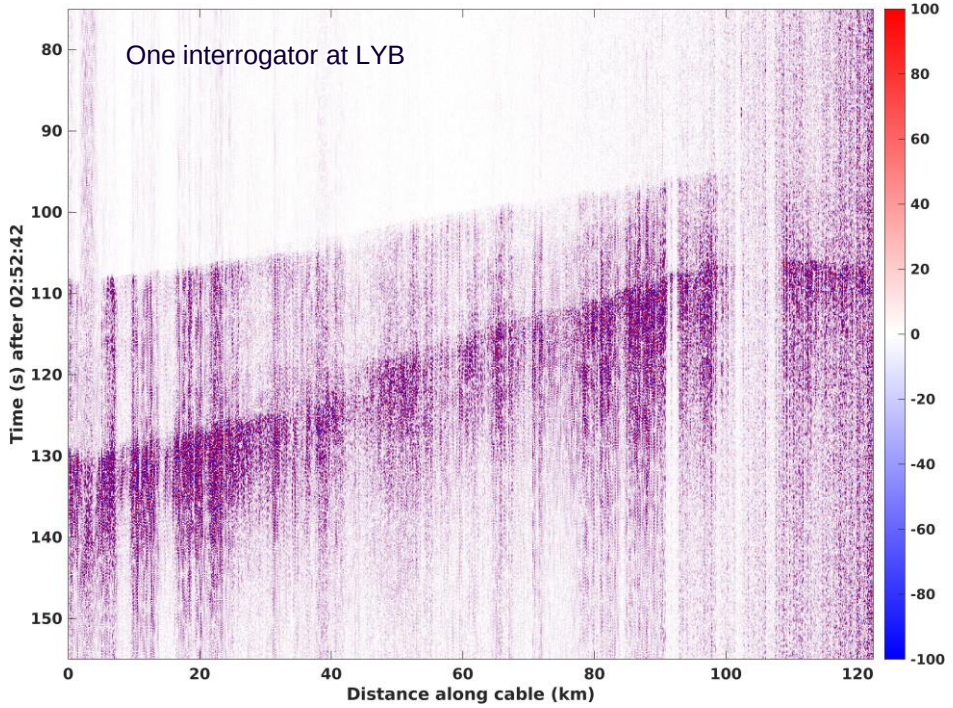
Earthquake analysis with two DAS interrogators



Two interrogators more fiber length and more data to analyse. It will gives a more precis detection of epicenter.(left) Future study will investigate the localization of depth of epicenter.



Source: Robin André Rørstadbotnen et al., 2022, Simultaneous Tracking of Multiple Whales using two Fibre-Optic cables in the Arctic, Front. Mar. Sci. 10:1130898. doi: 10.3389/fmars.2023.1130898

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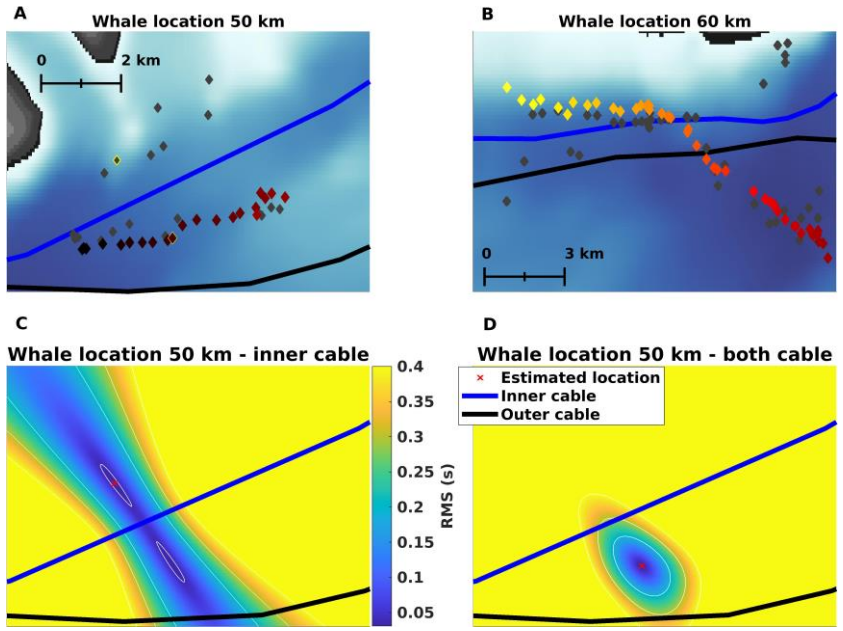
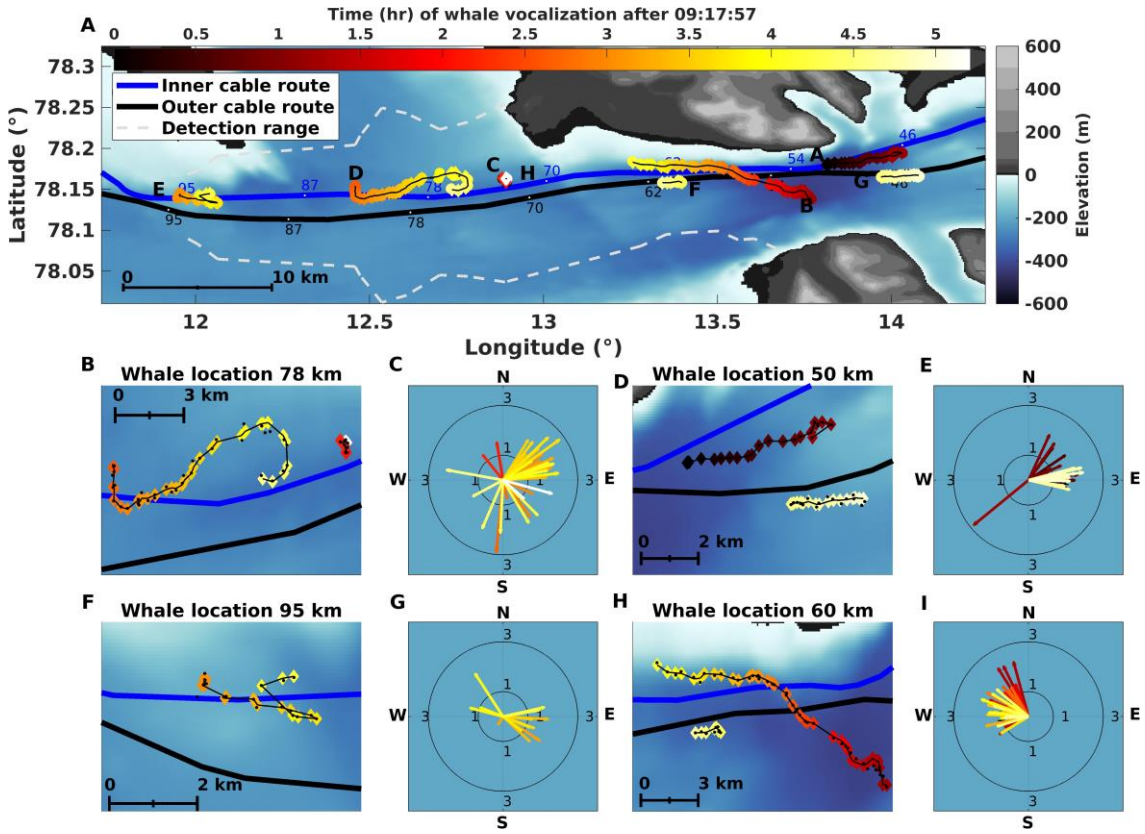
Whale tracking with DAS interrogation on two cables





Introducing DAS interrogation two cables resolved the well-known left-right ambiguity

Source: Robin André Rørstadbotnen et al., 2022, Simultaneous Tracking of Multiple Whales using two Fibre-Optic cables in the Arctic, Front. Mar. Sci. 10:1130898. doi: 10.3389/fmars.2023.1130898.

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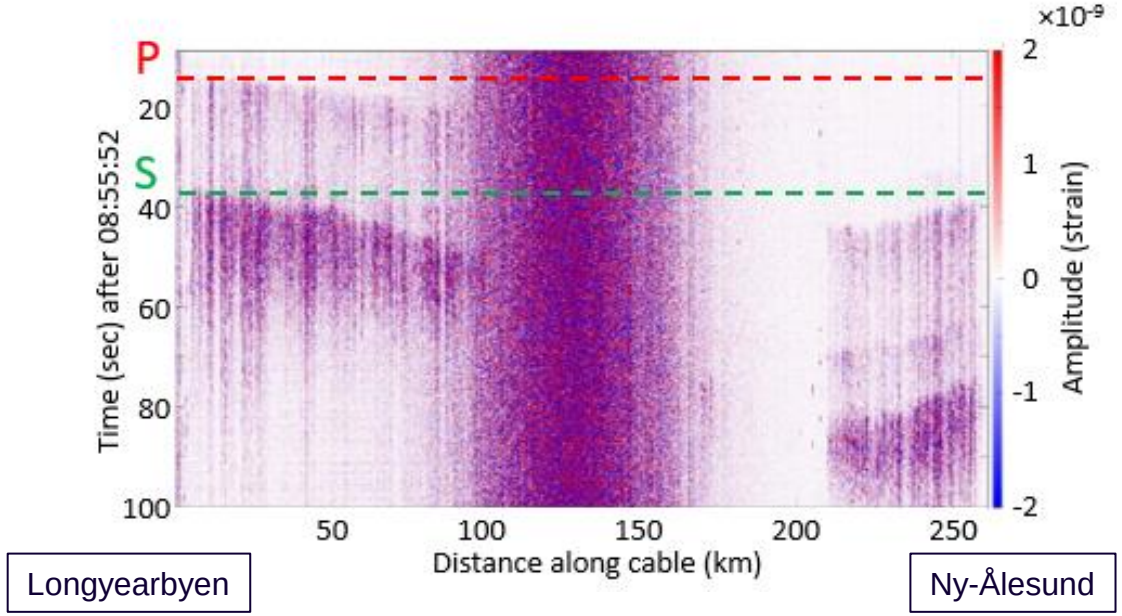
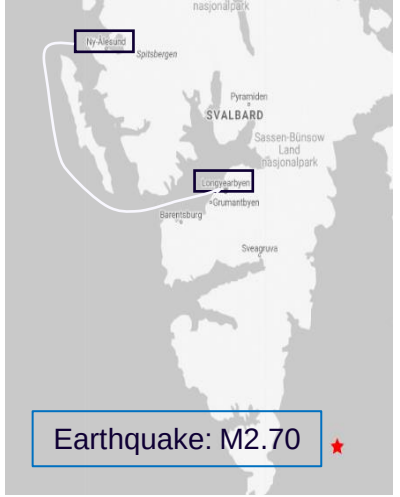
Detection of M2.7 Earthquake with DAS and SOP

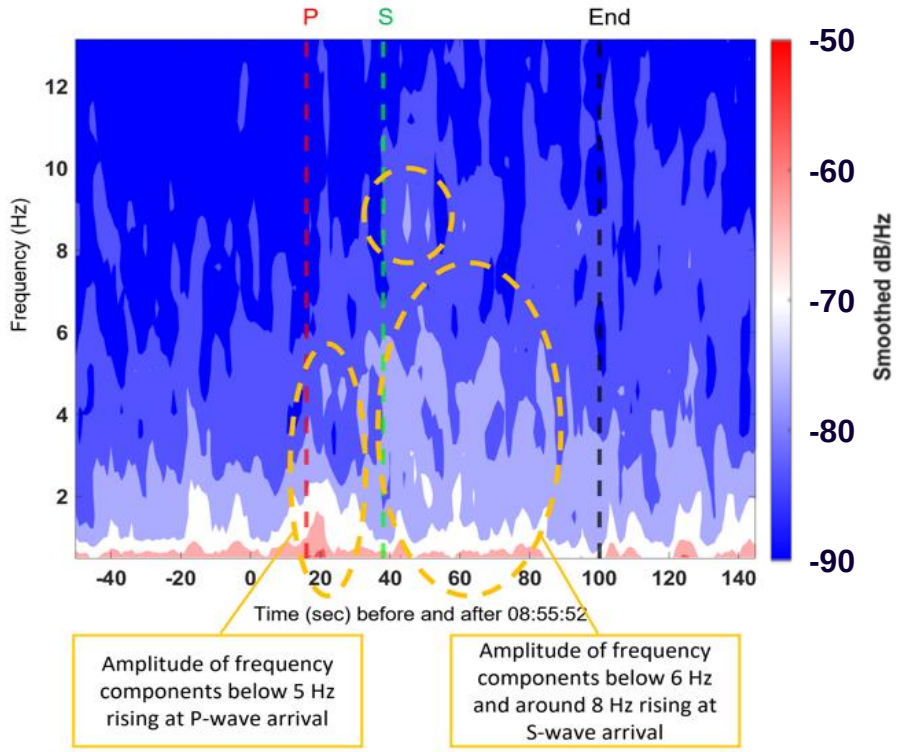


Longyearbyen

Ny-Ålesund



NORSAR seismometer



[Extract the timing the seismic waves hits the cable from DAS data]

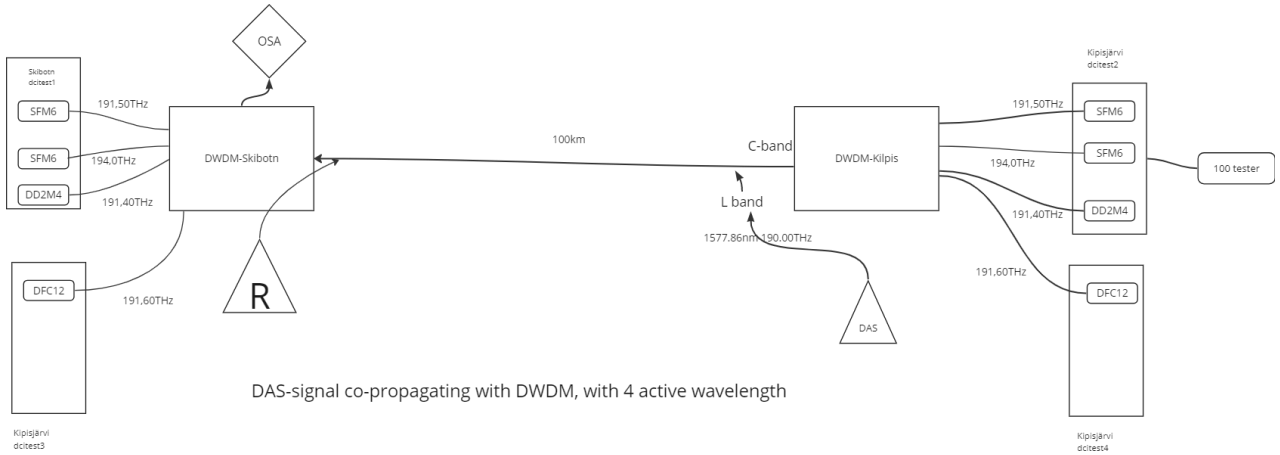
Source: Kristina Shizuka Yamase Skarvang et al., Observation of Local Small Magnitude Earthquakes using State Of Polarization Monitoring in a 250km Passive Arctic Submarine Communication Cable, OFC 2023

[SOP variation corresponds with the timing of the Earthquake hitting the cable]

Coexistence of DWDM and DAS

Coexistence of DWDM and DAS have been tested with four main scenarios

- co-propagating without Raman
- co-propagating with Raman
- counter-propagating without Raman
- counter-propagating with Raman



DAS-signal co-propagating with DWDM, with 4 active wavelength

DAS with different operational power range have been tested with running DWDM channels with a variety of modulation format, Symbol rate and bitrate

The effect of DAS seen from DWDM point of view

	No Raman	Raman
co-propagating	With normal DAS operation power range there will be no issue on running channels. With full DAS power the higher modulation format will be degraded but QPSK channel is less affected. To totally isolate the DAS signal from the channels it could be good to use a C/L-filter at receiver side (1,5dB insertion penalty)	DAS with normal operating power range has no negative impact on performance quality on the running channels. We see a change on noise floor (1-1,5dB)
counter-propagating	We see no signal degradation on running channel. To protect the laser on operation channels it will be beneficial to use C/L-filter at Tx-side of the DWDM-link (inbuilt filter on ROADM due OTDR usage 1575nm-1611nm).	Not possible We can't insert C/L-filter on Rx side of DWDM where we have the Raman pump

DAS/DWDM coexistence seen from DAS point of view

	No Raman	Raman
co-propagating	There is no impact on DAS-performance. This configuration is possible with available C/L-filters.	There is no impact on DAS-performance. This configuration is possible by using C/L-filters with an isolation ratio (leakage from other band than L-band on L-port) greater than 35dB on L-port. (The suppression of Raman at 1425 nm and 1454 nm through typical C/L-filters was not adequate, which causes DAS-noise floor to increase considerably in our test.
counter-propagating	There is no impact on DAS-performance. This configuration is possible with available C/L-filters.	Not possible. We can't insert C/L-filter on Rx side of DWDM where we have the Raman pump No impact on DAS performance, but not possible due to limitations in Raman amplification layout used in these tests.

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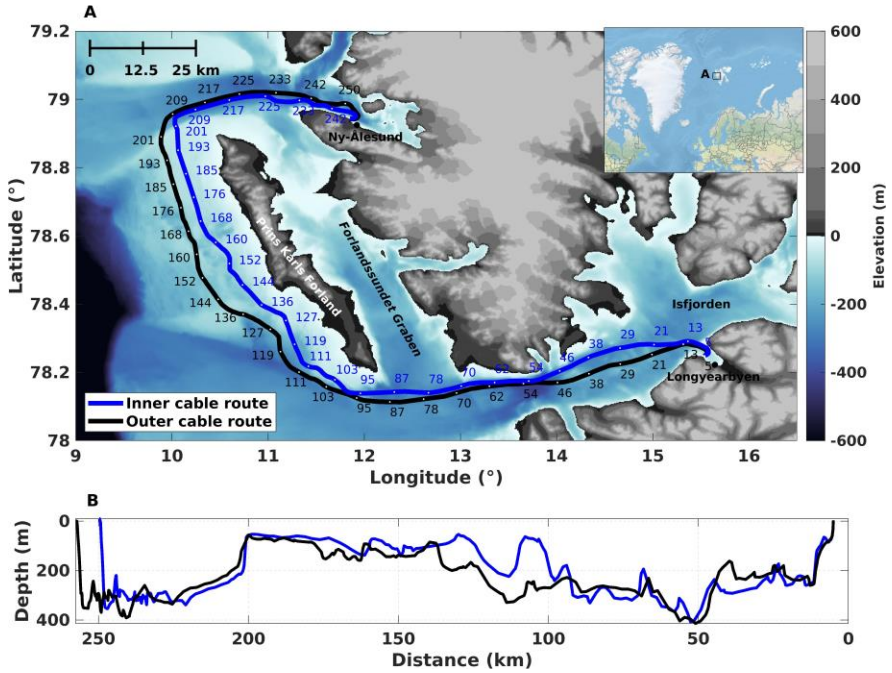
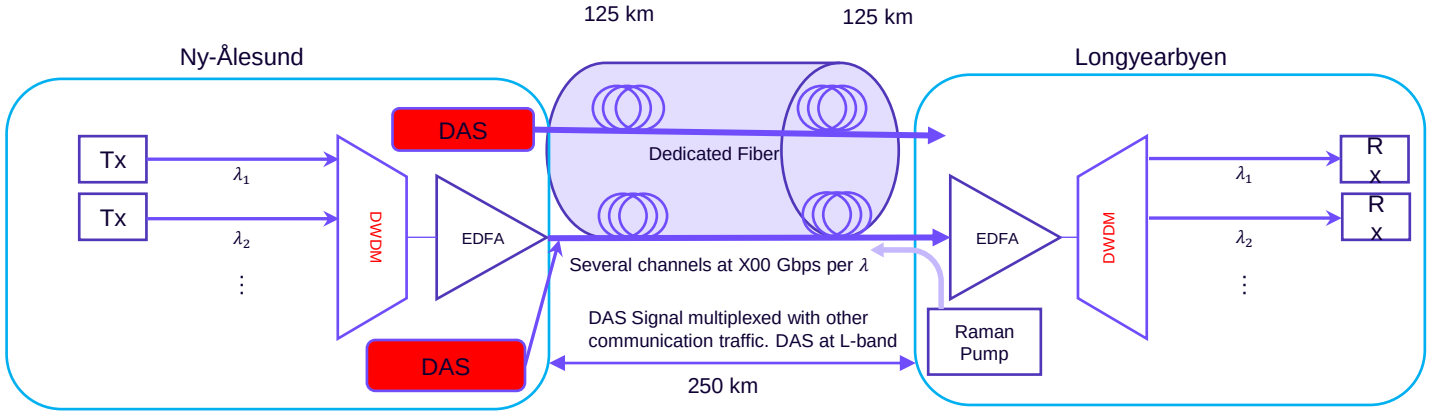
Field test 2023: comparing DAS sensitivity over DWDM vs. dark fiber

- L–band DAS (OptoDAS, ASN) connected to Nokia DWDM and C-band DAS connected to dark fiber over the same cable

- We have demonstrated uncompromised L-band DAS and telecom coexistence by showing equal event amplitude between L-band DAS muxed onto Live live telecom link and C-band DAS interrogating a dark fiber in the same submarine cable, and unaffected pre-FEC BER, post-FEC BER and Q-factor.





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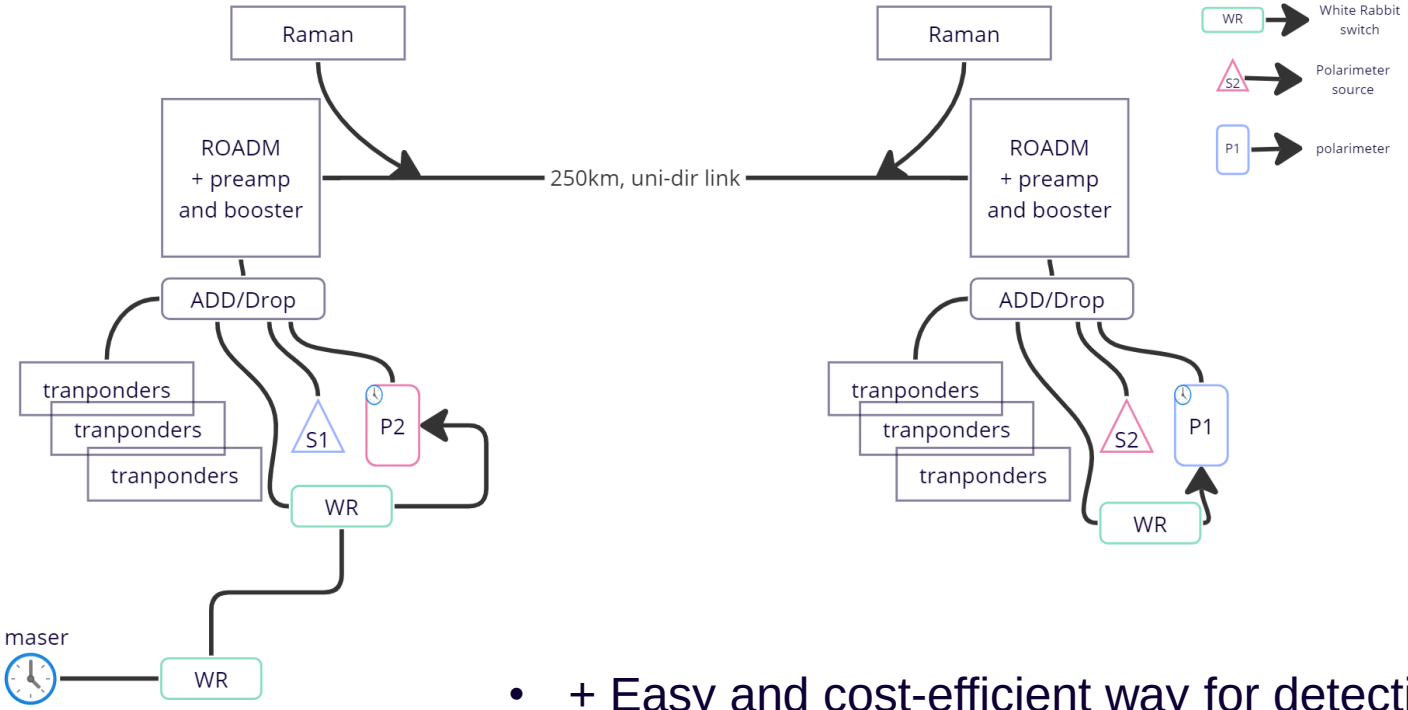
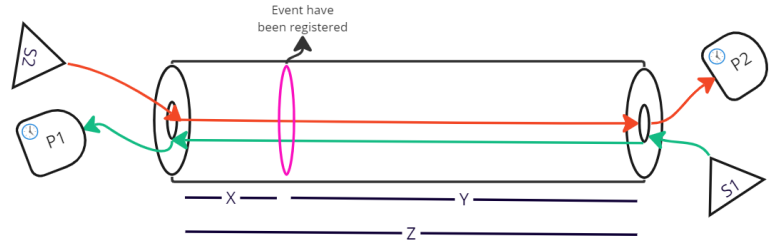
Field test 2024: Event detection and localization by SOP
the concept and test layout





$\Delta\tau$,Time delay between received events at the end points = Calculated by SOPs
v, Light speed in fiber=204 357 504 m/s
Z, Cable length =is known

$$\frac{X}{v} = \frac{Y}{v} - \Delta\tau$$

$$Y = \frac{Z + \Delta\tau . v}{2}$$

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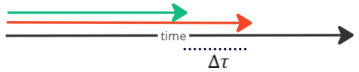

- \+ Easy and cost-efficient way for detection and localization of event (2 polarimeter with high level of time synchronization)
- Event identification is limited
- \- multiple simulations event can't be detected separately

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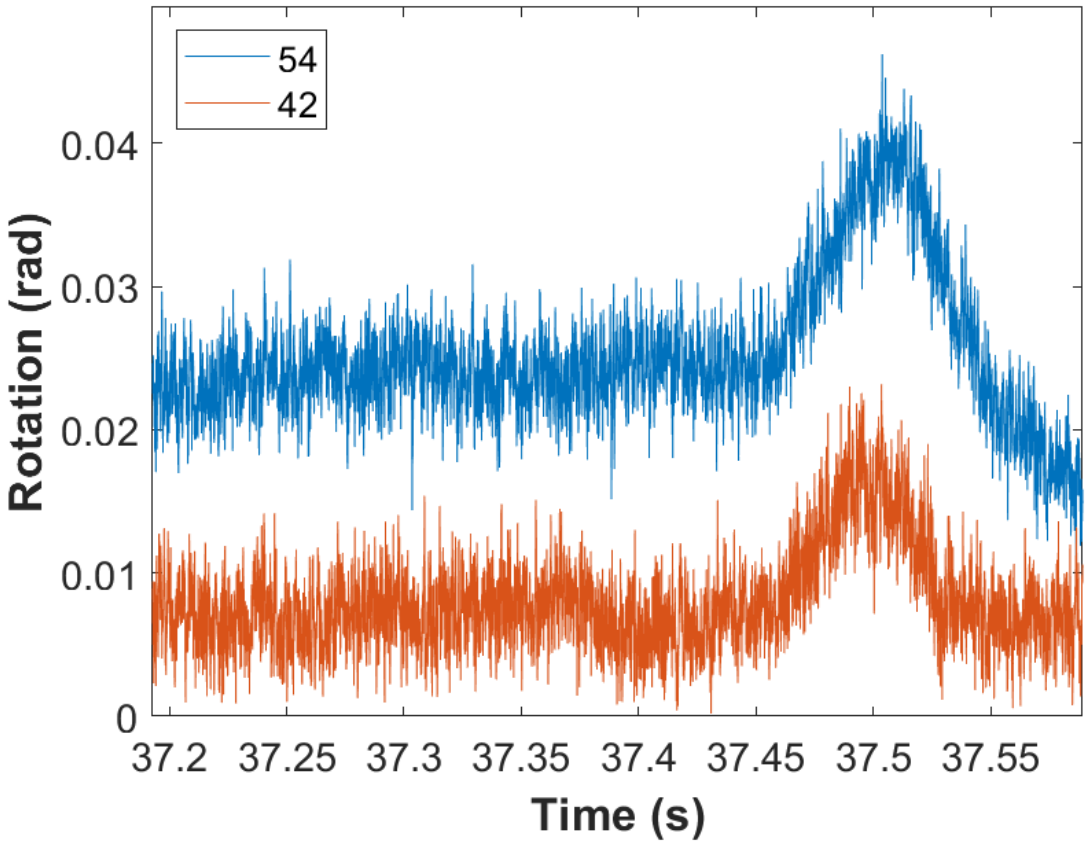
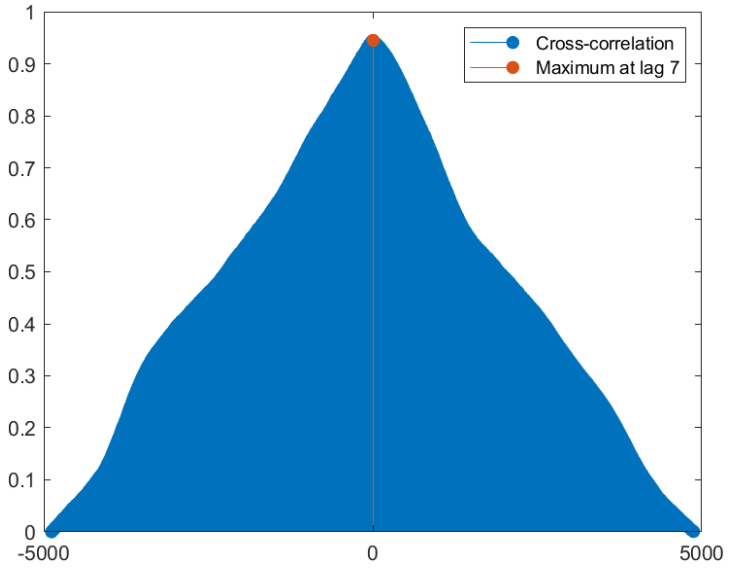
Cross-correlation





Lag of 7 samples
Sample freq: 8.1920e-05[sec/sample]

Δt will be 0.57344 [ms]

Can we verify if something happened at x=66.4 km onTuesday, April 13, 2024 17:09:41.529 PM (GMT) with DAS?

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Conclusion and further work

- Demonstrated the benefit of DAS for geophysics applications and environmental monitoring
- Demonstrated the advantage of DAS on multiple fiber cable for a more exact event localization
- Demonstrated feasibility of low magnitude earthquake detection by SOP in a 250 km passive submarine cable in live communication infrastructure
  - Combined SOP and DAS monitoring enabled identification of record low magnitude earthquakes (M2.7) in SOP data
- Demonstrated the coexisting of DAS and DWDM and its possibilities and limitations
- Demonstrated the performance of DAS under different scenarios (DWDM vs. Dark fiber)
- Demonstrated the SOP's ability to localize the events

- Ongoing and Next step:
  - DAS test Combined phase and SOP testing by coherent transmission transceivers
  - Correlation OTDR method DAS
  - Perform detailed comparison of SOP and DAS recordings of earthquakes
  - Establishing noise reduction methods for SOP by long-term field experiments
  - Time-synchronization between SOP detectors/devices on different cables
  - Coherent optic based forward-transmission based sensing

Thank you!

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