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

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Abstract: We demonstrate local small-magnitude earthquake observation using State of Polarization sensing on an alien wavelength in a live single-span passive submarine cable communication system. Distributed Acoustic Sensing verifies seismic waves propagating along the cable. © 2022 The Authors

1. Introduction

The existing optical fiber telecommunication infrastructure is attractive for realizing a global geophysical activity sensing network. Extracting the State of Polarization (SOP) information from coherent receivers in a long-haul sub-sea optical transmission system involving optical amplifiers, enables sensing over distances beyond the current limitation of approximately 150 km of Distributed Acoustic Sensing (DAS) systems [1,2]. SOP is susceptible to mechanical disturbances of the optical fiber cable caused by geophysical vibrations. SOP-based sensing applied for monitoring earthquakes (between M_w4.4 and M_w7.7) as well as ocean swells was demonstrated in [3], where a long active submarine cable of 10,000 km was applied. The study showed that SOP sensing can be integrated into the existing telecommunication infrastructure by extracting SOP information from the coherent receivers. However, the performance of SOP based seismic sensing on shorter submarine cables and for smaller magnitude earthquakes has not been evaluated. On a shorter fiber, the SOP variation is smaller due to smaller number of sections in the fiber contributing to the total Polarization Mode Dispersion (PMD) which describes the integrated mechanical perturbation to the fiber [4]. For telecommunication systems where extraction of SOP information from the coherent receiver is not supported, launching an alien wavelength in the system, and connecting a polarimeter at the receiver end is an alternative solution enabling monitoring of the entire length of the fiber. Because this type of SOP monitoring is a physical separate system, it allows a third party to monitor SOP without potential security issues of gaining access to the Network Management System or telemetry data from the telecommunication system. Hence, SOP sensing is less complex than DAS sensing and may therefore be an attractive technique also for distances where DAS is applicable. Measuring on medium range passive submarine cables, does however enable simultaneous SOP and DAS sensing, enabling validation of the SOP observations using data from the more sensitive DAS instrument possible.

In this paper, we show that weak earthquakes of M_L2.7 can be observed using SOP monitoring on a single-span passive submarine communication cable of 250 km. Results are from a field trial conducted between August 2022 and September 2022 between Longyearbyen and New Aalesund in the Arctic region in Svalbard, Norway. While SOP variations were measured on an alien wavelength in a live communication system, two DAS interrogators were connected on each side of a dedicated fiber within the same cable as the communication system, enabling analysis of how the earthquake signals affected the cable and when. Earthquakes in this region is typically of small to moderate magnitude (most events are below M_L4.0). The suitability using SOP sensing for observing weak earthquakes on a medium length cable will therefore be discussed.

2. Field Test Setup

Figure 1 shows the map of the optical fiber cable and the schematic setup for the SOP sensing system. A wavelength-specific 1 Gb/s Ethernet (GBE) SFP was used to send light with 1542.94 nm through the DWDM-system and an EDFA amplifier from Ny-Aalesund. The signal from the SFP propagates through a fiber wavelength multiplexed with other communication traffic through 250 km, the polarimeter (PM1000, Novoptel) at Longyearbyen after the EDFA and Raman amplifiers and DWDM-system. The received signal from the SFP at Longyearbyen side was -

8.59 dBm with Degree of Polarization (DOP) of 0.850. Two DAS interrogators (OptoDAS, ASN) were connected on each side of a dedicated dark fiber (type G.652D), within the same cable as the communication fiber monitored with the polarimeter. Both SOP and DAS monitoring data were then streamed from Svalbard to southern Norway through the network of Sikt.

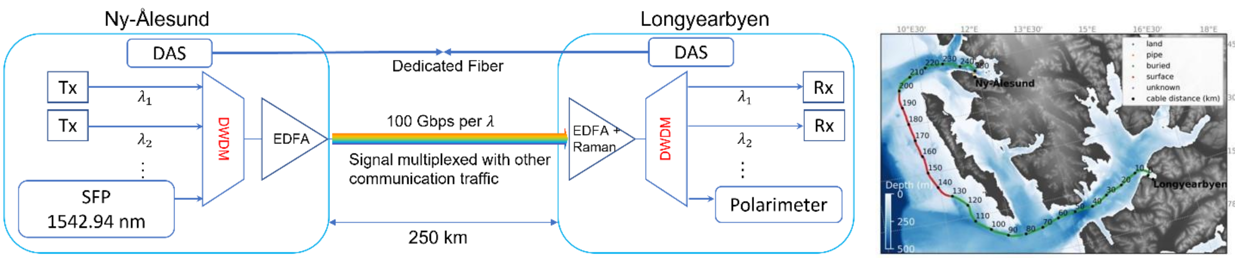

Fig. 1. Schematic of the field test setup and the map of Svalbard where the cable is placed

3. Analysis and Results

3.1. Signal analysis using SOP

The polarimeter placed in Longyearbyen gives the three Stokes-parameters as outputs. For the frequency analysis, we define $\overrightarrow{\Delta S} = \vec{S} - \overrightarrow{S_0}$, where $\overrightarrow{S_0}$ is the S-vector at t=0. For small variation in SOP, this vector lies in a plane normal to $\overrightarrow{S_0}$. The length of this vector will indicate the polarization variation. $\overrightarrow{\Delta S}$ has a small component along $\overrightarrow{S_0}$, so we redefine $\overrightarrow{\Delta S_t} = \overrightarrow{\Delta S} - \left(\overrightarrow{\Delta S} \cdot \frac{\overrightarrow{S_0}}{|\overrightarrow{S_0}|}\right)\frac{\overrightarrow{S_0}}{|\overrightarrow{S_0}|}$, and estimate the Power Spectral Density (PSD) of the length of $\overrightarrow{\Delta S_t}$. The PSD estimations were then smoothed over time and frequency.

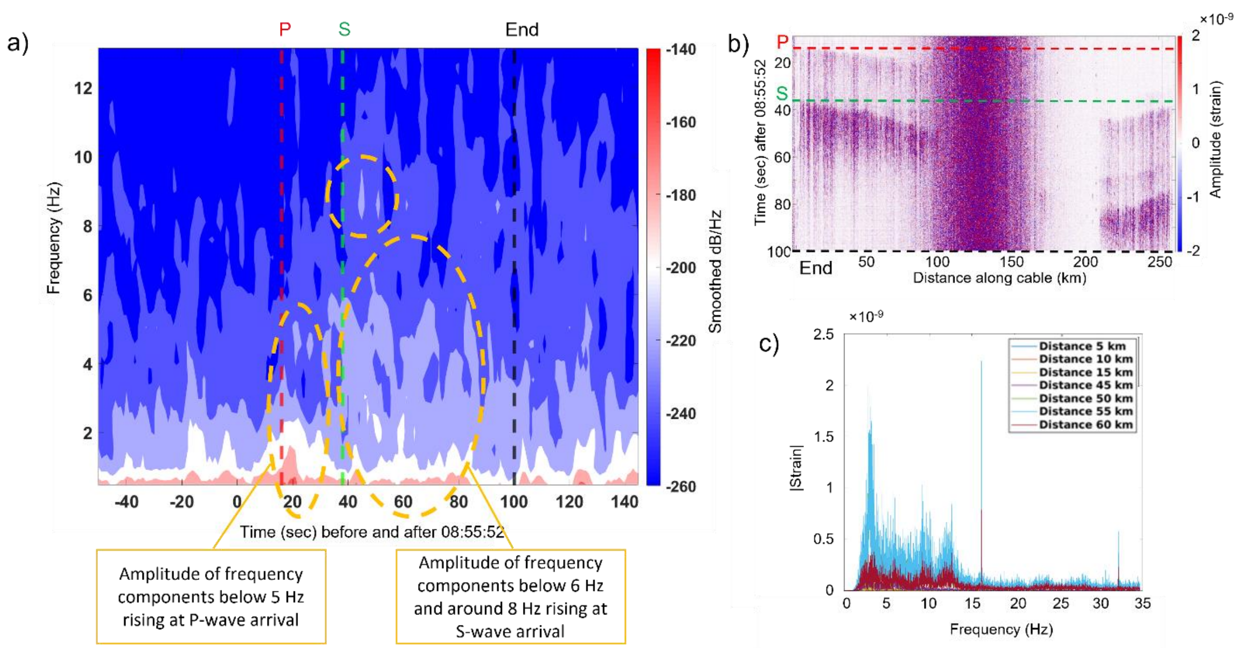

Fig. 2. a) SOP variation frequency analysis during the 21 August 2022 M_L2.70 earthquake. From DAS analysis, the timing of the on-set of the P-wave (red) and the S-wave (green) and the duration of the signal (signal ending time at DAS: black) is shown. b) DAS plot for the same earthquake. The DAS signals are analyzed from two interrogators situated on each side of the cable. The interrogator in Longyearbyen is set as zero distance. c) Frequency analysis from the DAS plots during the same earthquake for different distances along the cable.

3.2. SOP and DAS Earthquake observation

During the field experiment, several earthquakes were observed on the cable at Svalbard. Figure 2 shows an example of an earthquake with origin time shown in a Seismogram by NORSAR is 21st August 2022 at approximately 08:55:23 (UTC). From the DAS plots, the timing of the P-wave and S-wave of the earthquake hitting the cable, and the duration of the earthquake signal on the cable was extracted and compared with the SOP variation frequency analysis. On Figure 2 a), we see a slight increase of signals below 5 Hz corresponding to the time when the P-wave hits the cable and an increase of signals below 6 Hz when the S-wave hits the cable. The duration of the signal corresponds with the DAS plots. From the DAS frequency analysis, frequencies below 5 Hz are the dominating elements, particularly at 1.5-3.5 Hz. There is also a slight peak at around 9 Hz on both SOP and DAS frequency analysis for S-wave. The SOP frequencies on Figure 2 a) show peaks on frequency slightly different from the DAS frequencies. This is because the SOP frequencies show the integrated signal of the whole cable, while DAS signals show sections of the cable.

Other earthquakes of a similar magnitude were observed as well. Although earthquakes with larger magnitudes were observed, not all earthquakes were visible on SOP frequency analysis. The strain induced on the fiber due to the earthquake do not directly correlate with the magnitude of the earthquake, since it depends on the distance and how the wave hits the cable. When the frequency components of the strain affecting the cable were below 10^{-10} for the frequency analysis for DAS, the signals appearing on the SOP variation were not significant compared to other background signals.

4. Conclusion

Observations of earthquakes using SOP monitoring has previously been demonstrated on long-distance cables spanning thousands of km. In this paper, we have demonstrated that also 250 km single-span passive submarine communication cables can be used for earthquake detections using SOP sensing. By using an alien wavelength through a live optical communication system connected to a polarimeter, remote access to SOP monitoring data from a third-party user was allowed without any potential security concerns. The simultaneous monitoring using DAS systems for spatial and timing information enabled accurate verification of observed SOP data. Comparing with the DAS data, SOP variation monitoring the lower sensitivity threshold of fiber strain sensing a local low magnitude earthquake was found to be 10^{-10}. This cannot directly be converted to the magnitude of the earthquake since both the distance to the earthquake and how the seismic wave from the earthquakes hits the cable impact the induced strain. Observations from seismometer shows that the earthquakes around M_L2 to 3 happening near Svalbard may be observed. Further work will be targeting improvement of background noise-removing process to increase the strain-detection sensitivity and investigating the capability characterizing earthquakes causing lower strain than currently observed.

5. Acknowledgement

The authors acknowledge the Norwegian Research Council and the sponsors of the Centre for Geophysical Forecasting at NTNU for financial support (Grant No. 309960), ASN for the support with configuring the DAS interrogator, and Sikt for letting us use the DWDM-system to proceed this field trial.

6. References

[1] M. Landrø et al., "Sensing whales, storms, ships and earthquakes using an Arctic fibre-optic cable," Earth and Space Science Open Archive, pp. 39, 2021

[2] O. Waagaard et al., "Real-time low noise distributed acoustic sensing in 171 km low loss fiber," OSA Continuum, vol. 4, no. 2, pp. 688-701, 2021

[3] Z. Zhan et al., "Optical polarization-based seismic and water wave sensing on transoceanic cables," Science., vol. 371, no. 6532, pp. 931–936, 2021

[4] A. Mecozzi et al. "Polarization sensing using submarine optical cables", Optica, vol. 8, no. 6, pp. 788-795, 2021.