Ice Cover Monitoring with Distributed Acoustic Sensing (DAS)

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INTRODUCTION AND MAIN RESULTS

This study explores Distributed Acoustic Sensing (DAS) as an innovative approach to ice cover monitoring (ICM), overcoming the limited resolution and high costs of conventional seismic networks. By using optical fibers as dense arrays of sensors, DAS enables continuous, wide-area monitoring with reduced risk. A field experiment on the Klyazma reservoir (Feb 2024) validated its capability: a novel DAS setup with fiber loops detected flexural waves and, despite higher noise than geophones, successfully derived key ice parameters—thickness (0.4 m) and Young’s modulus (5.3 GPa). These results confirm DAS as a viable and scalable complement tool for cryospheric safety and research.

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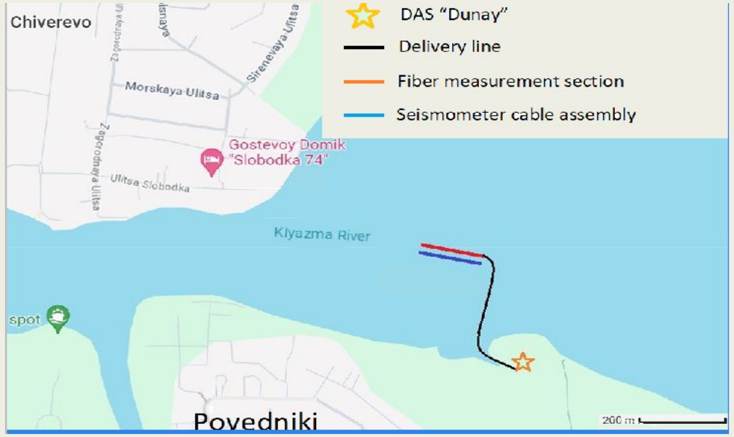
Introduction & Objectives

Ice cover monitoring (ICM) is vital for safety, infrastructure, and research, but conventional seismic methods face cost and resolution limits. Distributed Acoustic Sensing (DAS), using optical fibers as dense seismic arrays, offers continuous coverage. The study aims to test DAS for ICM and evaluate its ability to derive ice thickness and mechanical properties.

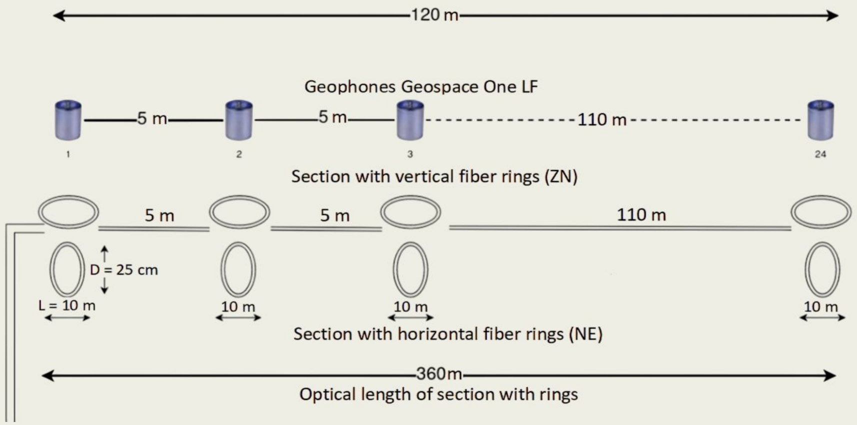
Methods

The approach combines DAS with conventional geophones for cross-validation. DAS exploits Rayleigh backscatter in fibers, where strain alters optical phase. By analyzing wave propagation, especially flexural waves, ice parameters such as thickness and Young's modulus can be inferred through dispersion curve inversion.



Experimental site

Experiment Setup



Experiment site: Klyazma Reservoir, near Moscow, February 2024.

Setup:

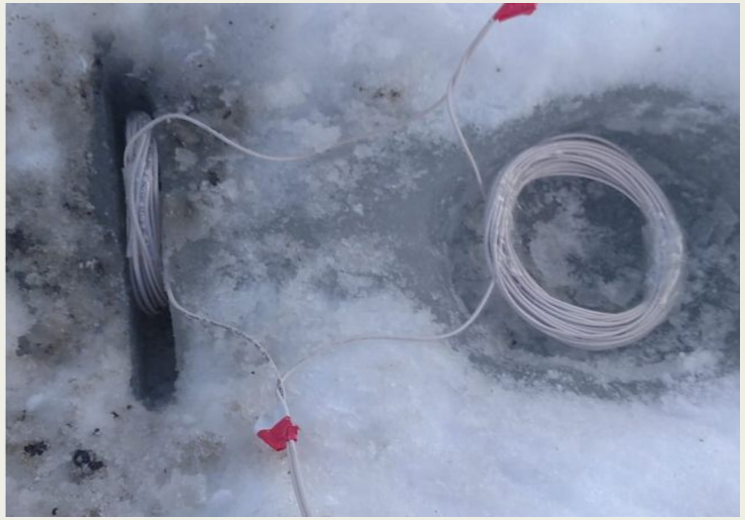
- 24 vertical-component geophones in a 5 m-spaced array.
- DAS interrogator *"Dunay"* system.
- Fiber-optic cable deployed in **linear** and **ring-loop** geometries.

Data collection:

- Active seismic sources: 4 kg sledgehammer strikes.
- Passive monitoring: 1.5–2 hours of ambient ice noise.
- Environmental monitoring: temperature, wind, water depth, ice thickness.

The novelty of approach

An innovative fiber-optic rings layout was superimposed on conventional linear cable deployment. Paired fiber loops (one oriented vertically and another horizontally) -were installed in proximity to geophones. 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.



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Disclaimer: This study presents experimental research results from a limited field campaign. The findings are intended for scientific discussion and should not be directly applied to operational ice monitoring or safety-critical decisions. Performance depends on fiber layout, coupling conditions, and environmental factors.

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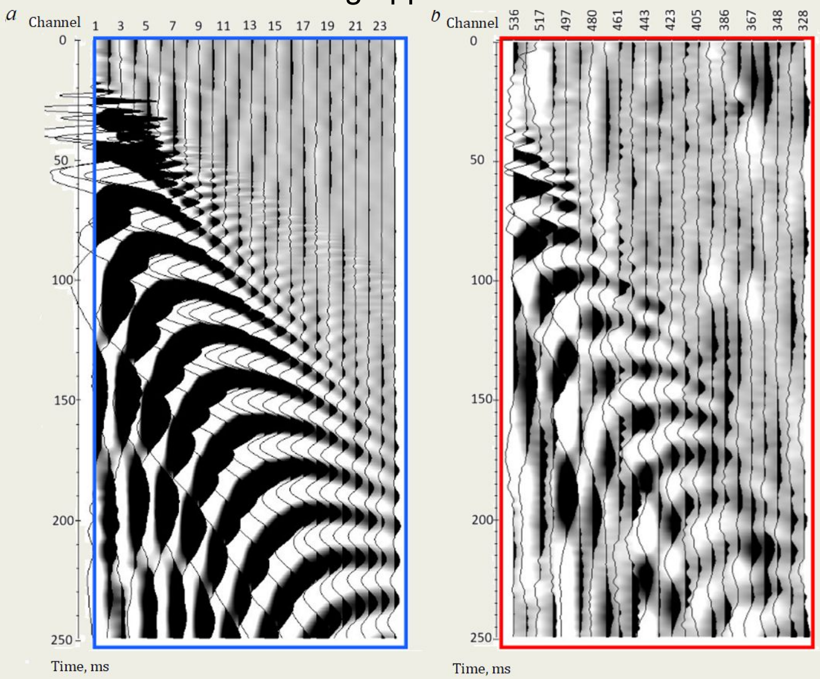
Data Analysis

DAS signals (b) were resampled to geophone (a) standards and compared. Noise and timing issues were mitigated using stacking and cross-correlation.

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. 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.



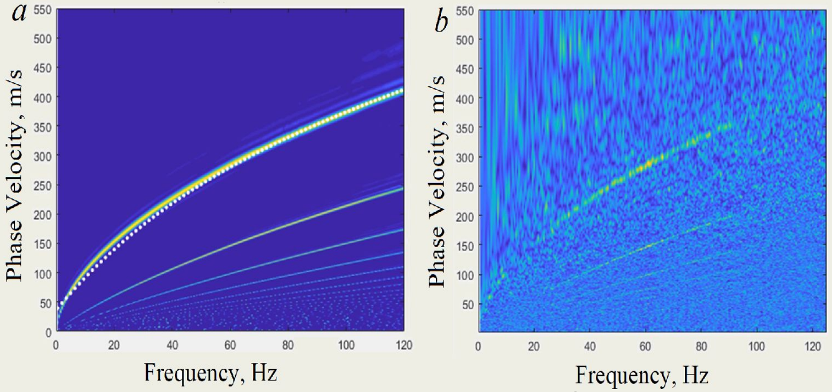
Results & Future Plans

DAS successfully detected flexural waves and matched geophone-derived dispersion curves despite lower SNR. Ice thickness 0.4 m and Young's modulus 5.3 GPa were obtained by MCMC inversion. Findings confirm DAS as a viable complement to traditional methods. Future work should extend monitoring duration, refine inversion with multi-wave analysis, and integrate temperature and strain data, apply passive monitoring methods along with automatic QC procedures.

Parameter	Value
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

Challenges

The experiment faced several limitations. The synchronization between multiple DAS timeseries for hammer strikes sequences was imprecise, requiring manual alignment. Strong anthropogenic noise from field activity further contaminated passive data. Additional signal degradation arose from mechanical pinching of the optical fiber in the delivery reel sleeve, introducing ~8 dB loss—equivalent to ~50 km of extra optical length. The lack of equipment to re-terminate ("digest") the fiber on site prevented correction, reducing signal quality and sensitivity.



(a) geophones; (b) stacked DAS;

Discussion

Most DAS–ice experiments remain pilot studies, while real ice cover is far more complex than homogeneous models. Young's modulus varies (3–12 GPa) with temperature, porosity, water content, and crystal structure; our value of 5.3 GPa shows that despite thaw and infiltration, the ice retained sufficient strength for light transport. More accurate parameter recovery requires using multiple wave types and full-wavefield modeling. For engineering use, DAS data should be calibrated against seismometers to ensure traceability. Overall, our test confirms DAS as a viable tool for high-resolution ice monitoring, though environmental factors and noise demand further study.

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