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Distributed Acoustic Sensing and Ice Cover Monitoring

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Distributed Acoustic Sensing (DAS) is a rapidly developing technology that has already been successfully applied to solve various problems in geology, geophysics, and geoecology. Its advantages include unprecedentedly high spatial resolution, covering areas of up to a hundred kilometers or more; high sensitivity; and a broad frequency range. High-quality ice cover monitoring requires a dense network of seismic sensors. DAS can serve as an excellent complement to observation networks based on traditional seismic instruments. An expensive interrogator remains in a safe location (e.g., onshore), while the optical fiber can be considered expendable. In this article, we discuss the current state of the problem, describe our experiment conducted in February 2024 on the ice of the Klyazma reservoir, and share some conclusions and recommendations.

Keywords: Distributed Acoustic Sensing, monitoring system, parallel recording, ice thickness, Young's modulus.

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1. Introduction

1.1. Distributed Acoustic Sensing (DAS) uses optical fibers, which are part of any optical communication line, as its sensing element. With an interrogator, it becomes possible to record acoustic and seismic waves. Combining data from segments of optical cables allows the creation of virtual sensors to measure deformation, temperature, and some other parameters. This enables the deployment of a chain of virtual sensors capable of covering vast areas.

The principle of DAS is based on monitoring of Rayleigh scattering which occurs in the fiber core due to minor variations in its effective index of refraction caused by glass inhomogeneities formed in the fiber during its fabrication. Because of the optical interference with random phase shifts, the backscattered light intensity recorded at the fiber's input looks like a speckle-like pattern, observed in time domain. In the absence of external influences, this pattern remains highly stable. When the fiber is subjected to mechanical deformations, the speckle-like pattern locally changes due to variation of the optical phase shifts. Continuous data acquisition allows tracking of these changes in the scattered light's behavior, specifically, by measuring its time-dependent optical phase. Thus, DAS can precisely determine the amplitude, frequency, and phase of seismic vibrations at every point along the fiber. While the data quality of an individual DAS channel may be inferior to that of a properly installed geophone, the advantages of dense spatial sampling and extensive coverage dominate for a full set of channels .

DAS has been successfully applied in numerous geological, geophysical, and geoecological studies [*Gorshkov et al.*, 2022; *Kislov and Gravirov*, 2023]. It is used in exploration geophysics [*Tertyshnikov et al.*, 2024], including borehole measurements [*Hu and Wang*, 2025; *You et al.*, 2025], seismology [*Rashid et al.*, 2025], volcano monitoring [*Bird et al.*, 2025], and early warning systems for earthquakes [*Katakami et al.*, 2024] and tsunamis [*SAFE Project*, 2025].

DAS also has diverse geoecological applications, ranging from studying whales [*Landrø et al.*, 2022] and coastal ocean currents [*Song et al.*, 2024] to monitoring natural and anthropogenic disasters [*Acharya and Kogure*, 2022; *Barrias et al.*, 2016; *Jena et al.*, 2024; *Kleine et al.*, 2024; *Ouellet et al.*, 2024; *Turquet et al.*, 2024] and landfill sites [*Sun et al.*, 2025]. Future plans include using DAS for planetary exploration [*Harmon et al.*, 2024].

1.2. Ice cover monitoring (ICM) is a task with both practical and scientific significance [*Mironov et al.*, 2020]. ICM involves obtaining data on ice thickness, strength, areas of ice formation and fracturing, as well as determining some characteristics such as ice age, volumetric moisture content, surface roughness, inhomogeneities, cracks, ridging, snow cover, water layers, and vertical stratification.

Navigation and safety in shipping and fishing zones, construction and maintenance of drilling platforms, subsea pipeline routing, oil spill monitoring, coastal infrastructure design, safety of cargo unloading onto ice, ice road and ice airfield operations, and tourism all require monitoring of both fast ice and drifting ice fields [*Buzin et al.*, 2022; *Kubyshkin et al.*, 2018; *Stepanyuk and Smirnov*, 2001].

In Russia, rivers and lakes remain ice-covered for 5–6 months or longer. The ice is used for crossings, winter roads, professional and recreational ice fishing, and temporary tourist and hotel installations. River ICM is also essential for predicting ice jams and flood forecasting [*Malygin and Aleshin*, 2022; *Tarasov*, 2020].

Scientific research on ice cover includes compiling and maintaining archives of ice maps, studying physical processes in ice, mathematical modeling of ice evolution (including physico-statistical, hydrodynamic, and climate models and investigating ice regime formation patterns. Additionally, seismic waves excited in water-bottom—carrying information about geological structures—can also be recorded on the ice surface [*Johansen et al.*, 2019].

ICM can be conducted via ice reconnaissance from coastal or drifting hydrometeorological stations, ships, aircraft, helicopters, unmanned vehicles, and Earth observation satellites [*INNOTER*, 2025; *Krylov et al.*, 2023; *Makhsidov et al.*, 2020; *Mikhailov et al.*, 2017].

Detailed and long-term ICM is achieved through seismic methods [*Kovalev et al.*, 2019; *Vinogradov et al.*, 2021]. Beyond tracking displacements and deformations, seismic techniques enable the determination of ice thickness, density, and Young's modulus by analyzing dispersion curves of flexural waves [*Abrahams et al.*, 2023; *Presnov et al.*, 2025].

Active artificial sources, such as explosives or sledgehammer impacts, are used for ice parameter inversion. Passive methods, such as studying flexural waves induced by ocean swells and their high-frequency attenuation, are also employed [*Marsan et al.*, 2012; *Sutherland and Rabault*, 2016]. Noise correlation techniques are another tool for ice parameter estimation [*Marsan et al.*, 2019; *Serripierri et al.*, 2022].

Flexural waves are the most informative for ICM. Under a thin-plate hypothesis (where wavelength greatly exceeds ice thickness), compressional and shear waves are generally non-dispersive, whereas flexural waves exhibit dispersion—higher-frequency signals propagate faster. Meanwhile, compressional waves on ice produce distinct signals (even for vertical sensors) useful for measuring P-wave velocities.

The phase velocity dispersion curve of flexural waves is primarily influenced by Young's modulus and ice thickness (Figure 1), with other parameters having negligible effects [*Xie et al.*, 2025].

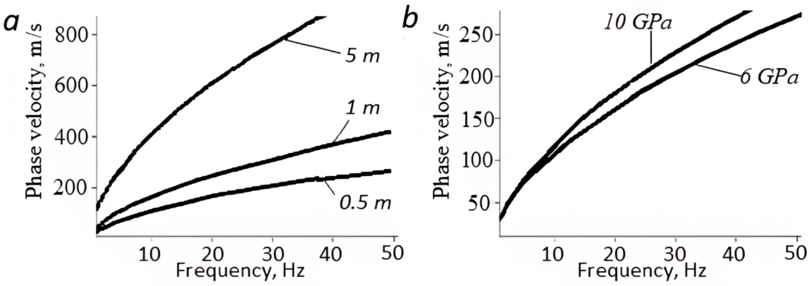

Figure 1. Theoretical dispersion curve variations according to [*Xie et al.*, 2025]: (a) with ice thickness (0.5, 1, and 5 m); (b) with Young's modulus (6 and 10 GPa).

Conventional studies typically use a small number of seismographs, making high spatial resolution unattainable. Reliable data require a dense seismic sensor network. Deploying such a system on ice is labor-intensive, and the risk of losing sensors renders this kind of ICM economically unviable. DAS technology can address these challenges.

DAS advantages include [*Kislov and Gravirov*, 2022]:

- Expensive interrogator remains safely onshore, while the optical fiber is expendable.
- Unprecedented spatial resolution.
- Coverage of an area of up to 100+ km.
- High sensitivity and broad frequency range.
- Continuous, all-weather, year-round measurements.
- DAS can enable long-term monitoring of ice cover parameter changes over time.

2. DAS-based ICM Experiments

In recent years, several successful ICM experiments utilizing DAS have been conducted (Table 1). These studies pursued diverse objectives ranging from volcanic monitoring [*Fichtner et al.*, 2022] to assessing the mechanical properties of ice cover. However, none of the known experiments were sustained for a sufficient duration to track the temporal dynamics of ice cover conditions.

DAS-based ICM can be implemented by using dark fibers within submarine communication cables or power cable monitoring systems of drilling platforms [*Smith et al.*, 2023]. However, the availability of such fiber-optic infrastructure remains limited in the Arctic region and virtually nonexistent in Antarctica. The second methodology involves the deployment of optical fiber directly onto the ice surface. This approach offers several operational advantages. The geometry of fiber layout can be precisely tailored to specific research requirements, enabling optimal sensor placement. Localization of the cable (virtual sensors) is straightforward. Snow cover often ensures adequate fiber-medium coupling [*Walter et al.*, 2020]. Additionally, the level of anthropogenic noise is low in the water areas covered with ice.

The technical challenges of this method become apparent when buried laying of fiber cable longer than several hundred meters, as ice embedding requires specialized equipment. Long-term monitoring campaigns face limitations due to ice dynamics, as mechanical stresses and shearing of ice ultimately lead to fiber rupture. Cable retrieval presents greater logistical difficulties than deployment, particularly when fibers become permanently frozen into the ice. In such cases, complete loss of the fiber optic cable must often be accepted as inevitable. Several retrieval strategies have been proposed, though all of them present significant practical limitations. Awaiting spring thaw represents a passive approach, but this requires extended timelines and offers no guarantee of intact recovery. Incorporating conductive heating elements within the cable design enables active thawing, though this increases system complexity and cost. Alternatively, installing the fiber within a retrievable protective tube appears theoretically feasible, but field implementation proves problematic. Each of these potential solutions introduces substantial technical or economic constraints that generally preclude their practical application.

Table 1. DAS ice cover experiments

Time	Duration	Site	Working part of fiber	Interrogator	Sampling	Gauge length	Spatial sampling	Additional data	Measured parameters	Note	Reference
06.2021	7 days	Beaufort Sea	34.5 km	Silixa iDAS	1 kHz	10 m	200 m	NRT DMSP and MASIE satellite data	Presence/absence of ice	The cable is buried in the bottom by 2–4 m. Dark fiber of the underwater cable	[*Peña Castro et al.*, 2023]
11.2021	7 days										
03.2012		Mendota Lakes, Wisconsin, USA	443 m	Silixa iDAS	1 kHz	10 m	10 m	Vertical and horizontal geophones	Estimate of capability of DAS for wave field measurement, cable comparison	Different cables in parallel 4 times in a triangle with a side of 30 m. Source – sledgehammer	[*Castongia et al.*, 2017]
03.2020	1 day	Lake Robert, France	200 m	A1-R (FEBUS-Optics)	0.5 kHz	10 m	0.8 m		Lake depth, ice thickness and Young's modulus measurements	Deployment using a drone. The cable is reinforced with kevlar	[*Nziengui-Bâ et al.*, 2022]
02.2021	1 day		320 m		2 kHz	2 m	0.1 m				
12.2023	1 day	Hanover Ponds, New Hampshire, USA	3 lines, 50 m each	Sintela Onyx	2.5 kHz	3.2 m	1.6 m	GPS time synchronization	Ice thickness measurements	Source – Proctor hammer	[*Quinn et al.*, 2025]
01.2025	1 day		100 m		5 kHz	2 m	0.25 m				
01.2023	65 hours	Xiushui Reservoir, China	1.2 km in two circles	Ovlink DAS Carina IU	1 kHz	2 m	2 m	CMG-40T seismometer	Study of ice destruction and deformation	Sources – underwater air gun and sledgehammer	[*Xie et al.*, 2024]
									Evaluation of ice thickness, Young's modulus		[*Xie et al.*, 2025]
05.2021	3 weeks	Volcanic Lake, Iceland	12.5 km	Silixa iDAS v2.	0.2 kHz	10 m	8 m		Detection of volcanic tremors	Ice cover of lake-signal amplifier at a certain frequency	[*Fichtner et al.*, 2022]

Continued on next page

Table 1. DAS ice cover experiments (Continued)

Time	Duration	Site	Working part of fiber	Interrogator	Sampling	Gauge length	Spatial sampling	Additional data	Measured parameters	Note	Reference
02.2024	1 day	Klyazma Reservoir, Moscow Region	360 m	Dunay, LLC T8 Sensor	0.5 kHz	10 m	5 m	See text	Ice thickness and Young's modulus measurements. Evaluation of coiled fiber capabilities	Fiber optic rings and straight sections were used	See text

Recent technological advancements in DAS interrogation units have increased sensitivity while reducing power consumption, enabling more sustainable field operations. These innovations collectively contribute to gradual improvements in monitoring system reliability, though fundamental physical constraints imposed by the ice environment remain.

3. Our Experiment

In February 2024, we conducted a field experiment on the ice cover of Klyazma reservoir at the Moscow State University Hydroacoustic Test Site near Povedniki village. This study aimed to validate the applicability of DAS technology for ice cover monitoring, employing a distinctive methodological approach compared to previous experiments referenced in Table 1. The core innovation of our measurement system involved the Dunay fiber-optic distributed sensing platform, developed by the Russian company LLC T8 Sensor as a versatile vibroacoustic monitoring solution with broad geophysical applications [*T8 Sensor*, 2025].

The experimental design incorporated multiple parallel measurement systems to enable cross-validation of results. As reference instruments, we deployed 24 vertical-component Geospace One LF geophones in a linear array with 5-meter spacing (Figure 2). This geophone array served as the ground truth for seismic wavefield characterization. Complementary environmental monitoring included recording of temperature gradients, wind speed, hydroacoustic measurements beneath the ice, and direct ice thickness verification.

The distinctive feature of our DAS implementation involved an innovative fiber-optic rings configuration superimposed on conventional linear cable deployment. We installed paired fiber loops – one oriented vertically and another horizontally (Figure 3) – in close proximity to selected geophones (Figure 4). This dual-ring architecture was designed to enhance directional sensitivity: the vertical ring configuration theoretically exhibits preferential sensitivity to all deformations in the vertical plane, while the horizontal ring configuration captures both orthogonal horizontal components of wave propagation. From a theoretical standpoint, the 10-meter fiber loop (equivalent to the gauge length, GL) functions as a point-like sensor analogous to a conventional geophone. Alternatively, the loop can be modeled as a zero-pitch helix [*Chugaev and Kuznetsov*, 2023], enabling precise mathematical simulation of its directional response characteristics.

Geospatial referencing constituted the next critical phase. The linear geometry of sensor placement simplified coordinate determination. GPS positioning was carried out only at the starting point of the measuring line. While conventional DAS systems suffer from positioning uncertainties related to GL limitations [*Kennett et al.*, 2024], our ring configuration effectively localized measurement points, eliminating this inherent spatial ambiguity. The point-like characteristics of the 10-meter rings effectively mitigated spatial averaging effects that typically plague conventional DAS measurements, enabling resolution comparable to discrete geophones.

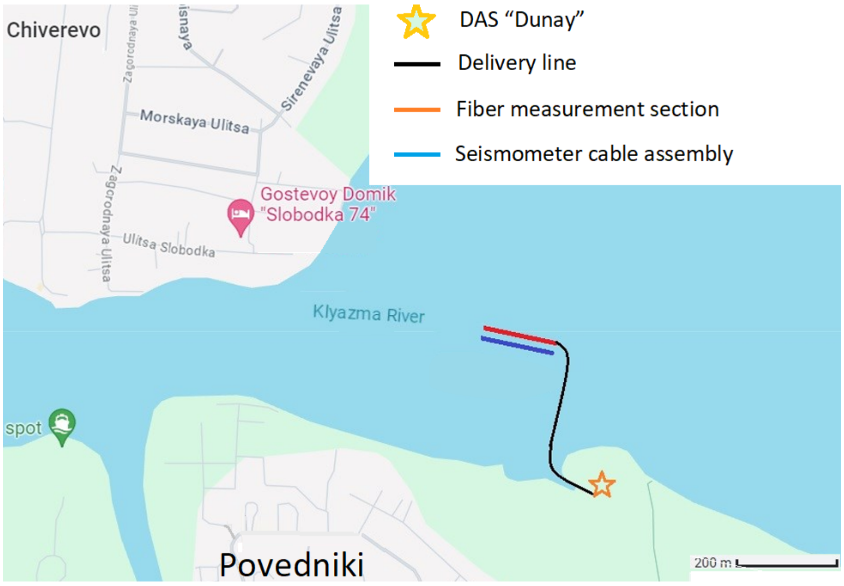

Figure 2. Experimental site.

Figure 3. Fiber-optic ring pair.

We recorded four replicate series of eight hammer strikes (4 kg sledgehammer) at two strategic locations: 10 meters from the first geophone in the array and at the midpoint of the measurement line with 4 meters offset. This configuration enabled comprehensive comparison of wave propagation characteristics between conventional geophones and the DAS system.

Passive monitoring constituted another component of the experiment [*Moreau et al.*, 2020; *Presnov et al.*, 2023; *Yanovskaya and Koroleva*, 2012]. Continuous ambient noise recording spanned 1.5–2 hours to capture natural ice-generated signals. For reliable noise tomography, conventional practice recommends extended recordings proportional to the target frequency range for dispersion curve construction. However, our dataset contained significant anthropogenic contamination from researcher foot traffic, snowmobile movements, and occasional aircraft overflights – all violating the fundamental assumption of homogeneous noise source distribution. Consequently, the acquired noise record, while useful for qualitative assessment, proved insufficient for robust dispersion analysis.

The entire experiment was completed within a single daylight period. Meteorological conditions exhibited notable variability (Figure 5), with air temperature fluctuations exceeding 15 °C, intermittent clouds with wind speeds varying between 0–1.5 m/s. The

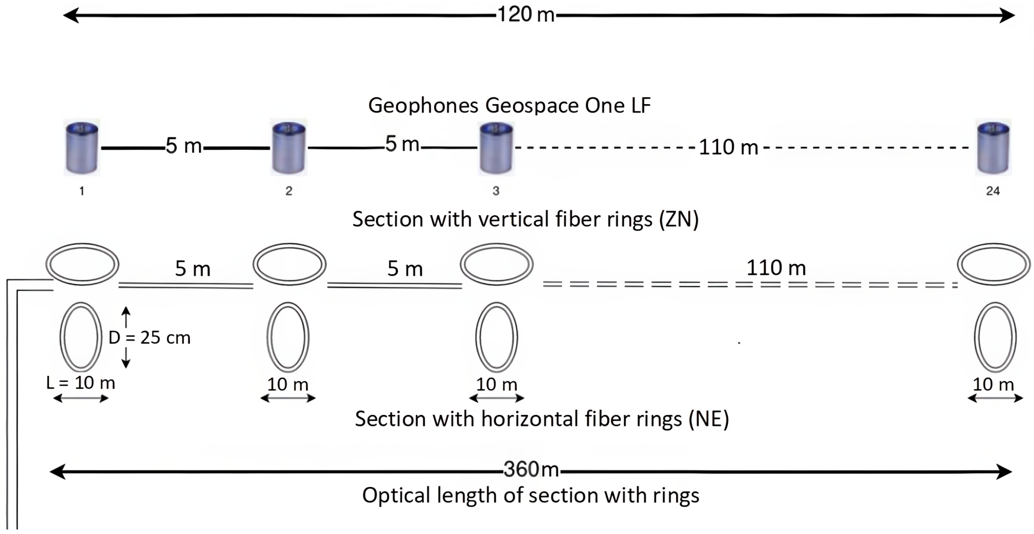

Figure 4. Schematic course of experiment.

temperature profile deviated from the expected diurnal curve due to intermittent cloud cover, as evidenced by inverse correlation between temperature and wind speed.

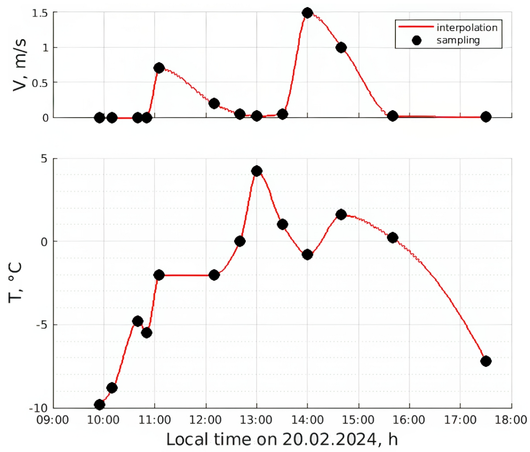

Figure 5. Wind speed (top) and air temperature (bottom) variations.

By combining linear and ring fiber configurations with conventional geophones, we created a unique dataset for comparative analysis of different sensor geometries. The inclusion of comprehensive environmental monitoring enabled quantitative assessment of meteorological effects.

4. Data analysis and results

The comparative analysis between DAS and geophone datasets required careful data processing to ensure methodological consistency. Initial data resampling standardized the DAS recordings to the geophones' 2 kHz sampling rate, enabling direct waveform comparison. Seismogram analysis conclusively demonstrated the DAS system's capability to detect flexural wave propagation, though with a notably lower signal-to-noise ratio (SNR) than conventional geophones (Figure 6). Despite this SNR disadvantage, the acquired data quality proved sufficient for robust extraction of ice mechanical properties, validating the applicability of DAS technology for ice cover monitoring applications.

Several operational factors contributed to the observed noise levels in the DAS recordings. Time constraints imposed by rapidly deteriorating ice conditions significantly limited experimental preparation. The unexpected February thaw compromised ice stability, forcing manual coiling of fiber-optic rings without proper spacing calibration. This improvisation resulted in non-uniform sensor distribution along the measurement line. Additional noise artifacts originated from mechanical stress concentrations at the fiber-optic coupling mounted on the delivery cable spool. Pinching effects at this interface introduced signal attenuation equivalent to approximately 50 km of additional fiber length. Uncompensated temperature variations further degraded data quality through thermally-induced phase noise in the optical system. Moreover, suboptimal coupling conditions affected linear fiber segments that were merely surface-deployed rather than properly frozen into the ice, reducing strain transfer efficiency.

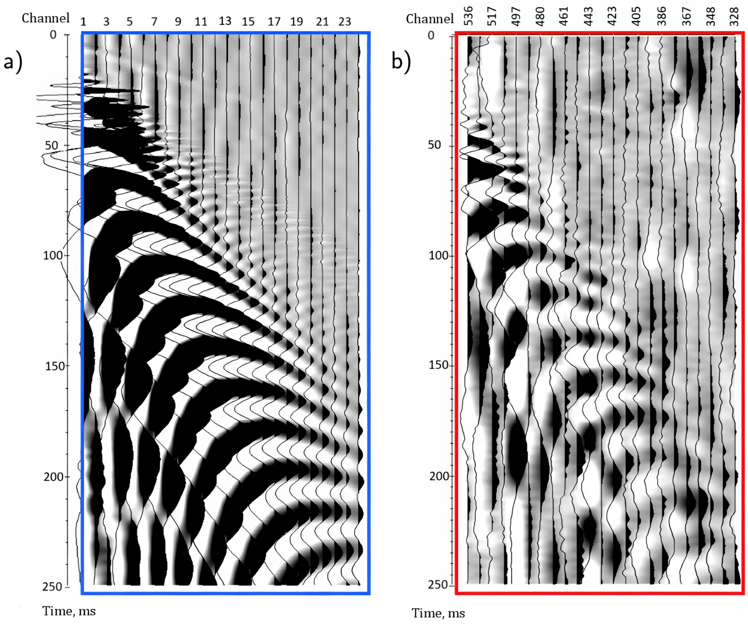

Figure 6. Seismogram comparison: (a) geophones; (b) DAS.

To enhance data quality, we use waveform stacking across multiple hammer strike sequences. The Dunay system's recording was continuous. Field conditions prevented perfect time synchronization. Lacking reliable absolute timing references, impact events were manually logged with an estimated 100 ms precision. Post-processing alignment using first-arrival picking (indicated by green markers in Figure 7a) compensated for these timing uncertainties through cross-correlation techniques.

The dispersion curves obtained using both geophone arrays and DAS look like equal (Figure 8). Despite higher noise floors, the DAS data clearly resolved flexural wave modes within the 30–90 Hz bandwidth – a frequency range suited for ice cover characterization. The inversion of these dispersion curves for ice parameters proved notably more straightforward than equivalent terrestrial analyses, owing to the simpler wave propagation mechanics in homogeneous ice plate compared to complex layered soils.

Current methodologies vary between research groups, but all of them fundamentally rely on minimizing the misfit functional between observed and theoretical dispersion curves. Our implementation successfully derived two key parameters: ice thickness and effective Young's modulus, while secondary analysis of non-dispersive low-frequency noise components provided complementary bathymetric information. The complete set of derived ice parameters appears in Table 2.

These results collectively establish DAS as a viable complement to conventional ice monitoring techniques. The technology's unique advantages – including continuous spatial coverage, directional sensitivity customization, and operational flexibility – outweigh its current limitations for many cryospheric applications.

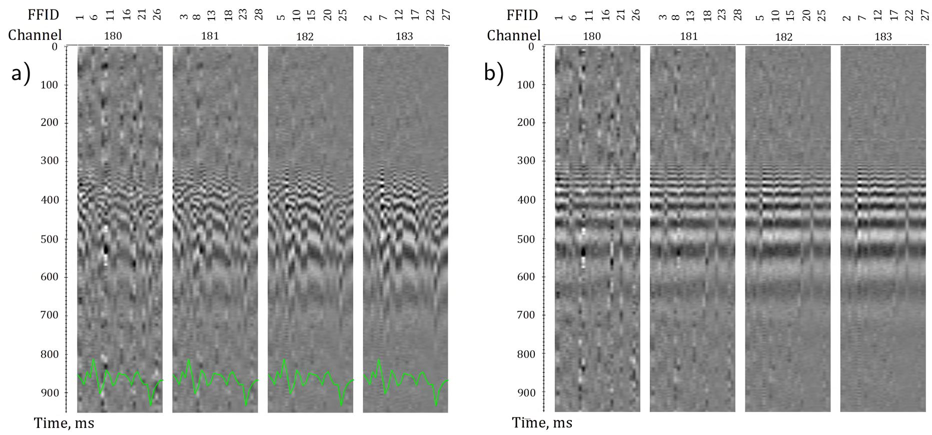

Figure 7. Time discrepancy compensation: (a) manual alignment; (b) after correction.

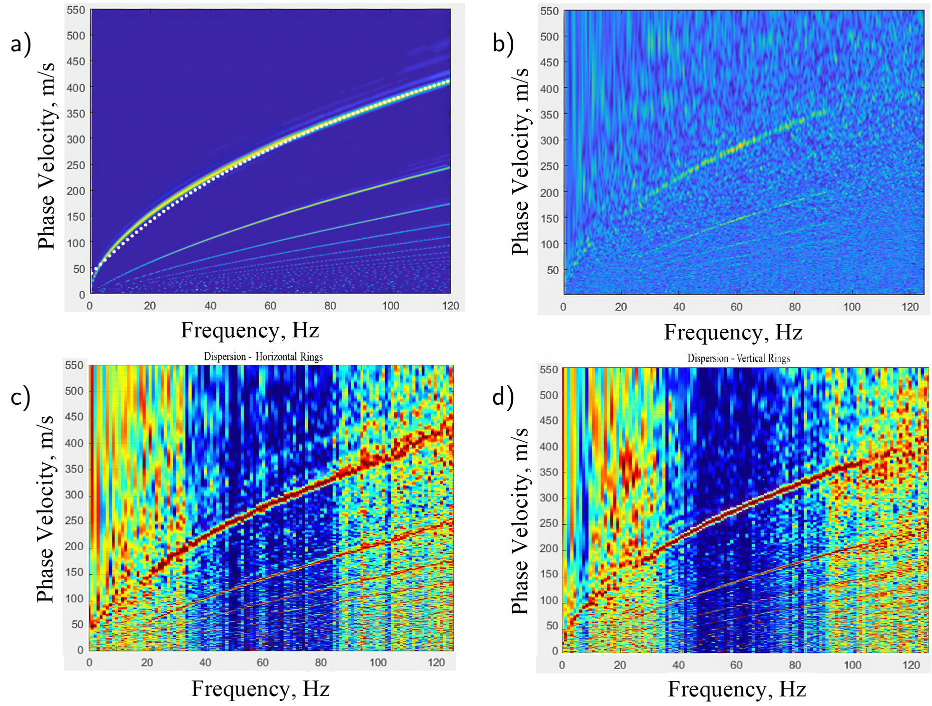

Figure 8. Dispersion images: (a) geophones; (b) stacked DAS; (c) horizontal rings; (d) vertical rings.

5. Discussion

The majority of experiments conducted to date represent pilot studies with limited scope. Actual ice cover structure demonstrates considerably greater complexity than the simplified model of a homogeneous ice layer suggests. Young's modulus of ice exhibits significant dependence on multiple physical parameters including temperature gradients, porosity distribution, water saturation levels, and crystalline structure characteristics. Field measurements typically report Young's modulus values ranging from 3 to 12 GPa under various environmental conditions. Our derived value of 5.3 GPa indicates that despite ongoing thaw processes, increased porosity, and water infiltration, the ice cover maintained sufficient structural integrity to support operational requirements such as light vehicle transportation.

Enhanced accuracy in ice parameter estimation and seismic source localization requires a comprehensive approach incorporating multiple wave types beyond flexural waves alone. The implementation of numerical modeling techniques for full-wavefield analysis could significantly improve inversion results by accounting for complex wave propagation

Table 2. Measured and derived ice parameters

Parameter	Value
Snow cover thickness, m	0.4
Ice cover thickness, m	0.4
Water depth, m	6.8
Compressional-wave velocity in ice plate, m/s	3464
Shear-wave velocity in ice plate, m/s	1973
Ice density, kg/m^3	845 ± 84
Effective Young's modulus, GPa	5.3

phenomena [*Zhang et al.*, 2023]. When precise strain amplitude measurements are critical (e.g., for engineering applications), DAS data requires calibration against conventional seismometers or alternative independent measurement systems to ensure metrological traceability [*Chien et al.*, 2025].

6. Conclusion

DAS is a promising technology for high-resolution, long-distance ice monitoring. Our experiment demonstrated its viability despite noise challenges. Operational constraints highlight the complex interplay between environmental factors and measurement quality in cryospheric DAS applications, emphasizing the need for future studies. Future work should focus on extending monitoring durations to capture temporal evolution of ice properties and integrating multi-physical measurements (seismic, temperature, strain) within unified interpretation frameworks.

Future monitoring systems would benefit from standardized implementation of such combined sensor architectures, particularly in critical applications where both spatial resolution and measurement accuracy are paramount.

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References

Abrahams L., Mierzejewski J., Dunham E., et al. Ocean Surface Gravity Wave Excitation of Flexural Gravity and Extensional Lamb Waves in Ice Shelves // Seismica. — 2023. — Vol. 2, no. 1. — https://doi.org/10.26443/seismica.v2i1.213.

Acharya A. and Kogure T. Application of novel distributed fibre-optic sensing for slope deformation monitoring: a comprehensive review // International Journal of Environmental Science and Technology. — 2022. — Vol. 20, no. 7. — P. 8217–8240. — https://doi.org/10.1007/s13762-022-04697-5.

Barrias A., Casas J. R. and Villalba S. A. A Review of Distributed Optical Fiber Sensors for Civil Engineering Applications // Sensors. — 2016. — Vol. 16, no. 5. — P. 748. — https://doi.org/10.3390/s16050748.

Bird E., Atterholt J., Li J., et al. Constraining Dike Opening Models With Seismic Velocity Changes Associated With the 2023-2024 Eruption Sequence on the Reykjanes Peninsula // AGU Advances. — 2025. — Vol. 6, no. 1. — https://doi.org/10.1029/2024av001516.

Buzin I. V., Klyachkin S. V., Frolov S. V., et al. Compression of the ice cover in the Pechora Sea: a natural phenomenon and its impact on marine operations // Arctic: Ecology and Economy. — 2022. — Vol. 12, no. 4. — P. 500–512. — https://doi.org/10.25283/2223-4594-2022-4-500-512. — (In Russian).

Castongia E., Wang H. F., Lord N., et al. An Experimental Investigation of Distributed Acoustic Sensing (DAS) on Lake Ice // Journal of Environmental and Engineering Geophysics. — 2017. — Vol. 22, no. 2. — P. 167–176. — https://doi.org/10.2113/jeeg22.2.167.

Chien C.-C., Gerstoft P., Hatfield W., et al. Calibrating Strain Measurements: A Comparative Study of DAS, Strainmeter, and Seismic Data // Earth and Space Science. — 2025. — Vol. 12, no. 2. — https://doi.org/10.1029/2024ea003940.

Chugaev A. V. and Kuznetsov A. I. Evaluation of the Capabilities of Distributed Acoustic Sensing with a Helical Fiber for Cross-Well Seismic Survey // Instruments and Experimental Techniques. — 2023. — Vol. 66, no. 5. — P. 868–874. — https://doi.org/10.1134/s0020441223050081.

Fichtner A., Klaasen S., Thrastarson S., et al. Fiber-Optic Observation of Volcanic Tremor through Floating Ice Sheet Resonance // The Seismic Record. — 2022. — Vol. 2, no. 3. — P. 148–155. — https://doi.org/10.1785/0320220010.

Gorshkov B. G., Yuksel K., Fotiadi A. A., et al. Scientific Applications of Distributed Acoustic Sensing: State-of-the-Art Review and Perspective // Sensors. — 2022. — Vol. 22, no. 3. — P. 1033. — https://doi.org/10.3390/s22031033.

Harmon N., Porter R., Rychert C., et al. Distributed Acoustic Sensing for Future Planetary Applications: Initial Results From the San Francisco Volcanic Field, a Lunar Analogue // Earth and Space Science. — 2024. — Vol. 11, no. 12. — https://doi.org/10.1029/2024ea003640.

Hu J. and Wang Y. Wellbore fluid flow velocity calculation based on distributed acoustic sensing data // Journal of Geophysics and Engineering. — 2025. — Vol. 22, no. 3. — P. 799–809. — https://doi.org/10.1093/jge/gxaf014.

INNOTER. Monitoring of the Northern Sea Route. — 2025. — URL: https://innoter.com/articles/monitoring-severnogo-morskogo-puti/ (visited on 07/30/2025) ; (in Russian).

Jena J., Mahed G., Chabata T., et al. Monitoring and early warning detection of collapse and subsidence sinkholes using an optical fibre seismic sensor // Cogent Engineering. — 2024. — Vol. 11, no. 1. — https://doi.org/10.1080/23311916.2023.2301152.

Johansen T. A., Ruud B. O., Tømmerbakke R., et al. Seismic on floating ice: data acquisition versus flexural wave noise // Geophysical Prospecting. — 2019. — Vol. 67, no. 3. — P. 532–549. — https://doi.org/10.1111/1365-2478.12756.

Katakami S., Korenaga M., Iwata N., et al. Immediate and High-Precision Hypocentral Determination for Earthquake Early Warning Applications Using Distributed Acoustic Sensing // Bulletin of the Seismological Society of America. — 2024. — Vol. 115, no. 1. — P. 174–190. — https://doi.org/10.1785/0120240184.

Kennett B. L. N., Lai V. H., Miller M. S., et al. Near-source effects on DAS recording: implications for tap tests // Geophysical Journal International. — 2024. — Vol. 237, no. 1. — P. 436–444. — https://doi.org/10.1093/gji/ggae055.

Kislov K. V. and Gravirov V. V. Distributed Acoustic Sensing: A New Tool or a New Paradigm // Seismic Instruments. — 2022. — Vol. 58, no. 5. — P. 485–508. — https://doi.org/10.3103/s0747923922050085.

Kislov K. V. and Gravirov V. V. Overview of promising applications of distributed acoustic sensing // Science and Technological Developments. — 2023. — Vol. 102, no. 4. — P. 4–37. — https://doi.org/10.21455/std2023.4-1. — (In Russian).

Kleine F., Bruland C., Wüstefeld A., et al. Seismic Signal Classification of Snow Avalanches using Distributed Acoustic Sensing in Grasdalen, Western Norway/ Preprint // Natural Hazards and Earth System Sciences Discussions. — 2024. — https://doi.org/10.5194/nhess-2024-202.

Kovalev S. M., Smirnov V. N., Borodkin V. A., et al. Physical and Mechanical Characteristics of Sea Ice in the Kara and Laptev Seas // International Journal of Offshore and Polar Engineering. — 2019. — Vol. 29, no. 4. — P. 369–374. — https://doi.org/10.17736/ijope.2019.jc767.

Krylov A. A., Novikov M. A., Kovachev S. A., et al. Features of Seismological Observations in the Arctic Seas // Journal of Marine Science and Engineering. — 2023. — Vol. 11, no. 12. — P. 2221. — https://doi.org/10.3390/jmse11122221.

Kubyshkin N. V., Buzin I. V., Golovin N. V., et al. Aspects of ice engineering for the aims of construction of the transport infrastructure and reconnaissance drilling in the Arctic // Arctic and Antarctic Research. — 2018. — Vol. 64, no. 4. — P. 407–426. — https://doi.org/10.30758/0555-2648-2018-64-4-407-426. — (In Russian).

Landrø M., Bouffaut L., Kriesell H. J., et al. Sensing whales, storms, ships and earthquakes using an Arctic fibre optic cable // Scientific Reports. — 2022. — Vol. 12, no. 1. — P. 19226. — https://doi.org/10.1038/s41598-022-23606-x.

Makhsidov V. V., Smirnov O. I., Razomasov N. D., et al. Structural health monitoring of natural and artificial structures based on ice (review) // Proceedings of VIAM. — 2020. — No. 3. — P. 111–118. — https://doi.org/10.18577/2307-6046-2020-0-3-111-118. — (In Russian).

Malygin I. V. and Aleshin I. M. Forecasting Ice Jams on the Lena River Using Machine Learning Methods // Izvestiya, Atmospheric and Oceanic Physics. — 2022. — Vol. 58, no. 10. — P. 1218–1225. — https://doi.org/10.1134/s0001433822100061.

Marsan D., Weiss J., Larose E., et al. Sea-ice thickness measurement based on the dispersion of ice swell // The Journal of the Acoustical Society of America. — 2012. — Vol. 131, no. 1. — P. 80–91. — https://doi.org/10.1121/1.3662051.

Marsan D., Weiss J., Moreau L., et al. Characterizing horizontally-polarized shear and infragravity vibrational modes in the Arctic sea ice cover using correlation methods // The Journal of the Acoustical Society of America. — 2019. — Vol. 145, no. 3. — P. 1600–1608. — https://doi.org/10.1121/1.5094343.

Mikhailov M. I., Muzalevskiy K. V. and Mironov V. L. Ice thickness measurements at freshwater lake and river using GLONASS and GPS signals // Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa. — 2017. — Vol. 14, no. 2. — P. 167–174. — https://doi.org/10.21046/2070-7401-2017-14-2-167-174. — (In Russian).

Mironov Ye. U., Klyachkin S. V., Smolyanitsky V. M., et al. Current state and perspectives of ice cover studies in the Russian Arctic seas // Russian Arctic. — 2020. — No. 10. — P. 13–29. — https://doi.org/10.24411/2658-4255-2020-12102. — (In Russian).

Moreau L., Weiss J. and Marsan D. Accurate Estimations of Sea-Ice Thickness and Elastic Properties From Seismic Noise Recorded With a Minimal Number of Geophones: From Thin Landfast Ice to Thick Pack Ice // Journal of Geophysical Research: Oceans. — 2020. — Vol. 125, no. 11. — e2020JC016492. — https://doi.org/10.1029/2020jc016492.

Nziengui-Bâ D., Coutant O., Moreau L., et al. Measuring the thickness and Young's modulus of the ice pack with DAS, a test case on a frozen mountain lake // Geophysical Journal International. — 2022. — Vol. 233, no. 2. — P. 1166–1177. — https://doi.org/10.1093/gji/ggac504.

Ouellet S. M., Dettmer J., Lato M. J., et al. Previously hidden landslide processes revealed using distributed acoustic sensing with nanostrain-rate sensitivity // Nature Communications. — 2024. — Vol. 15, no. 1. — P. 6239. — https://doi.org/10.1038/s41467-024-50604-6.

Peña Castro A. F., Schmandt B., Baker M. G., et al. Tracking Local Sea Ice Extent in the Beaufort Sea Using Distributed Acoustic Sensing and Machine Learning // The Seismic Record. — 2023. — Vol. 3, no. 3. — P. 200–209. — https://doi.org/10.1785/0320230019.

Presnov D. A., Sobisevich A. L. and Shurup A. S. Determination of Ice Cover Parameters Using Seismoacoustic Noise // Acoustical Physics. — 2023. — Vol. 69, no. 5. — P. 725–737. — https://doi.org/10.1134/s1063771023600341.

Presnov D. A., Spiridonov E. P., Kostenko M. V., et al. Method for seismoacoustic monitoring of ice cover parameters // Science and Technological Developments. — 2025. — Vol. 104, no. 1. — P. 50–62. — https://doi.org/10.21455/std2025.1-3. — EDN: YGSTYJ ; (in Russian).

Quinn M., Doran A. K., Coclin C., et al. Freshwater Thin Ice Sheet Monitoring and Imaging with Fiber Optic Distributed Acoustic Sensing // Glacies. — 2025. — Vol. 2, no. 3. — P. 7. — https://doi.org/10.3390/glacies2030007.

Rashid A., Tackie-Otoo B. N., Latiff A. H. Abdul, et al. Research Advances on Distributed Acoustic Sensing Technology for Seismology // Photonics. — 2025. — Vol. 12, no. 3. — P. 196. — https://doi.org/10.3390/photonics12030196.

SAFE Project. Tsunami early warning system using available seafloor fiber cables: Aragon Photonics. — 2025. — URL: https://aragonphotonics.com/safe-project/ (visited on 07/30/2025).

Serripierri A., Moreau L., Boue P., et al. Recovering and monitoring the thickness, density, and elastic properties of sea ice from seismic noise recorded in Svalbard // The Cryosphere. — 2022. — Vol. 16, no. 6. — P. 2527–2543. — https://doi.org/10.5194/tc-16-2527-2022.

Smith M. M., Thomson J., Baker M. G., et al. Observations of Ocean Surface Wave Attenuation in Sea Ice Using Seafloor Cables // Geophysical Research Letters. — 2023. — Vol. 50, no. 20. — https://doi.org/10.1029/2023gl105243.

Song Z., Zeng X., Ni S., et al. Near Real-Time In Situ Monitoring of Nearshore Ocean Currents Using Distributed Acoustic Sensing on Submarine Fiber-Optic Cable // Earth and Space Science. — 2024. — Vol. 11, no. 9. — https://doi.org/10.1029/2024ea003572.

Stepanyuk I. A. and Smirnov V. N. Methods of measuring the characteristics of ice cover dynamics. — St. Petersburg : Gidrometeoizdat, 2001. — 136 p. — (In Russian).

Sun S., Su Y., Cao D., et al. Subsurface structure assessment for landfill using distributed acoustic sensing: A case study in Qingdao, China // Journal of Applied Geophysics. — 2025. — Oct. — Vol. 241. — P. 105855. — https://doi.org/10.1016/j.jappgeo.2025.105855.

Sutherland G. and Rabault J. Observations of wave dispersion and attenuation in landfast ice // Journal of Geophysical Research: Oceans. — 2016. — Vol. 121, no. 3. — P. 1984–1997. — https://doi.org/10.1002/2015JC011446.

T8 Sensor. Distributed acoustic sensor Dunay. — 2025. — URL: https://en.t8-sensor.ru (visited on 07/30/2025).

Tarasov A. S. Modeling of ice jams in riverbeds (review) // Ice and Snow. — 2020. — Vol. 60, no. 1. — P. 121–133. — https://doi.org/10.31857/s2076673420010028. — (In Russian).

Tertyshnikov K., Yurikov A., Bona A., et al. 3D DAS VSP for Coal Seam Exploration: A Case Study from Queensland, Australia // Sensors. — 2024. — Vol. 24, no. 8. — P. 2561. — https://doi.org/10.3390/s24082561.

Turquet A., Wuestefeld A., Svendsen G. K., et al. Automated Snow Avalanche Monitoring and Alert System Using Distributed Acoustic Sensing in Norway // GeoHazards. — 2024. — Vol. 5, no. 4. — P. 1326–1345. — https://doi.org/10.3390/geohazards5040063.

Vinogradov Y. A., Fedorov A. V., Baranov S. V., et al. Identification of iceberg-forming ice quakes from seismic and infrasound data // Ice and Snow. — 2021. — Vol. 61, no. 2. — P. 262–270. — https://doi.org/10.31857/S2076673421020087. — (In Russian).

Walter F., Gräff D., Lindner F., et al. Distributed acoustic sensing of microseismic sources and wave propagation in glaciated terrain // Nature Communications. — 2020. — Vol. 11, no. 1. — https://doi.org/10.1038/s41467-020-15824-6.

Xie J., Zeng X., Liang C., et al. Ice plate deformation and cracking revealed by an in situ-distributed acoustic sensing array // The Cryosphere. — 2024. — Vol. 18, no. 2. — P. 837–847. — https://doi.org/10.5194/tc-18-837-2024.

Xie J., Zeng X., Ni S., et al. Using distributed fiber optic sensing data to invert for the properties of the ice layer // Chinese Journal of Geophysics. — 2025. — Vol. 68, no. 1. — P. 153–163. — https://doi.org/10.6038/cjg2024R0583. — (In Chinese).

Yanovskaya T. B. and Koroleva T. Y. The velocity structure of the upper mantle in the transition zone from the East European Platform to Western Europe from seismic noise data // Izvestiya, Physics of the Solid Earth. — 2012. — Vol. 48, no. 7/8. — P. 555–561. — https://doi.org/10.1134/s1069351312060080.

You S., Feng G., Qian X., et al. Distributed Fiber Optic Sensing for Fracture Geometry Inversion Using All Time Steps Data // Sensors. — 2025. — Vol. 25, no. 14. — P. 4290. — https://doi.org/10.3390/s25144290.

Zhang H. J., Zhang Y. X., Xiong J. J., et al. Numerical simulation and experimental research of Lamb wave propagation characteristics in ice // Journal of Experiments in Fluid Mechanics. — 2023. — Vol. 37, no. 2. — P. 68–77. — https://doi.org/10.11729/syltlx20210170. — (In Chinese).