Photonic Seismology
Lighting the Way Forward
7–10 October 2024 • Vancouver, BC

Welcome to Vancouver!

Thank you for joining us to discuss the latest research driving cutting-edge advancements in DAS and fiber-sensing technologies. We're excited to explore the implications for the future of geosciences through so many different disciplines and perspectives.

Please be sure to have questions ready to raise after each session, and join us for demonstrations from our conference exhibitors on Tuesday and Wednesday night.

Your feedback helps shape our plans for future meetings, so don't hesitate to share your thoughts on this event with us or SSA staff members.

A special thank you to our meeting sponsors and to each of you for helping us make this an engaging and informative program.

Best,
Zack Spica
Zhongwen Zhan
Conference Co-Chairs

WiFi Information:

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Congratulations, Travel Grant Recipients

Each of the recipients below received complimentary registration to the Photonics Seismology: Lighting the Way Forward Conference as well as a stipend for travel expenses. SSA is grateful to our members and friends who gave generously to the Society's General Fund that make these grants possible.

- Richard Asirifi, Texas A&M University
- Thomas Luckie, Sandia National Laboratories
- Elisa McGhee, Colorado State University
- Yan Yang, California Institute of Technology

Technical Program

The following schedule of events and abstracts are valid as of 6 September 2024. See "Program Changes" handout at the Registration Desk for changes to the program.

Monday, 7 October

- Registration Open, 4–7:30 PM
- Opening Reception & Posters, 5–6 PM
- Opening Session & Keynote Presentation, 6–7:30 PM

Tuesday, 8 October

- Breakfast & Posters, 7–8:30 AM
- Session: Sensing Technologies and their Latest Developments, 8:30–10:45 AM
- Coffee Break, 10:45–11:15 AM
- Session: Earthquake Characterization Using Fiber-optic Cables, 11:15 AM–1:15 PM
- Lunch & Posters, 1:15–3 PM
- Session: Real-Time Monitoring and Warning with Fiber Optic Seismology, 3–5 PM
- Posters, Reception and Sponsor Demos by ASN, Febus Optics and Sintela, 5–7 PM

Wednesday, 9 October

- Breakfast & Posters, 7–8:30 AM
- Session: Exploring the Frontier of Environmental Processes Using Fiber-optic Sensing, 8:30–11:30 AM
- Coffee Break, 11:30 AM–Noon
- Session: Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables, Noon–1 PM
- Lunch & Posters, 1–3 PM
- Session: Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables, continued 3–5 PM
- Posters, Reception and Sponsor Demos by AP Sensing, Aragón Photonics and Silixa, 5–7 PM

Thursday, 10 October

- Breakfast & Posters, 7–8:30 AM
- Session: An Innovative Photonic Vision of Volcanoes and Geothermal Systems, 8:30–10:45 AM
- Coffee Break, 10:45–11 AM
- Session: Urban Seismology, 11AM–1 PM
- Lunch & Posters, 1–2 PM
- Session: How to Scale, 2–3:30 PM
- Final Summary Talk & Discussion, 3:30–4 PM
- Closing Reception, 4–5:15 PM

Technical Sessions

Monday, 7 October, 5–7:30 PM

Opening Session Introduction

Zack Spica, University of Michigan; Zhongwen Zhan, California Institute of Technology

Keynote Presentation

Illuminating a Decade of DAS and Beyond. Jonathan Ajo-Franklin, Rice University

SSA Code of Conduct

SSA is committed to fostering the exchange of scientific ideas by providing a safe, productive and welcoming environment for all SSA-sponsored meeting participants, including attendees, staff, volunteers and vendors. We value the participation of every member of the community and want all participants to have an enjoyable and fulfilling experience. Please do your part by following the SSA Code of Conduct (seismosoc.org/meetings/code-of-conduct) throughout the entire conference.

Audio and Video Recording Policy

Audio and video recording by individuals for personal/social media use is allowed only in public spaces throughout the meeting.

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Sensing Technologies and their Latest Developments

Tuesday, 8 October, 8:30–10:45 AM

Optical fiber communication networks are one of the largest global infrastructures humans have ever built, providing a vast web of cables spanning across the globe. Current sensing modalities under exploration in this context can imply fully distributed measurements (such as Distributed Acoustic Sensing, DAS) or end-to-end measurements such as State of Polarization (SoP) and phase measurements. Distributed measurements have the advantage of providing an unprecedented level of spatiotemporal details, while end-to-end measurements leverage mostly the re-use of data so far discarded by the optical fiber transceivers. Hybrid schemes involving, e.g., the use of loop-back channels already available in fiber-optic repeaters are also currently under exploration. By gaining more insight and combining these sensing modalities wisely, the possibilities ahead are extremely broad and, so far, largely unexplored. This session aims to understand the current progress in fiber-optic measurement technologies for seismology, from the first principles to the more general aspects of their application. Submissions are welcome on all topics related to (1) progress in DAS, SoP, and phase schemes, including loop-back configurations; (2) novel architectures enabling compatibility of communications and sensing on the same infrastructure; (3) prospects of finding new applications in the edges of current array seismology.

Earthquake Characterization Using Fiber-optic Cables

Tuesday, 8 October, 11:15 AM–1:15 PM

Photonic seismology has grown into an exciting topic within observational seismology over the last decade. The flexibility of how and where a fiber optic cable can be deployed provides significant opportunities for both novel network designs and a broad spectrum of short-term and long-term monitoring applications, addressing temporal and spatial resolution as well as sensing needs. Despite this growth in interest, we are still, as a community, trying to understand both what the current limitations are and how far we can push these limits. Fundamental differences exist between earthquake records from fiber optic cables and traditional seismometers. While the differences in physical measurements require adaptation to extract meaningful signal characteristics, the continuous spatial measurements provide new opportunities for novel signal processing techniques that can take advantage of the vast quantities of recorded data. The high resolution offered by optical fiber presents an opportunity to enhance observations, facilitating a deeper understanding of earthquake physics. Existing telecom networks have repurposed their fiber and underwater cables for seismological applications. These networks have been used to demonstrate the potential for earthquake-related studies including, earthquake detection and location, magnitude estimation and stress drop, focal mechanisms, fault rupture processes, and imaging Earth structure. In this session, we encourage contributions that showcase the latest research and technological innovations that are pushing the frontiers of earthquake characterization and analysis through fiber optics. We are interested in contributions focused on novel methods, applications, network designs, and case studies that can enrich our understanding of earthquake processes and contribute to the evolution of photonic seismology.

Real-Time Monitoring and Warning with Fiber Optic Seismology

Tuesday, 8 October, 3–5 PM

Real-time warning systems that rapidly detect and characterize earthquakes are increasingly operational around the world with the mission to provide accurate forecasts of both damaging shaking and tsunami warnings. These early warning systems rely on real-time seismic and geodetic data to provide seconds to minutes of warning. The inherent ability of fiber optic-based measurements to cover large spatial scales with instantaneous telemetry of data, including from offshore locations, provides a key motivation to investigate the potential to apply these methods to warning systems. In recent years, fiber optic sensing has rapidly evolved in scale and sophistication, and much effort is being spent harnessing these improvements for real-time applications. In this session, we welcome contributions dealing with a variety of topics, including both scientific and technical aspects of real-time fiber sensing. Scientific aspects may include real-time demonstrations and performance assessments of various algorithms, assessment of the limitations and feasibility, combining fiber optics with traditional sensing technologies, and new approaches for robust, strong shaking and long-period measurements. Technical aspects may include real-time data processing strategies, ensuring robust data streams, and developing effective partnerships with fiber owners and manufacturers of sensing equipment. Additionally, studies aimed at understanding the overall costs of system operation, including data management, are invited. We encourage forward-looking submissions that are aimed at identifying ways to make progress toward improving real-time warning systems through the adoption of fiber optic-based technologies.

Exploring the Frontier of Environmental Processes Using Fiber-optic Sensing

Wednesday, 9 October, 8:30–11:30 AM

Fiber-optic sensing offers unique capabilities for capturing high-resolution data across spatial and temporal scales, making it particularly valuable for studying dynamic environmental systems. This session aims to explore the unprecedented opportunities and advancements in monitoring enabled by Distributed Acoustic Sensing (DAS) and other fiber sensing technologies, transforming our understanding of environmental processes. We seek contributions from researchers and practitioners working on cutting-edge applications of seismological and acoustic fiber optic techniques that showcase their unique capacities to unravel complex environmental dynamics of the cryosphere, geosphere, atmosphere, hydrosphere, and biosphere. Example topics may include but are not limited to: mass movement (landslides, rockfalls, debris flows, lahars); hydrologic processes (groundwater, open-water waves/tides, floods, turbulence, sediment transport), cryospheric (avalanches, icequakes, ice calving/fracture/deformation, glacial hydrology/sliding), atmospheric and oceanic phenomena (microseisms, weather, gravity waves); as well as methodological developments (spatio-temporal imaging, how environmental changes affect fiber-optic sensing operations and data quality, advances in logistical techniques for deployments in harsh environments). Contributors are encouraged to share their research findings, methodologies, and case studies that showcase the versatility and potential of fiber-optic sensing in advancing environmental process monitoring. This session provides a platform for cross-disciplinary discussions, bringing together experts from seismology, acoustics, hydroacoustics, fiber optics, and a wide range of Earth and environmental sciences. Submit your abstract to be part of this transformative session, where fiber-optic sensing technologies take center stage in reshaping our ability to monitor and interpret environmental seismo-acoustic signals.

Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables

Wednesday, 9 October, Noon–1 PM & 3–5 PM
Are we at the beginning of a new era for Earth monitoring?

Our ability to monitor our planet has been continuing to expand over the last several decades, with ever improving sensing capabilities both on land and from space. In contrast, the bottom of the oceans remains largely unmonitored to this day. As the oceans account for 70% of the Earth's surface, the lack of permanent ocean-bottom sensors results in a huge data gap. However, the giant network of optical fiber cables at the bottom of the oceans, which enabled the digital revolution over the last 30 years, could now be the key to a new revolution. By turning seafloor cables into arrays of environmental sensors, many research groups around the world are expanding our monitoring capabilities from land to the bottom of the oceans. Crucially, this can be achieved without requiring new seafloor installations. This session will explore the state of the art in the emerging field of ocean-bottom fiber-optic sensing, covering a number of science areas, from seismology to oceanography and acoustics. We invite contributions on optical interferometry, distributed acoustic sensing (DAS), and other techniques that enable short and long-range sensing over seafloor cables, as well as applications of ocean-bottom sensing from monitoring offshore earthquakes and subsurface imaging to detecting marine mammal vocalizations and measuring ocean temperature changes. In addition to the talks, the session will include engaging discussions on the exciting possibilities, the challenges, and the future outlook of cable-based ocean-bottom sensing.

An Innovative Photonic Vision of Volcanoes and Geothermal Systems

Thursday, 10 October, 8:30–10:45 AM
The structure and dynamics of volcanoes and geothermal systems can benefit from a new vision: fiberoptic sensing. Fiber-optic sensing single point sensors (such as rotational sensors and gyroscopes), fiber Bragg arrays, and distributed fiber-optic sensing have been recently used to improve our knowledge of the subsurface features and mechanisms driving the phenomena occurring within volcanic and geothermal systems. Whether temperature, strain, or chemical sensing, these new tools help us to highlight unknown structural features of the complex plumbing systems of the earth, with a clear reduction of cost for exploration. Monitoring of such systems is also facilitated as deployment on existing telecommunication and dedicated fibers is becoming easier, and the instruments' sensitivities are enhanced at both high and low frequencies. The session aims to provide an innovative vision of volcanic and geothermal areas with contributions to the exploration and monitoring of these systems in various environments, such as boreholes, underwater, and acidic and high-temperature conditions. We welcome diverse applications related to volcano/geothermal seismicity and tremor, related landslides, and volcanic glaciers that employ new sensing and processing technologies such as machine learning and artificial intelligence. We aim in particular at attracting contributions on the long-term deformation of volcanoes or geothermal systems due to magma, gas, and tectonic processes, as seen with fiber optic and photonic tools to offer geoscientists a new vision of Earth processes leading to new knowledge, better resource management, hazard assessment, as well as for more sustainable energy solutions and risk mitigation.

Urban Seismology

Thursday, 10 October, 11 AM–1 PM
More than half the world's population lives in cities, and an additional 2.5 billion people are expected to move to cities by 2050. The cities of the future must support thriving human

communities but also reduce their carbon footprint and be resilient to the new challenges presented by climate change. Seismic data can provide invaluable information to achieve these goals by cost-effective continuous monitoring of the subsurface, the built environment, and the impact of human activities. Potential monitoring applications range from managing geologic hazards and water resources by time-lapse subsurface imaging and analysis of local and regional seismicity to cost-effective monitoring of urban infrastructure such as bridges and tunnels. The potential value of urban seismology has been recently enhanced by the development of new acquisition technologies such as autonomous nodes and fiber optic sensing, which, combined with cloud/edge computing, enable the creation and management of large-scale, dense seismic networks. In particular, repurposing unused fiber-optic telecommunication networks as massive arrays of seismic sensors enables continuous imaging and monitoring of the urban subsurface at unprecedented resolution with minimum effort, providing opportunities for a wide range of new urban seismic studies. The future realization of the potential value of leveraging fiber-optics sensing technologies for urban seismology depends on developing new data acquisition strategies, processing algorithms, computational tools, and interpretation workflows. We welcome contributions on all aspects of using fiber-optic sensing technologies in urban seismology, ranging from advances in instrumentation to algorithmic development, modeling studies, and new field experiments. Applications include, but are not limited to, characterization and mitigation of geologic hazards, urban hydrogeophysics, monitoring energy development and storage activities, traffic monitoring, and any other application contributing to advancing urban resilience and sustainable development.

How to Scale Up

Thursday, 10 October, 2–3:30 PM

Fiber optic sensing technologies hold immense promise for advancing geophysical studies. Distributed Acoustic Sensing (DAS) has demonstrated remarkable capabilities in studying surface and subsurface processes with unprecedented resolution and over extended periods, even in challenging environments. Emerging technologies like phase transmission and state of polarization (SoP) offer the potential for continental or oceanwide scale monitoring with continuously improving data quality. Yet, to fully leverage the potential of fiber sensing for geophysical applications, several key steps must be taken. This includes facilitating access to existing fibers and streamlining the installation of new fibers in both onshore and submarine environments. Overcoming challenges in telemetry, real-time monitoring, and data transportation is crucial, as proven by many ongoing efforts underway to address these obstacles. Additionally, ensuring common standards for metadata and providing user-friendly software interfaces are essential for encouraging broader use and analysis of fiber optic sensing datasets, especially as they become more accessible to the public. While advancements in photonics technology have led to faster algorithms, there is a need to develop techniques and infrastructure tailored to fully exploit the richness of fiber optic sensing datasets such as DAS and enable greater synergy among scientists. As new techniques such as SoP and projects such as smart cables emerge, it will be important for the geophysical community to embrace these innovations and integrate them effectively into existing practices. This session will feature a series of short talks followed by a panel-style discussion, exploring these topics, presenting new and emerging solutions, and addressing open challenges in deploying fiberoptic sensing technologies to the next level.

Schedule

Monday, 7 October 2024

4–7:30 PM	Registration Open
5–6 PM	Opening Reception & Posters
6–7:30 PM	Opening Session and Keynote Presentation: Illuminating a Decade of DAS and Beyond. **Jonathan Ajo-Franklin**.

Tuesday, 8 October 2024

7–8:30 AM	Breakfast & Posters
Session: Sensing Technologies and their Latest Developments	
8:30–9 AM	KEYNOTE: Phase Transmission Fiber-optic Sensing: Theory and Emerging Technologies. **Andreas Fichtner.**
9–9:15 AM	INVITED: Novel Types of Distributed Acoustic Sensing (DAS) Systems with Unconventional Performance. **Miguel Gonzalez-Herraez.**
9:15–9:30 AM	Harnessing Transatlantic Submarine Cables for Tidal and Strain Measurements. **Meichen Liu.**
9:30–9:45 AM	Comprehensive Evaluation of DAS Performance: Instrument Response, Noise Floor, and Amplitude Saturation. **Qiushi Zhai.**
9:45–10 AM	Rotation Sensing with Optic Technology. **Heiner Igel.**
10–10:15 AM	Rayleigh Scattered Wave Analysis Techniques in Distributed Optical Fiber Sensing for Broadband Geophysical Observation in the Seafloor. **Eiichiro Araki.**
10:15–10:45 AM	Discussion Period
10:45–11:15 AM	Coffee Break
Session: Earthquake Characterization Using Fiber-optic Cables	
11:15–11:45 AM	KEYNOTE: South Island Seismology at the Speed of Light Experiment (SISSLE)—Characterizing the Alpine Fault at Haast (South Westland, New Zealand). **Meghan S. Miller.**
11:45 AM–12 PM	INVITED: Advancing Earthquake Characterization with Telecom Fiber Networks. **Jiaxuan Li.**
12–12:15 PM	INVITED: 10-m-deep Earthquake Swarms (Mw −2) Near the Milun Fault in Hualien, Taiwan, Detected by the MiDAS Seismic Monitoring System. **Yen-Yu Lin.**
12:15–12:30 PM	STUDENT: Exploring Earthquake Source Characteristics Using Borehole Optical Fiber Arrays: Insights from the 2022 M6.8 Chihshang, Taiwan, Earthquake. **Jolan Liao.**
12:30–12:45 PM	Accurate Magnitude and Stress Drop Using the Spectral Ratios Method Applied to Distributed Acoustic Sensing. **Itzhak Lior.**
12:45–1:15 PM	Discussion Period
1:15–3 PM	Lunch Break and Posters
Session: Real-Time Monitoring and Warning with Fiber Optic Seismology	
3–3:30 PM	KEYNOTE: Assessing Distributed Acoustic Sensing for Real-time Monitoring and Earthquake Early Warning (EEW) in the Southernmost Cascadia Subduction Zone. **Jeffrey McGuire.**
3:30–3:45 PM	INVITED: Low-cost DAS Arrays using Commercially Owned Fibers and Interrogators for Continuous Seismic Monitoring and Early-warning. **Itzhak Lior.**
3:45–4 PM	STUDENT: Toward Integration of DAS Arrays and Traditional Seismic Networks for Real-Time Earthquake Monitoring and Early Warning. **Yuancong Gou.**
4–4:15 PM	Seismic Event Monitoring with DAS in the Cloud. **Marlon D. Ramos.**
4:15–4:30 PM	Distributed Acoustic Sensing of Fiber Networks for Earthquake Monitoring and Early Warning Operations. **Ettore Biondi.**
4:30–5 PM	Discussion Period
5–7 PM	Reception, Posters and Sponsor Demos by ASN, Febus Optics and Sintela

Monday, 7 October and Tuesday, 8 October—Posters

An Innovative Photonic Vision of Volcanoes and Geothermal Systems

1. STUDENT: Fine Scale Southern California Moho Structure Uncovered with Distributed Acoustic Sensing. **James Atterholt.**
2. STUDENT: Time Varying Crustal Anisotropy at Whakaari/ White Island Volcano. **Dagim Y. Mengesha.**

Earthquake Characterization Using Fiber-optic Cables

3. STUDENT: Downhole DAS Array for Microseismic Event Characterization at FORGE Combining Direct and Converted Phase Picks from Machine Learning. **Richard Asirifi.**
4. Source Parameter Measurement Validation Using DAS and Seismic Stations. **Xiaowei Chen.**
5. A Waveform-Based Earthquake Detector for DAS Data. **Sonja Gaviano.**
6. STUDENT: Passive Seismology in Urban Environments Using Distributed Acoustic Sensing in Auckland, New Zealand. **Patrick Hollands.**
7. Using DAS and Seismometer Arrays to Analyze Strain for Explosion Monitoring. **Gene A. Ichinose.**
8. STUDENT: Resolving Asperity- and Barrier-like Fault Heterogeneity by Back-Projection of High-Frequency Signals. **Taeho Kim.**
9. STUDENT: Unmasking Traffic Noise: Unsupervised Denoising for Distributed Acoustic Sensing (DAS) Data. **Sebastian Konietzny.**
10. Detection of Cement Grouting Induced Events in Continuous Downhole Distributed Acoustic Sensing Data using Machine Learning. **Chin-Shang Ku.**
11. Shallow Imaging of the Alpine Fault Zone, New Zealand Using Distributed Acoustic Sensing (DAS). **Voon Hui Lai.**
12. Construction of Horizontal Strain Array from DAS Sensor. **Chin-Jen Lin.**
13. Distributed Acoustic Sensing Data Denoising with Deep Learning. **Jiun-Ting Lin.**
14. STUDENT: PYROS: A Python Framework for Modeling DAS Data. **Davide Pecci.**
15. Evaluation of Passive Source DAS Methods on the Source Physics Experiment Phase II. **Robert Porritt.**
16. STUDENT: Numerical Investigations of the Potential of Joint Source-Structural Full Waveform Inversion (FWI) Using DAS Arrays. **Eyal Shimony.**
17. Downhole DAS for Induced Seismicity and Reservoir Monitoring in the Groningen Gas Field. **Anna L. Stork.**

Real-Time Monitoring and Warning with Fiber Optic Seismology

18. Earthquake Location With Distributed Acoustic Sensing (DAS) Using Beamforming and Phase Arrival Time Differences. **Shahar Ben-Zeev.**
19. Developing Local to Near-regional Distance Explosion Monitoring Capabilities Using Distributed Acoustic Sensing (DAS). **Brent G. Delbridge.**
20. Machine-Learning Based Techniques Enabling Real-time Monitoring of Induced Seismicity in Offshore CO2 Sequestration Sites. **Stuart Farris.**
21. Integrating DAS Seismic Data into the National Earthquake Monitoring at the Swiss Seismological Service. **Frederick Massin.**
22. Toward Automatic Avalanche Detection With Distributed-Acoustic-Sensing, Leveraging Telecommunication Infrastructure. **Frederick Massin.**
23. Assessing Distributed Acoustic Sensing Strain-Rate Waveform Statistics for Improving Earthquake Early Warning. **Theresa M. Sawi.**
24. Utility of Distributed Acoustic Sensing for Locating Seismic Events Over Multiple Distance Ranges. **Clifford Thurber.**
25. STUDENT: Real-Time Monitoring of Centrifuge Operational Status and its Impact on Surrounding Structures Using Distributed Acoustic Sensing (DAS). **Peng Wu.**

Sensing Technologies and their Latest Developments

27. STUDENT: Calibrating Strain Measurements: A Comparative Study of DAS, Strainmeter, and Seismic Data. **Chih-Chieh Chien.**
28. Monitoring Blasting Operations at the Sanford Underground Research Facility (SURF) Using a Three-dimensional Distributed Acoustic Sensing (DAS) Array. **Dante Fratta.**
29. STUDENT: Quaternion Processing of 3C Rotational Motion Based on FOGs. **Yifan Jian.**
30. Ocean Space Surveillance Using Distributed Acoustic Sensing on Submarine Networks. **Jan Petter Morten.**
31. STUDENT: Full-Waveform Inversion with Distributed and Integrated Strain Sensing for Complex Cable Geometries. **Sebastian Noe.**
32. Monitoring of Seismic Surface Waves in Trackside Dark Fibers Using High-Fidelity Distributed Acoustic Sensing. **Javier Preciado-Garbayo.**
33. Comparison of DAS Recordings With a Calibrated Underground Strain Meter Array. **Andreas Rietbrock.**
34. Amplitude Calibration for Distributed Acoustic Sensing. **Christian Stanciu.**
35. The Potential of DAS to Detect Long-Period Signals. **Shun (Shane) Zhang.**
36. STUDENT: Distributed Acoustic Sensing (DAS) Calibration in a Laboratory Wellbore System. **Zhi Yuan.**

Wednesday, 9 October 2024

7–8:30 AM	Breakfast & Posters
Session: Exploring the Frontier of Environmental Processes using Fiber-optic Sensing	
8:30–9 AM	KEYNOTE: Fluvial Monitoring with Distributed Acoustic Sensing. **Danica L. Roth.**
9–9:15 AM	INVITED: Fiber Optic for Environment Sensing (FORESEEx): Examples from Urban and Arctic Arrays. **Tieyuan Zhu.**
9:15–9:30 AM	INVITED: STUDENT: Enhancing Hydrological Monitoring with Fiber-Optic Sensing. **Yan Yang.**
9:30–9:45 AM	STUDENT: Evaluating Strain and Temperature Variations with Low Frequency Distributed Acoustic Sensing. **Susanne Ouellet.**
9:45–10 AM	Exploiting DAS Records Directly for Source and Structural Properties – Examples from the Greenland Ice Sheet. Brian **L. N. Kennett.**
10–10:30 AM	Break
10:30–10:45 AM	STUDENT: Monitoring Groundwater Dynamics in the Lyon Water Catchment using DAS combined with Ambient Noise Interferometry. **Destin Nziengui Bâ.**
10:45–11 AM	Multiplexed Distributed Acoustic Sensing at the Ocean Observatory Initiative Regional Cabled Array. **Bradley P. Lipovsky.**
11–11:30 AM	Discussion Period
11:30 AM–12 PM	Coffee Break
Session: Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables	
12–12:30 PM	KEYNOTE: Science with Transoceanic Seafloor Cables. **Giuseppe Marra.**
12:30–12:45 PM	INVITED: Spatio-temporal Observations of Nonlinear Wave-wave and Wave-current Interaction with DAS. **Ethan F. Williams.**
12:45–1 PM	INVITED: DAS Observation for High-frequency Tsunamis Excited Near Torishima Island, Japan. **Takashi Tonegawa.**
1–3 PM	Lunch Break and Posters
3–3:15 PM	Imaging the Near-surface Structure and Monitoring the Microseismicity Around the Changdao Earthquake Swarm Area with Distributed Acoustic Sensing. **Baoshan Wang.**
3:15–3:30 PM	Exploring the Potential of Distributed Acoustic Sensing in Ocean Acoustics. **Shima Abadi.**
3:30–3:45 PM	Results from an Optical Fiber Seafloor Strainmeter. **Mark Zumberge.**
3:45–4 PM	Distributed Optical Fiber Sensing over Multi-Span Subsea Telecom Cables with Active Amplification. **Mikael Mazur.**
4–4:15 PM	Observing Seafloor Processes by Distributed Fiber Optic Sensing Using an Academic Cable Offshore Catania Sicily (Italy) and a Commercial Telecom Network in the Guadeloupe Archipelago (Lesser Antilles). **Marc-Andre Gutscher.**
4:15–5 PM	Discussion Period
5–7 PM	Reception, Posters and Sponsor Demos by AP Sensing, Aragón Photonics and Silixa

Thursday, 10 October 2024

7–8:30 AM	Breakfast & Posters
Session: An Innovative Photonic Vision of Volcanoes and Geothermal Systems	
8:30–9 AM	KEYNOTE: Fibre Optic Sensing for Innovative Imaging and Monitoring of Geothermal and Volcanic Systems. **Philippe Jousset.**
9–9:15 AM	INVITED: A New Imaging Standard for Volcanic Systems Through Fiber Sensing and Novel Processing Algorithms. **Ettore Biondi.**
9:15–9:30 AM	INVITED: STUDENT: Fibre-Optic Seismology on Remote, Subglacial, Submarine and Actively-Erupting Volcanoes. **Sara Klaasen.**
9:30–9:45 AM	Imaging Magma Flow Migration Through a Dike Using Low-frequency DAS Measurements. **Jiaxuan Li.**
9:45–10 AM	Using Low-frequency DAS Signals for Early Warning During the Sundhnúksgígur, Iceland, Eruptions in 2024. **Vala Hjörleifsdóttir.**

10–10:15 AM	STUDENT: Seismic Velocity Changes Associated with the 2023–2024 Eruption Sequence on the Reykjanes Peninsula. **Elijah Bird.**
10:15–10:45 AM	Discussion Period
10:45–11 AM	Coffee Break
Session: Urban Seismology	
11–11:30 AM	KEYNOTE: Large-scale Monitoring of Urban Environments by Fiber-optic Seismology: Lessons from Eight Years of the Stanford DAS Project. **Biondo L. Biondi.**
11:30–11:45 AM	INVITED: Optimizing DAS Ambient Seismic Noise Interferometry Workflows for Efficient, High-resolution Investigation of the Urban Subsurface. **Verónica Rodríguez Tribaldos.**
11:45 AM–12 PM	Building Health Monitoring Using Ambient Noise Interferometry Across Multistory DAS Arrays. **Chen Gu.**
12–12:15 PM	STUDENT: Data Augmentation Techniques to Improve Automatic Detection in DAS Records. **Alfonso Ortiz-Avila.**
12:15–12:30 PM	STUDENT: Fiber Optic Seismology in Densely Populated Urban Areas Exposed to Seismic Hazard. **Krystyna T. Smolinski.**
12:30–1 PM	Discussion Period
1–2 PM	Lunch break and Posters
Session: How to Scale Up	
2–3:30 PM	Panel Discussion consisting of the following panelists: Zack Spica (University of Michigan), Eileen Martin (Colorado School of Mines), Voon Hui Lai (Australian National University), Allen Husker (California Institute of Technology), Connie Stewart (California State Polytechnic University, Humboldt), Benoît Pirenne (Ocean Networks Canada).
3:30–4 PM	Final Summary and Discussion Period
4–5:15 PM	Closing Reception

Wednesday, 9 October and Thursday, 10 October—Posters

Exploring the Frontier of Environmental Processes using Fiber-optic Sensing

1. What Does free-floating fiber in a River Record? Insights from a DAS Deployment in Clear-Creek Colorado. **Maximiliano J. Bezada.**
2. Using Co-Located DAS and Nodal Data to Interpret Flow Hydraulics and Sediment Transport During Flume Experiments. **Susan Bilek.**
3. Detection of an Artificial Meteoroid Via Distributed Acoustic Sensing. **Carly M. Donahue.**
4. Forecasting Coastal Cliff Collapse Using Distributed Sensing. **Jessica H. Johnson.**
5. STUDENT: Automatic Monitoring of Rock-Slope Failures Using Distributed Acoustic Sensing and Semi-Supervised Learning. **Jiahui Kang.**
6. STUDENT: Characterizing Environmental Noise in Hypersonic Object Detection: Insights from a Fiber Optic Cable Deployment. **Elisa A. McGhee.**
7. Local Variations in Microseisms Recorded off the Coast of Sicily. **Florian Le Pape.**
8. STUDENT: Looking into a Disappearing Glacier: An Active Source DAS Experiment on Langjökull Ice Cap. **Auden M. Reid-McLaughlin.**
9. STUDENT: DAS Observations of Ice-Wedge Cracking in Utqiagvik, Alaska. **Gabriel Fernando Rocha dos Santos.**
10. Correlation of DAS Strain Data and Oceanographic Variables in the North-East Atlantic. **David Schaphorst.**
11. Distributed Acoustic Sensing of Debris Flow Dynamics at Illgraben, Switzerland. **Christoph Wetter.**
12. Fiber-optic Observations of Wind-induced Gravity Waves in Lake Ontario. **Chu-Fang Yang.**
13. Long-Term Analysis of Cryoseismic Events and Earthquakes at the South Pole Using Distributed Acoustic Sensing. **Qiushi Zhai.**

Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables

14. STUDENT: How Cable Architecture Influences Distributed Fiber Optic Sensing Along a Submarine Cable Offshore Catania. **Giuseppe Cappelli.**
15. Application of Distributed Acoustic Sensing for Fin Whale Calls Detection and Localization. **Quentin Goestchel.**
16. STUDENT: SeaFOAM : A Permanent Offshore DAS Deployment in Monterey Bay, California. **Yuancong Gou.**
17. Feasibility Study: Integrating Fiber Optic Sensing into the NEPTUNE Cabled Observatory for Enhanced Ocean Monitoring and Earthquake Early Warning. **Martin Heesemann.**

18. Potential and Challenges in Body Wave Travel Imaging From an Offshore Telecommunication Fiber in Southern Alaska. **Walid Ben Mansour.**
19. Trans-dimensional Inversion of Multi-mode Dispersion Curves From Ocean Bottom Distributed Acoustic Sensing. **Walid Ben Mansour.**
20. Student: Wavefield Reconstruction of Distributed Acoustic Sensing: Compression, Wavefield Separation, and Edge Computing. **Yiyu Ni.**
21. Denoising Offshore Distributed Acoustic Sensing Using Masked Auto-encoders to Enhance Earthquake Detection. **Qibin Shi.**
22. Mapping Ocean Surface Gravity Waves in the Coastal Ocean with Distributed Acoustic Sensing from Seafloor Fiber Optic Cables. **Madison M. Smith.**
23. Student: Near-coast Subsurface Imaging with Distributed Acoustic Sensing and Double Beamforming. **Zack Spica.**
24. Event Detection Threshold on Submarine Fiber Optic in the Arctic. **Christian Stanciu.**
25. Advanced Monitoring Techniques for Mitigating Induced Seismicity in Offshore Subsurface Energy Projects: A Case Study from the CASTOR Gas Storage Site. **Arantza Ugalde.**
26. Mining Ocean Bottom Distributed Acoustic Sensing data with 2D Scattering Network. **Loïc Viens.**
27. DeepDAS: Earthquake Phase Picker from Submarine Distributed Acoustic Sensing Data. **Han Xiao.**

How to Scale Up

28. DAS Fiber Optics in Brazil, Why We Are Not Using It Yet. George **Sand Franca.**
29. Enabling Access to DAS Earthquake Data with FiberSense's DigitalSeismic Platform. **Nathaniel J. Lindsey.**
30. Student: Lossless and Lossy Compression for Distributed Acoustic Sensing Using Inter-channel Predictions. **Aleix Seguí.**
31. Developing Standards and Building Capacity for Photonic Seismology Data. **Chad Trabant.**

Urban Seismology

32. A Corpus of Signals From a 12-month DAS Experiment at Southern Methodist University. **Stephen Arrowsmith.**
33. Student: Characterizing Near-surface Velocity Structure and Site Responses at the MIT Campus Using Telecommunication Dark Fibers with DAS. **Hilary Chang.**
34. Detection and Location of Operational Activity at the Sanford Underground Research Facility. **Erin Cunningham.**
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36. Spatiotemporal Models of Pedestrians and Vehicles Using Machine Learning and Back-projection. **Thomas Luckie.**
37. Assessing Impact of Preprocessing Techniques for DAS Ambient Noise Survey in Urban Environments. **Nathan Maier.**
38. Student: Characterizing Low-yield Mining Blasts Using Distributed Acoustic Sensing (DAS). **Joseph J. Miller.**
39. Student: On the Spatial Subsurface Localization of Seismic Velocity Changes in Mexico City Using DAS. **Valente Ramos-Avila.**
40. Student: Imaging the Urban Subsurface Using Thunderquakes. **Nolan Roth.**
41. Addressing Challenges of Accurately Measuring Earthquake Ground Motions Using Commercial Dark Fiber in an Urban Environment. **Jyoti Sharma.**
42. Innovative Applications of Distributed Acoustic Sensing in Railway Monitoring. **Lena Urmantseva.**
43. Student: Deep Learning Models Applied to Localization of Mexico City Microseismicity Recorded with DAS. **Kevin A. Vargas.**
44. Detecting Potential Sinkholes Using Distributed Acoustic Sensing Array. **Zhinong Wang.**
45. Student: Physics-Informed Deep Learning for Bridge Displacement Estimation Using DAS Data. **Yichen Zhong**.

Oral Presentation Abstracts

Presenting author is in bold.

Opening Session and Keynote Presentation

Oral Session • Monday 7 October • 06:00 PM Local

Illuminating a Decade of DAS and Beyond

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During the last decade (2014-2024), distributed acoustic sensing (DAS) has emerged from categorization as a niche technology, utilized primarily for vertical seismic profiling, to a broadly available seismological tool deployed at length scales from local to continental. This transformation has been enabled by improvements in interrogator technologies, creative optimization and exploitation of fiber optic cables in diverse environments, and, most recently, aggressive adoption of edge and cloud computational frameworks to manage the vast resulting datasets. In addition to these technological improvements, the DAS community has made a concerted effort to understand exactly which geophysical problems benefit from the high spatio-temporal resolution afforded by DAS acquisition and which parts of our seismic processing toolbox can be easily ported to this new data stream. In parallel, the growing availability of widely distributed DAS datasets has allowed researchers to uncover a surprising abundance of unexpected signals of scientific importance; examples include tidal and thermal signals of relevance to oceanography, both marine and terrestrial bioacoustic signatures, and in-situ indicators of ice sheet dynamics. Given these successes, related optical technologies are now being explored to expand photonic seismology beyond what DAS has traditionally provided, adding different physical measurands, detecting seismic events across even greater spatial domains, and further leveraging the next generation of telecommunication networks as a sensing fabric. In this presentation, I hope to provide a brief high-level overview of this decade of progress using examples taken from the many outstanding researchers pushing DAS forward in seismology and the geosciences more broadly. I will conclude with a summary of several technological frontiers that may (or may not!) allow for exciting advances in the decade to come.

Sensing Technologies and their Latest Developments

Oral Session • Tuesday 8 October • 08:30 AM Local

Phase Transmission Fiber-optic Sensing: Theory and Emerging Technologies

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As DAS matures into a standard ingredient of the seismological toolbox, other fiber-optic sensing technologies are emerging to fill remaining application niches. A particularly promising class of technologies, characterized by low cost and long reach, is based on measurements of deformation-induced phase changes of forward transmitted laser signals.

The first part of this presentation is focused on the relation between the deformation that we wish to infer and optical phase changes that we can measure. We demonstrate that measurement sensitivity is proportional to local fiber curvature. Strongly curved fiber segments make large contributions to the measurement, meaning that a cable layout that produces a sequence of high-curvature segments may effectively mimic a distributed seismometer array. Conversely, perfectly straight fiber segments make no contribution to the measurement. The application of adjoint techniques to simulated phase transmission data produces sensitivity kernels with respect to earthquake source parameters and Earth structure, thereby paving the way towards an incorporation of such data into seismic inverse problems.

The second part is concerned with the presentation of two technologies that operate on long telecommunication fibers and produce measurements of earthquake-induced deformation: [1] Microwave-frequency fiber interferometry (MFFI), employs microwave-modulated continuous laser signals in a closed-loop configuration. The system is portable and low-cost (<10 kUSD), thereby enabling the installation of multiple systems to improve coverage. In field tests performed in Athens (urban) and the Greek island of Cephalonia (submarine), the MFFI system has demonstrated its ability to detect local events with magnitudes around 0. [2] Active phase noise cancellation (PCN) in metrological frequency dissemination produces earthquake recordings as a by-product in the form of a correction anti-frequency. Using a 123 km fiber loop between Bern and Basel, we show that PCN cannot only detect regional earthquakes but also constrain their moment tensor.

Novel Types of Distributed Acoustic Sensing (DAS) Systems with Unconventional Performance

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Distributed Acoustic Sensing (DAS) systems have become a standard measurement tool in geophysics, with applications ranging from earthquake seismology to tsunami early warning. While most DAS users in this field are familiar with the basic principles and typical performance of commercially available interrogators, there is a general lack of understanding about the physical limitations of conventional DAS technology and how these affect measurement performance.

In this talk, we will explore the origins of these limitations. By understanding these constraints and ways to overcome them, we will introduce two innovative systems currently being developed in our lab that offer significantly different performance compared to conventional DAS. First, we will present a DAS system capable of achieving centimeter-scale gauge lengths over distances of approximately 1 km. Second, we will introduce a DAS system with standard performance (meter-scale resolutions over tens of kilometers) but with completely suppressed 1/f instrumental noise, making it suitable for long-term monitoring of processes with periods spanning days, weeks, or even months. We will also briefly discuss the potential applications of these novel DAS systems.

Harnessing Transatlantic Submarine Cables for Tidal and Strain Measurements

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Submarine sensing has been constrained by high costs and the harsh underwater environment, but advancements in fiber optic technology offer new possibilities. Fiber optic sensing via transatlantic seafloor cables presents a promising approach for submarine studies. For example, Marra et al. (2020) employed phase interferometry of transmitted waves reflected by a high-loss loop-back (HLLB) system for earthquake detection and localization. Similarly, Zhan et al. (2021) measured fiber deformation by monitoring the state of polarization. However, these methods either require expensive research-grade laser sources or suffer from high noise. Moreover, they have low sensitivity at sub-millihertz frequencies. Recently, Bogris et al. (2022) introduced the Microwave Frequency Fiber Interferometry (MFFI) technique which is cost-effective and stable over long distances.

Using a transatlantic cable from Lisbon, Portugal, to Fortaleza, Brazil, we demonstrate our equipment combining MFFI and HLLB can provide stable detection of signals down to microhertz frequencies. Our system successfully observed the propagation of semidiurnal ocean tides along the 6,000 km cable. The tidal signals align with barotropic pressure changes induced by tidal height variations. With its clear observation of long-period tidal signals and cheap, user-friendly setup, our method has the potential for widespread use, notably in enhancing rapid tsunami early warning systems.

Comprehensive Evaluation of DAS Performance: Instrument Response, Noise Floor, and Amplitude Saturation

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Distributed Acoustic Sensing (DAS) can convert optical fibers into dense arrays of strainmeters. Amplitudes in DAS recordings, particularly for pre-existing telecommunication cables with uncertain fiber-ground coupling, have not been fully quantified. By calibrating with co-located seismometers, we systematically assessed the performance of three DAS arrays in California and one DAS array at the South Pole. Our results indicate that the average DAS amplitude of earthquake signals aligns with seismometer data, showing fluctuations within an order of magnitude across channels and frequencies from 0.01 to 10 Hz. The noise floor of DAS, crucial for detecting weak signals, is comparable to strong-motion stations within this frequency range but exceeds broadband stations below 0.1 Hz. The saturation amplitude of DAS, essential for capturing strong signals, is adjustable by modifying pulse repetition rate and gauge length, although this adjustment comes with trade-offs regarding array length and data quality. Our comprehensive evaluation highlights the potential of using both DAS phase and amplitude data in seismic studies.

Rotation Sensing with Optic Technology

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Portable fibre-optic gyros (FOG) and ring lasers allow measuring rotational ground motions and have recently been the method of choice for first-generation broadband observations for seismology at observatories and in the field. FOGs and ring lasers have a unity transfer function, are insensitive to translations and – combined with broadband seismometers – allow the exploitation of the power of six-degree-of-freedom processing (6 DoF) methods, returning similar information like a seismic array but in a broader frequency band and with a single-point measurement. This includes phase separation, backazimuth and phase velocity estimation as well as tilt-correction. Recently, a permanent 6 DoF system has been installed at the Pinon Flat Observatory, California. We report on the observation of local seismicity and the detection limit of a commercial FOGs. Furthermore we present results on 6 DoF observations on volcanoes, the estimation of 1D velocity models based on 6 DoF noise observations, and applications in structural health monitoring. Finally, we discuss the current limits of portable rotation instrument, and the future potential of 6 DoF sensing when the sensitivity is improved.

Rayleigh Scattered Wave Analysis Techniques in Distributed Optical Fiber Sensing for Broadband Geophysical Observation in the Seafloor

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Observations in seismological and volcanological fields often require very broadband (1/years ~ 0.01Hz) spectrum and dynamic range (< nano strain ~ milli strain). Distributed Acoustic Sensing (DAS) has significantly high sensitivity and suitable for observing rapid phenomena, but causes phase tracking error in rapid and large change during earthquakes, limiting its ability in slow process observation.

TW-COTDR is a DOFS technology that analyses the same Rayleigh scattered wave as DAS, but analyzes Rayleigh Intensity Pattern (RIP) in optical frequency domain to measure fiber strain change between measurements by their frequency shift. We applied TW-COTDR with an instrument manufactured by Neubrex, Co. Ltd. (NBX-7031) and our off Muroto seafloor fiber optic cable which extends about 86 km offshore reaching to deep seafloor since April 2022. We scanned Rayleigh scatter wave over 30 GHz at 0.002 GHz interval in 20 minutes to obtain seafloor fiber strain data up to ~ 80 km offshore every 1 m interval. This observation provided valuable information regarding small seafloor temperature fluctuations occurring ~ 0.1 degree over day even in large seismic events.

TW-COTDR technology has a problem that field strain change during frequency scan would make it difficult to evaluate frequency shift between each scan. To deal with such strain change during frequency scan, we jointly developed with Neubrex a new instrument called Rayleigh Frequency Acoustic and Strain (RFAS) which uses chirped frequency optical laser pulse to evaluate RIP every 2 msec, where field strain change from microseisms would be negligible. We started long-term field test with the new RFAS instrument (NBX-7800) and the same off Muroto seafloor cable from March 23, 2024. In comparison with the DAS in the field test, the RFAS measured the strain every 1 m, which is much finer than 20~80 m in DAS. So, RFAS would be especially suitable for targets such as seafloor downhole measurement where greater spatial resolution is necessary.

Earthquake Characterization Using Fiber-optic Cables

Oral Session • Tuesday 8 October • 11:15 AM Local

South Island Seismology at the Speed of Light Experiment (SISSLE) — Characterizing the Alpine Fault at Haast (South Westland, New Zealand)

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We introduce initial results from a DAS array deployed in two phases for nearly 5 months between late-February and mid-May 2023 and again in October–November 2023 near Haast, New Zealand. The South Island Seismology at the Speed of Light Experiment (SISSLE) utilizes two lengths of telecommunication fiber: one running roughly parallel to the Alpine Fault (~18 km) and the Tasman Sea and the second that runs perpendicular to and crosses the Alpine Fault (~30 km). The Alpine Fault marks the boundary between the Australian and Pacific plates. Haast lies near a geometrically and paleoseismically distinctive segment boundary where large (~M8) earthquakes appear to preferentially nucleate and terminate on ~300-year timescales.

In addition to the DAS array, acquisition coincided with the ~450 km-long Southern Alps Long Skinny Array (SALSA) deployment of 45 seismometers installed ~10 km apart within ~3 km of the fault trace. We also deployed 27 nodal seismometers along the fiber cable within the geologically mapped fault zone to provide opportunities for interpreting DAS and conventional seismometer data.

Due to the high temporal (1 kHz) and spatial (4 m) resolution, data from this DAS experiment have demonstrated improvements in the detection of weak seismic sources, including low-magnitude earthquakes diagnostic of fault activity. Our analyses to date have focused on detection and characterization of local and regional seismicity using the DAS and co-located nodal data. Using manually-picked P and S arrivals, we have successfully located seismicity reported by GeoNet and magnitude 1–2 earthquakes detected using the nodal data. We observe consistent P and S waveform complexity on DAS channels within the mapped fault zone and are working to understand these in terms of either fault-zone trapped/guided waves or low-velocity structures associated with the fault. The dense spacing across the Alpine Fault allows for high-resolution imaging of the fault zone including the near-surface fault geometry and structure using correlation and waveform modelling techniques.

Advancing Earthquake Characterization with Telecom Fiber Networks

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The emerging distributed acoustic sensing (DAS) technology can convert a pre-existing telecommunication fiber cable of tens of kilometers in length into a dense seismic array of thousands of recording channels. Here, we present a workflow for leveraging DAS together with the conventional seismic network to analyze high-resolution earthquake source properties, including seismic phase picking, earthquake relocation, focal mechanism inversion, and high-resolution rupture imaging. We first introduce PhaseNet-DAS, a deep neural network model, for automated earthquake detection and seismic phase identification from DAS recordings. Following detection, our scalable cross-correlation framework, CCTorch, robustly measures differential phase travel-times and relative polarities between detected seismic events. Furthermore, we have devised a matrix-free adjoint solver that performs double-difference relocation using data from thousands of DAS channels. We have also developed a data-driven method for reliably inverting absolute first-motion polarities on DAS, which are critical for tightly constraining the nodal plane orientations and accurately inverting high-resolution focal mechanisms. We have successfully applied these methods to several DAS arrays in California. Finally, we present the DAS-based high-resolution back-projection rupture imaging using the Mw6 crustal earthquake that occurred in Antelope Valley, CA in 2021 as an example. These successful research progresses underscore the potential of DAS as a next-generation seismic monitoring tool that can significantly enhance and complement existing seismic networks. With the extensive existing and proposed network of onshore and offshore telecommunication fiber cables, DAS could provide critical datasets for systematically investigating detailed seismic source properties.

10-m-deep Earthquake Swarms (Mw -2) Near the Milun Fault in Hualien, Taiwan, Detected by the MiDAS Seismic Monitoring System

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After the 2018 M6.4 Hualien earthquake in Taiwan, the Milun fault Drilling and All-inclusive Sensing (MiDAS) project drilled two scientific boreholes on the hanging (Hole A) and foot walls (Hole B) of the Milun fault, which had 0.5-m co-seismic slip during the earthquake and caused serious damage in Hualien City. The project deployed a 7.5-km-long optical-fiber cable perpendicular to the Milun fault, passing through Hole A and B (from top to bottom) as well as the main fault zone on the surface. The downhole triaxial seismometer arrays were installed in the boreholes. Both distributed acoustic sensing (DAS) and traditional seismometer systems operate continuously in earthquake monitoring. In the present study, we manually detect earthquakes from the continuous seismic records in a period of 2023/3/16-5/31 (76 days) and identify two local seismic swarms occurring on 4/7 and 5/2. It is worth noting that the swarm on 5/2, including 75 events within 5 hours, has an extremely small ts-tp arrival time of ~0.15 s in the sensors in Hole B, suggesting that the events were very close to the borehole. Benefited from the combined seismic monitoring system of the DAS and downhole seismometers, we determine (i) the DAS node with the first arrival time of S wave in Hole B to estimate the event depth, as well as (ii) the P-wave polarization and amplitude in ground velocity from the downhole seismometers to obtain the horizontal location and magnitude. In the end, we recognize that these earthquakes occurred at the depths of ~10 m and at the locations ~50 m away from the Hole B wellhead with the magnitudes approximating to Mw -2. The ultra-shallow microearthquakes observed in the present study are perhaps a record value of natural earthquakes, which can further contribute to the seismological studies, such as, the earthquake initial-phase and finite-dimension issues, as well as temporal variation of physical parameters (e.g., rigidity and wave velocity) in the ultra-shallow structures.

Exploring Earthquake Source Characteristics Using Borehole Optical Fiber Arrays: Insights from the 2022 M6.8 Chihshang, Taiwan, Earthquake

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The application of distributed acoustic sensing (DAS) offers unique advantages for earthquake monitoring, providing spatially dense measurements with high-temporal resolution and broadband response. Since 2020, the Milun fault Drilling and All-inclusive Sensing (MiDAS) project has successfully drilled into a recent ruptured active fault on the northwestern edge of the Milun Terrace in Hualien, Taiwan. This project provides cross-fault zone seismic observations with optical-fiber sensing technology. In 2022, the MiDAS network recorded more than 10 seismic events with magnitude > 6 which occurred in eastern Taiwan. In this study, we aim to explore the potential of DAS data from the MiDAS project by investigating the source characteristics of the 2022 M6.8 Chihshang, Taiwan, earthquake. We apply a deconvolution method, considering a smaller events in 2022 Chihshang earthquake sequence as an empirical Green's function (EGF), to determine the relative source time function (RSTF) of the mainshock. The RSTF reveals gross temporal and spatial characteristics of faulting during the mainshock. The approximated source time function exhibits a notable high-frequency pattern, which differs from the results of surface seismic stations at MiDAS site and other stations in the national seismic network. We hypothesize that this high-frequency pattern may be attributed to ruptures on heterogenous fault. It might suggest that DAS could potentially capture small-scale rupture behaviors. Further investigation and analysis are needed to confirm our hypothesis and provide deeper insights into the seismic source characteristics.

Accurate Magnitude and Stress Drop Using the Spectral Ratios Method Applied to Distributed Acoustic Sensing

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The reliable estimation of earthquake magnitude and stress drop are key in seismology. The novel technology of distributed acoustic sensing (DAS) holds great promise for source parameter inversion owing to the measurements' high spatial density. In this study, I demonstrate the robustness of DAS for magnitude and stress drop estimation using the empirical Green's function deconvolution method. This method is applied to 9 co-located earthquakes recorded in Israel following the 2023 Turkey earthquakes. Spectral ratios were stacked along the fiber, and fitted with a relative Boatwright source spectral model. Excellent fits were obtained even for similar sized earthquakes. Stable seismic moments and stress drops were calculated assuming the moment of one earthquake is known. DAS derived estimates were found to be more stable and reliable than those obtained using a dense accelerometer network. The results demonstrate the great potential of DAS for source studies.

Real-Time Monitoring and Warning with Fiber Optic Seismology

Oral Session • Tuesday 8 October • 03:00 PM Local

Assessing Distributed Acoustic Sensing for Real-time Monitoring and Earthquake Early Warning (EEW) in the Southernmost Cascadia Subduction Zone

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The southernmost Cascadia subduction zone presents considerable earthquake hazard from interplate and intraplate faults and is the most active region within the ShakeAlert EEW System's reporting area. Both real-time performance assessments and offline simulations indicate that ShakeAlert

would benefit from low-latency offshore seismic data in this region. To build towards this possibility, the USGS, Cal Poly Humboldt University, Luna Inc., and Seismics Unusual have begun a long-term effort to collect DAS data in this region to evaluate data quality and analysis methods. As a result of the Middle-Mile initiative and other partnerships, Cal Poly Humboldt's campus is expected to be a regional hub for fiber optic cables in the coming years that cover the locked portion of the megathrust and dozens of active crustal faults. Since 2022, we have collected ~1.5 years of DAS data on a 15 km cable between Arcata and Eureka CA, including over 35 nearby earthquakes with magnitude estimates between 3.5 and 5.4, and over 400 earthquakes total. We are evaluating both real-time detection algorithms operating directly on the data acquisition system as well as algorithms for magnitude and location estimation. An automated detection algorithm running on the acquisition system detects M3 earthquakes by the time the P-wave has been recorded on about half the cable with a total latency of about 0.9 to 1.2 s between the first P-arrival on one end of the cable and the issuing of the detection. If the earthquake is within about 30 km from the cable, the detection is often issued before the first ShakeAlert message is published. By comparing with co-located nodal seismometer data, we have established the reliability of peak-strain measurements over four orders of magnitude. Magnitude estimates from peak-strain measurements and existing scaling relations are reliable once site effects are accounted for. We are investigating faster P-wave based magnitude estimates for warning applications, and future experiments will involve multiple cables and a variety of interrogators.

Low-cost DAS Arrays using Commercially Owned Fibers and Interrogators for Continuous Seismic Monitoring and Early-warning

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With the expansion of DAS technology for high-resolution infrastructure monitoring, many commercial companies own and operate DAS units to secure critical infrastructures. Such systems operate 24/7 for various purposes such as perimeter control, pipeline, gridline, railway and highway monitoring. By tapping into existing fibers and units, DAS data may be continuously extracted at the extremely low cost of installing a storage unit and processing computer (~10k$ per system). By forming such data sharing collaborations, infrastructure operators may benefit from seismological insights, while continuous data and complete DAS earthquake catalogs can promote scientific research. In Israel, we currently extract continuous DAS data from 2 fibers: a Febus Optics system monitoring a 15 km pipeline in a horizontal tunnel and a Prisma Photonics system monitoring a 66 km motorway segment, with additional systems planned for the near future. This data is used to study earthquakes and develop early warning capabilities. In this talk, I will detail data extraction procedures and show initial observations and results from these measurements, including the use of a meteor acoustic signal to validate the fibers' geometry, and earthquake location estimation via beamforming with real-time implications.

Toward Integration of DAS Arrays and Traditional Seismic Networks for Real-Time Earthquake Monitoring and Early Warning

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Real-time earthquake monitoring and early warning relies on dense seismic networks with coverage around faults zones. Distributed Acoustic Sensing (DAS), a technology that turns fiber-optic cables into seismic arrays, can complement traditional networks where they lack sufficient observations. For example, detecting offshore earthquakes in real-time is challenging for traditional land-based seismic networks due to insufficient station coverage. Application of DAS to submarine cables has the potential to extend the reach of seismic networks and thereby improve real-time earthquake monitoring and Earthquake Early Warning (EEW).

We present an integrated methodology that uses DAS data and traditional seismic stations for EEW. We use data from the SeaFOAM DAS deployment (52 km-long submarine cable) in Monterey Bay, CA and the surrounding Northern California Seismic System (BK+NC networks). The region is seismically active with the nearby San Andreas Fault system, and the offshore San Gregorio Fault zones which the cable crosses. The algorithms to analyze the DAS data include a machine learning-based phase picking model (PhaseNet-DAS), a grid-search location method and an empirical magnitude estimation equation. This approach to analyzing the DAS data is compatible with the EPIC point source EEW algorithm currently used by ShakeAlert. We are therefore able to combine detection results from the DAS array with outputs from EPIC using the onshore seismic network. The preliminary results show that the integrated algorithms can reduce the detection time for offshore events and potentially increase warning time. We plan to implement the algorithms in the real-time EEW system and evaluate the performance. The proposed workflow can also accommodate the future integration of additional DAS cables to improve monitoring of specific fault zones in California.

Seismic Event Monitoring with DAS in the Cloud

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The incredibly high spatial and temporal resolution of Distributed Acoustic Sensing (DAS) makes it an excellent technology to capture geophysical signals, and this has important implications for seismic monitoring efforts. DAS provides strain measurements at a spatial resolution of meters along cables that can be tens of kilometers in length at kilohertz sample rates, surpassing the resolution provided by setups of traditional seismic instrumentation. The sensitivity of DAS in the 10^{-1} to 100 Hz bandwidth combined with its operational capability on land and on the seafloor means that it not only provides a mechanism to track the change in frequency and amplitude of seismic signals over distance, but it can supplement recordings from conventional observatory-quality sensors in regions such as the ocean floor where station density is extremely sparse. However, two issues impede the systematic study of DAS to quantify its benefit: (1) the vast volumes of data generated by the system makes it difficult to telemeter and, once at a datacenter, analyze efficiently and (2) the lack of consistently compiled metadata inhibits the comparison of correlated signals across geographically separated fibers. Both issues need to be addressed to provide calibrated and quality-controlled DAS data sets suitable for downstream ingestion into signal detection, association and characterization algorithms. We standardize the metadata across the 32 data sets collected for the 2023 Global DAS project and show how this enables comparison of DAS data across networks. We also showcase how seismic event monitoring data analysis software may be containerized and leveraged on cloud compute architecture. Our workflow is useful to seismic monitoring agencies because it establishes a DAS data processing paradigm that efficiently manages the metadata in an open-software environment.

Distributed Acoustic Sensing of Fiber Networks for Earthquake Monitoring and Early Warning Operations

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Distributed Acoustic Sensing (DAS) instrumentation deployed on existing telecommunications fiber cables has emerged as a highly effective tool for seismological applications. Its unique capability to convert extensive lengths of fibers into dense seismic arrays offers unparalleled observational advantages compared to conventional seismic stations. Despite the significant advancements in using DAS data for earthquake research, non-negligible challenges still need to be solved to achieve continuous earthquake monitoring and develop reliable real-time data processing methods.

The ever-expanding fiber network onshore and offshore could serve as a platform for the next generation of seismic network operations, especially if widespread usage of DAS is adopted for earthquake detection and early warning systems. We outline how we are taking the first steps toward integrating DAS data within seismic network operations, from providing additional constraints to earthquake detection and localization to improving early warning performance. We explore how innovative machine-learning methods, combined with efficient processing techniques, have the potential to shape the future of monitoring and early warning systems. Specifically, we employ PhaseNet-DAS to fully leverage the high spatial density provided by DAS for accurately determining earthquake arrival times, which are then streamed within an Earthworm pick-ring server. We then describe how ground-acceleration-calibrated DAS channels can be introduced to the existing early warning algorithms. Current earthquake early warning (EEW) approaches employ ground motions to perform real-time magnitude and shaking-intensity estimation. However, assessing the benefits and challenges of DAS for EEW can lead to a new effort to develop dedicated strain-based methods. We finally demonstrate how high-performance computing processing, picking, and localization tools are opening new opportunities for real-time earthquake detection and early warning.

Exploring the Frontier of Environmental Processes using Fiber-optic Sensing

Oral Session • Wednesday 9 October • 08:30 AM Local

Fluvial Monitoring with Distributed Acoustic Sensing

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Fluvially generated seismo-acoustic waves provide a novel means of investigating otherwise hidden river processes. However, signals from individual seismometers or hydrophones are challenging to interpret due to environmental heterogeneity and the superposition of multiple signal sources. Fiber-optic distributed acoustic sensing (DAS) arrays combine the advantages of high frequency in-stream hydrophone monitoring with the broad spatial extent and array methods of seismic and geophone deployments, providing unprecedented opportunities to interrogate river signals at high spatiotemporal resolution. We present data from two deployments with meter-scale along-stream spatial resolution and 10 kHz sampling to highlight new opportunities and challenges posed by DAS as a tool for fluvial monitoring. First, hydroacoustic strain-rate spectra along ~160 m of cable submerged in Clear Creek, Colorado, USA, highlight fine-scale spatial variation in flow hydraulics and complex interactions between the free-floating cable, flow, and bed. These observations demonstrated the capacity for array methods to identify and locate distinct signal sources in DAS data as well as the need for additional work to improve deployment techniques and address cable coupling in dynamic fluvial environments. We explore these ideas further in a second deployment in a ~39 m long, 1.5 m wide cement-bedded outdoor flume at the University of Texas, Austin, where we examine different cable coupling scenarios and a range of water turbulence and sediment transport phenomena under closely controlled and monitored experimental conditions.

Fiber Optic for Environment Sensing (FORESEEx): Examples from Urban and Arctic Arrays

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Fiber-optic sensing is increasingly utilized for subsurface resource exploration, near-surface geology characterization, and earthquake monitoring. Fiber-optic sensing offers three key advantages: dense sensors, centralized power system, and integration with existing telecom infrastructure, making it particularly beneficial for urban and remote areas. In this talk, I will introduce the Fiber-Optic Sensing for Environment Dynamics (FORESEEx) project, showcasing two Distributed Acoustic Sensing (DAS) experiments conducted in urban and Arctic environments. The urban study uncovers unique rain storm-induced signals, enhancing our understanding of rainstorm processes and rain water-groundwater interactions. Additionally, in the second experiment conducted in Alaska, I will discuss newly discovered signals associated with glacial ice movement and ice-wedge cracking, offering valuable insights into their physical mechanisms.

Enhancing Hydrological Monitoring with Fiber-Optic Sensing

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Hydrological monitoring is essential for managing water resources, especially in the context of climate variability. Recent advancements in ambient seismic noise interferometry offer a cost-effective method to monitor subsurface hydrological processes by using seismic velocity changes (dv/v) as indicators of water saturation levels. Distributed Acoustic Sensing (DAS) has emerged as a transformative technology that repurposes existing fiber-optic cables into dense arrays of seismic sensors. Offering dense spatial sampling and continuous long-term recordings, DAS facilitates the monitoring of aquifer dynamics at unprecedented spatiotemporal resolutions.

While groundwater aquifers receive consistent attention, the intermediate-depth vadose zone—the unsaturated layer between the surface and groundwater table—has been less thoroughly monitored. In this work, we focus on monitoring the vadose zone and validating our results with hydrological methods. We converted a telecommunication fiber-optic cable in Indian Wells Valley, California, into a dense seismic array to measure temporal variations of seismic velocity. With in-situ soil moisture sensors co-located with the DAS array and hydrological modeling to benchmark our seismic observations, we demonstrate that DAS effectively captures the dynamics of the vadose zone. This research highlights the potential of DAS to significantly enhance hydrological monitoring and contribute to more resilient environmental and agricultural management strategies.

Evaluating Strain and Temperature Variations with Low Frequency Distributed Acoustic Sensing

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Geohazards are expected to increase in frequency over the coming decades considering the effects of climate change. Robust monitoring systems are needed to support risk mitigation efforts where geohazards impact nearby communities and infrastructure. Distributed acoustic sensing (DAS) is a fiber optic sensing technology sensitive to changes in strain and temperature over a broad range of frequencies. Furthermore, DAS offers capabilities of monitoring over broad spatial extents, with current DAS systems capable of monitoring up to ~100 km of optical fiber. Earlier work demonstrated how low frequency (< 1 Hz) DAS can be used to track the evolution of a slow-moving landslide. Here, we advance our analysis at the Hollin Hill Landslide Observatory to evaluate the effects of cable type on the sensitivity of DAS to strain and temperature changes. Our work demonstrates that selection of the appropriate cable can yield enhanced strain measurements to support monitoring of ground deformations.

Exploiting DAS Records Directly for Source and Structural Properties – Examples from the Greenland Ice Sheet

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Many applications of DAS employ transformations of strain-rate records into ground velocity so that familiar tools can be applied. Nevertheless, only modest modifications need to be made to computational methods to provide a direct representation of DAS records including the influence of cable orienta-

tion and gauge-length effects. With such aids it is possible to fully exploit the wealth of information on the seismic wavefield contained in the DAS records.

We illustrate this approach with DAS records from 3 km cables at the EastGRIP ice core drilling site on the Northeast Greenland Ice Stream (NEGIS) collected in summer 2022. From both a landing aircraft and small shots nearly in line with the cables it is possible to extract from the DAS records a broad spectrum of Rayleigh surface wave modes as well as pseudo-acoustic modes dominated by P waves. Fitting the dispersion of these various modes allows a structural model to be constructed for the near surface that can then be used for source studies.

For near sources offset from the cable the pattern of arrivals associated with the orientation effects on the cable provide a convenient means of assessing both the character of the source and its distance from the cable. Both aspects are very helpful in untangling a complex pattern of seismic signals associated with an advancing front of snow collapse in the top few centimeters.

Monitoring Groundwater Dynamics in the Lyon Water Catchment using DAS combined with Ambient Noise Interferometry

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Ambient noise interferometry (ANI) applied to Distributed Acoustic Sensing (DAS) arrays is an emerging method for subsurface investigations, particularly for imaging and monitoring hydrologic processes. In this study, we analyze ambient seismic noise acquired on a spiral DAS array to track velocity variations caused by groundwater level changes in an alluvial aquifer.

We tested our methodology to the Crépieux-Charmy water catchment, a strategic site for water supply to the city of Lyon, France, located in the Rhône alluvial aquifer. This site supplies 94% of the city's drinking water and uses a Managed Aquifer Recharge (MAR) system, which allows controlled recharge of the aquifer through infiltration basins. The filling of the basins creates a localized hydraulic dome that plays two major roles: recharging the aquifer and preventing pollution risks coming upstream. Our objective was to characterize the dynamics of this hydraulic dome.

We analyzed four weeks of DAS ambient noise data recorded on a 3 km spiral DAS array surrounding an infiltration basin. During this period, a controlled water infiltration experiment was conducted by the site operators. We used traffic noise in the 2-5 Hz frequency band and performed DAS-based time-lapse surface wave tomography of velocity variations in the area. We were then able to map velocity variations in the vadose zone. Comparison of point-scale piezometer measurements and adjacent cells in the velocity variation maps shows good agreement between the two observables. These velocity variations are directly related to the water table variations and to residual water saturation changes within the unsaturated zone.

This pilot application demonstrates the potential of DAS combined with ANI to track aquifer dynamics at high spatial and temporal resolutions.

Multiplexed Distributed Acoustic Sensing at the Ocean Observatory Initiative Regional Cabled Array

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Distributed acoustic sensing (DAS), a technology that converts ordinary telecommunication optical fibers into dense arrays of strain sensors, conventionally requires unused or "dark" fibers. This poses a significant practical limitation because the vast majority of fibers in existing submarine cables are "lit," not dark. We proposed to solve this problem through optical multiplexing—splitting the optical traffic in the fiber between two frequency bands, C-band (communications) and L-band (DAS), so that both systems independently operate simultaneously in the same optical fiber without conflict. Here, we report a successful multiplexed DAS deployment at the Ocean Observatory Initiative (OOI) Regional Cabled Array (RCA) shore station in Pacific City, Oregon. The primary goals of the proposed 2024 Lit DAS experiment were to demonstrate that: (1) multiplexed DAS will work on the particular configuration of the OOI RCA; (2) the communications of the OOI RCA are not impacted by multiplexed DAS; and (3) multiplexed DAS on the OOI RCA is of high quality (i.e., as good as that collected by the same system on a dark fiber). Although we have additional data analysis tasks ahead to fully address the third goal, we can conclude that we have met the first two goals and that there is no obvious change in data quality between acquisition on dark and lit fibers.

Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables

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Science with Transoceanic Seafloor Cables

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The 1.5 million km-long network of seafloor telecommunication cables is one of the largest infrastructures ever built by humans. After enabling the digital revolution of the last 30 years, it could now play a key role in expanding Earth monitoring capabilities from land to the ocean. Indeed, although 70% of the Earth's surface is covered by water, only a very small number of permanent real-time sensors exist on the seafloor. Recent research from several groups has shown the wide range of new possibilities that Distributed Acoustic Sensing (DAS) techniques offer for Earth sciences. When applied to seafloor cables, DAS enables high spatial resolution monitoring of coastal areas. Other techniques, such as optical interferometry and State of Polarization (SOP), have demonstrated the ability to extend the monitoring capabilities beyond coastal areas, at the expense of a lower spatial resolution. Here we show how ultra-stable interferometric techniques enable existing cables to be used as arrays of environmental sensors across thousands of kilometres on the seafloor, with results from tests on an intercontinental cable between the UK and Canada. We will discuss the possibilities opened by these techniques, with applications ranging from seismology and oceanography [1], and outlook for expansion of these techniques to a global scale.

[1] Marra G at al., Science, 376 (2022).

Spatio-temporal Observations of Nonlinear Wave-wave and Wave-current Interaction with DAS

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Nonlinear interactions of ocean surface gravity waves are the dominant source of ambient seismic noise globally, yet this process has been only rarely observed in-situ. From a year of data acquired in Lower Cook Inlet offshore Homer, AK, we will first compare DAS observations to a nearby wave buoy, showing how standard sea surface statistics (significant wave height and wave period) can be estimated from DAS and how these quantities are modified by wave interaction with strong (>1 m/s) tidal currents. Then, we will apply array analysis to show how up to six overtones of the wind wave spectrum observed with DAS are composed of bound (evanescent) acoustic-gravity modes through wave-wave interaction. Under particular conditions, some of this energy couples into local, high-frequency Scholte-wave microseism.

DAS Observation for High-frequency Tsunamis Excited Near Torishima Island, Japan

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Various types of wavefield have been captured by submarine fiber optic cables, including earthquake and ocean waves. However, tsunami signals have been less captured because whether their observations depend on experimental periods and locations for distributed acoustic sensing (DAS). In southern Japan on October 8, 2023 (UT), sea level changes due to tsunamis were observed by tide gauges, and the tsunami generation is likely to be related to activities of submarine volcanoes. We observed the tsunami signals in the continuous records of DAS off Muroto in southern Japan. In this study, to investigate the characteristics of the tsunami signals, we calculate the frequency-dependent phase velocities, and compare the waveforms with those observed at nearby absolute pressure gauges (APGs).

In the DAS records, coherent signals propagating landwards are observed in the northern part of the submarine cable. The dominant frequency is 6–30 mHz. The frequency-dependent propagation velocities of the observed signals correspond to those of infragravity waves (i.e., deep water waves, ocean surface gravity waves), and the infragravity waves are categorized into high-frequency tsunamis.

We also estimated time-series of the tsunami generation at the source location. Relatively high frequency components within high-frequency tsunamis are excited in early stage of the volcanic activities, and their frequency components are shifted to middle and low ones in later stages. This indicates that the volcanic activities tend to be large at the later stage. The obtained features of the time-series were consistent with those using records of the APGs. Our results indicate that DAS records are useful for detecting tsunami propagations and also elucidating excitation mechanisms of tsunamis.

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Imaging the Near-surface Structure and Monitoring the Microseismicity Around the Changdao Earthquake Swarm Area with Distributed Acoustic Sensing

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From February 14 to May 31, 2017, an earthquake swarm occurred near Changdao Island East China. Located in the Bohai Sea the swarm was poorly covered by the seismic network which hinders the further understanding of the tectonic background and mechanism of the swarm. To better illuminate the local structure and monitor the earthquakes, we recast a 20-km long dark subsea optic fiber as 2500 DAS nodes with a channel spacing and gauge length of 8 m using a self-developed interrogator (ZD-DAS). Local, regional, and teleseismic earthquakes as well as local traffic are clearly recorded. The low frequency (<0.05 Hz) signal from the M7.4 Hualien earthquake correlates well with records from the co-located broadband seismometer, which indicates an excellent low-frequency response of the DAS system. The recording sections from earthquakes suggest complex fault and geological structures in the study area. The seabed S-wave velocity structure is imaged with ambient noise tomography using a frequency-Hankel transform. The S-wave velocity increases from ~ 200 m/s at the seabed to ~1400 m/s at the depth of 400 m. Our results further verify the feasibility of earthquake monitoring and subsurface imaging with subsea dark optic fibers.

Exploring the Potential of Distributed Acoustic Sensing in Ocean Acoustics

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Distributed Acoustic Sensing (DAS) revolutionizes fiber optic cables into extensive sensor arrays, capable of converting environmental vibrations into detectable signals. By analyzing the phase shift of backscattered light caused by varying strain from an acoustic field, DAS effectively converts fiber-optic cables into sensitive acoustic arrays. This technology can measure signals to distances of up to approximately 100 kilometers and has a spatial resolution as low as a few meters. While DAS has found successful application in seismic monitoring within the scientific community, its potential for monitoring higher frequency hydro-acoustic signals remains under-explored. In this presentation, we explore the prospects of DAS in the realm of ocean acoustics. Focusing on experimental observations of signals <1 kHz, we demonstrate its utility for capturing hydro-acoustic signals emanating from sources such as vessels, marine mammals, and broadband impulse sources close to the sea surface. Furthermore, we explain the DAS array response and its sensitivity to paths arriving parallel or perpendicular to the cable. We also discuss the challenges of evaluating the effectiveness of DAS for observing hydro-acoustic signals, particularly marine mammals, at frequencies > 1 kHz.

Results from an Optical Fiber Seafloor Strainmeter

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Widespread deployments of GPS sensors in the past decade have helped identify Slow Slip Events (SSEs), especially near subduction zone faults in Cascadia, Costa Rica, Japan, and New Zealand. Understanding SSEs presents an opportunity to gain new insights into the mechanisms governing locking and unlocking of subduction zone faults. While GPS networks have sufficient sensitivity to detect onshore SSEs, they do not cover that portion of the crust under the oceans.

To address this gap, we deployed two 250-m long optical fiber strainmeters at 770 m depth off the coast of Oregon. The two strainmeters, deployed with a Remotely Operated Vehicle (ROV) in July of 2022, are oriented approximately north-south and east-west. Strain is continuously recorded by forming Michelson interferometers along the lengths of the stretched sensing cables, which are buried 25 cm beneath the seafloor sediment. Temperature is inferred from the difference between two fibers in each of the sensing cables having contrasting thermal responses.

Data from the first year were recovered from the battery-powered system in July of 2023 and new batteries were installed on the east-west sensor. The raw records show signals at the microstrain level correlated with seawater temperature, seawater pressure, and fiber temperature (experienced both by the sensing cable fibers and reference fibers of equal length wrapped on a quartz mandrel). After removal of these signals using auxiliary data and downsampling to a 3 second sampling interval, residuals of RMS amplitude 13 nanostrain remain. A 2-day running median filter captures tectonic signals well and reduces the noise amplitude to 6 nanostrain. A suspected SSE is apparent in both sensors in October 2022, at the same time as a large onshore episodic tremor and slip event at the location along strike. The observed strains are significantly larger than expected from the onshore slow slip alone and imply the existence of a second shallower slow slip zone.

Distributed Optical Fiber Sensing over Multi-Span Subsea Telecom Cables with Active Amplification

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We present a fiber sensing system capable of performing distributed sensing over live submarine telecommunication cables. The system was demonstrated over a ~2000km long subsea cable with ~25 repeaters. In contrast to traditional distributed acoustic sensing (DAS) systems, which are limited to the first span (~50-100km offshore), our prototype is capable of performing distributed measurements over the entire cable length. We achieve a spatial resolution of ~200m for a measurement frequency of about 500Hz.

The system, based on optical frequency domain reflectometry, is inherently compatible with live telecom traffic. We demonstrate this by measuring the performance of multiple telecom transceivers while performing sensing, showing zero outages or performance degradation. The system consists of a photonic integrated circuit (PIC), laser source and an FPGA for signal generation and detection. The receiver-side processing is implemented in real-time using custom FPGA+GPU design. All components used are manufactured in volume and present in state-of-the-art optical and wireless communication systems. This ensures that the system can be scaled and easily manufactured in volume. The powerful combination of FPGA+GPU also enables flexibility and the system can easily be customizable to tackle unique challenges in fiber sensing. The system supports multi-channel operation and advanced customizable real-time post processing enabling applications such as real-time cross-correlation between multiple measured cables and ML-based event characterization.

Finally, we discuss system trade-offs and how they can be addressed to realize "DAS"-like measurements over multi-span live subsea cables. Our goal is to provide an overview of the work and engage with the meeting attendees to jointly understand how to tailor system performance to maximize its ability to enhance sensor coverage in the sparsely monitored deep ocean. Applications for this include seismic monitoring/detection, tsunami warning, climate change research and more.

Observing Seafloor Processes by Distributed Fiber Optic Sensing Using an Academic Cable Offshore Catania Sicily (Italy) and a Commercial Telecom Network in the Guadeloupe Archipelago (Lesser Antilles)

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We report on BOTDR (Brillouin Optical Time Domain Reflectometry) time series spanning up to 3.5 years on academic and commercial fiber-optic cables. Offshore Catania a 6-km-long dedicated fiber-optic cable (connected to a 29-km-long electro-optical cable), recorded natural and man-made strain signals of 40 - 250 microstrain at the seafloor (in 1800 - 2000 m water depths). The strongest natural signal (40 microstrain elongation) developed from 19 - 21 Nov. 2020, probably due to sea-bottom currents. The 6-km long FOCUS cable includes a redundant, triple-loop, consisting of 1 loose and 2 tight optical fibers. The tightly bound fibers typically record a strain signal twice as high as the loose fibers (40 vs 20 microstrain for the natural signal). Weight bag drops created man-made signals along four 120-m-long segments, with amplitudes of 80 - 250 microstrain (in the tight fibers), which gradually decay in the following months / years.

In June 2022, we began long-term monitoring of a network of unrepeated submarine telecom cables that link the islands of the Guadeloupe archipelago. We repeated measurements of the same fiber segments (30 - 70 km length), in Dec. 2022, June 2023, Nov/ Dec. 2023, and May 2024. We confirm that using the BOTDR technique, we detect shifts in the Brillouin frequency (2 - 5 MHz), which could represent substantial strain signals (40 - 100 microstrain in amplitude). These positive (elongation) or negative (shortening) signals typically occur in areas of steep seafloor slopes (e.g. the shelf break) or in submarine valleys/canyons and suggest that stretching and shortening of the cable (~1 cm over a few hundred meters) is occurring, most likely due to sea-bottom currents. We also observe a significant shift of 1.5 MHz over the shallow shelf (20 - 300 m depth) south of Grande Terre Guadeloupe (near Saint François) over 2 years, which represents a temperature increase of 1.5°C from June 2022 to June 2024. These preliminary results are encouraging and imply that standard telecom cables can be used for environmental monitoring of the oceans.

An Innovative Photonic Vision of Volcanoes and Geothermal Systems

Oral Session • Thursday 10 October • 08:30 AM Local

Fibre Optic Sensing for Innovative Imaging and Monitoring of Geothermal and Volcanic Systems

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Fiber optic sensing has gained popularity in the Geosciences community in recent years due to the ability of fiber optic cables to sense environmental physical quantities such as temperature, dynamic strain, rotation, and chemical composition with high accuracy and sensitivity over a broad frequency range, and with dense spatial and temporal resolution. This presentation will provide an overview of fiber optic sensing methodologies and their applications for understanding structure and processes within geothermal and volcanic systems.

The physical principles underlying fiber optic sensing have been known for several decades. These principles relate to various processes involving electromagnetic interactions of light emitted by a laser within glass. The intrinsic physical properties of the glass within the optical fiber, when properly designed and interrogated with an appropriate light source, allow us to access these environmental parameters. However, it is only recently that instruments have been developed that can efficiently measure these parameters, either at a single point or densely in a distributed way for geothermal and volcanological applications. Rotational sensors allow us to measure the rotational components of the seismic wave field, which have been discarded in the past. Distributed fiber optic sensing provides access to quasi-continuous measurements along km-long fibers with a high spatial resolution (meter) and sampling rate (kHz).

I will show examples of studies on volcanoes both on land and in submarine environments and geothermal systems in different geodynamic contexts. These examples demonstrate that data from these innovative optical strainmeters, rotational sensors, distributed fiber optic strain and/or temperature sensors can reveal unknown structural features and processes in geothermal and volcanic systems. Finally, fiber optic sensing methods need to be implemented as additional tools for improved volcano monitoring and for volcanic crisis management and for more effective resource management of geothermal systems.

A New Imaging Standard for Volcanic Systems Through Fiber Sensing and Novel Processing Algorithms

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Seismic tomography, a concept with nearly five decades of history, has significantly advanced our understanding of subsurface structures. In particular, high-quality tomographic imaging can provide valuable insights into the dynamics of volcanic systems. Recent advances in processing algorithms and computational architectures have enabled a new rise in the applications of tomographic approaches to magmatic systems. Furthermore, the advent of fiber sensing technologies for seismological applications has opened new avenues for exploring volcanic systems at a resolution unattainable by conventional station networks. The high spatial sampling and ease of deploying distributed acoustic sensing (DAS) instruments on telecommunication cables make DAS a powerful tool for characterizing subsurface structures of volcanoes at unprecedented scales and resolutions compared to dedicated nodal deployments.

In this presentation, I showcase successful examples of traveltime tomographic applications to volcanic systems, where DAS data are inverted using novel physics-based and machine-learning processing algorithms. The extensive range of modern DAS instruments enables the creation of high-resolution images of structures in the upper crust, offering a new outlook on volcanic science. We conclude by describing how future applications could leverage the full bandwidth DAS recordings inverted using full-waveform methodologies in which primaries and secondary waves contribute to setting a new standard for tomographic imaging.

Fibre-Optic Seismology on Remote, Subglacial, Submarine and Actively-Erupting Volcanoes

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We present highlights of Distributed Acoustic Sensing (DAS) experiments in different volcanic settings. The experiments show several ways in which DAS can contribute to volcano monitoring, and which challenges need to be overcome before DAS can become standard practice as a volcano monitoring tool.

Mount Meager is a volcano in Canada with a high geothermal potential and it is prone to severe landslides. We deployed a 3 km long fibre-optic cable along a ridge, and partly trenched it into the glacier. We record previously unknown high-frequency events that we analyse with beamforming, and low-frequency tremor that may be related to the geothermal activity.

We deployed a 12 km long fibre on Grímsvötn, which is covered by the Vatnajökull ice cap. We discover high levels of previously undetected microseismicity using an image processing algorithm and locate events with local magnitudes as low as -3 using the Hamiltonian Monte Carlo algorithm. These events are used to set up a full-waveform source inversion workflow, with the option to expand to a full-waveform tomography.

We interrogated a 45 km long dark fibre that extends from the island of Santorini, Greece, Northwards, past the submarine volcano Kolumbo. We detect more events than the local network, and we show the challenges of a cable geometry that is not ideal. We analyse the limitations of the cable layout to locate events for observed and synthetic data, with both homogeneous models and full-waveform modelling in a complex environment.

We monitored the seismic unrest at Svartsengi, Iceland, between November 2023 and April 2024 with an 8 km dark fibre near the eruption site. We set up live data streaming and analysis to aid the monitoring by the Icelandic Met Office. We use the detected events to set up a time-dependent non-linear tomography of the intrusion.

This research shows the potential of DAS to detect events with a lower detection threshold, locate events depending on its cable geometry, characterise events and model the subsurface using a full-waveform framework that takes the complex environment into account.

Imaging Magma Flow Migration Through a Dike Using Low-frequency DAS Measurements

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Tracking the magma flowing pathways is critical to understanding the magmatic evolution, forecasting eruptions, and assessing volcanic hazards. In this study, we demonstrate the use of a telecommunication fiber cable as a dense array of strain meters to image the magma migration kinematics within a dike through low-frequency distributed acoustic sensing (LFDAS) recordings. On 10 November 2023, a 15-km-long dike formed below the Sundhnúkur crater row, crossing the town of Grindavík in the Reykjanes Peninsula of Iceland. Eleven days later, we deployed a DAS interrogator in the Peninsula, converting a 100-km-long telecommunication fiber cable crossing Grindavík into a dense array with 10,000 strain sensors. Since then, six intrusive events have occurred, four of which resulted in fissure eruptions. Clear LFDAS signals emerged tens of minutes to several hours before eruptions, showing consistent spatial strain response throughout these intrusive events. To image the dike opening evolution, we developed a joint finite-fault inversion using both LFDAS strain and GPS displacement. Our results show an ascending intrusion propagating to the surface, coinciding with surface lava fissures during eruptions. For the non-eruptive intrusion, our imaging reveals an intrusion trapped at depth. Our findings highlight the feasibility of using DAS as a dense array of strain meters to provide high-resolution, nearly real-time imaging of subsurface deformations, particularly in active volcanic regions.

Using Low-frequency DAS Signals for Early Warning During the Sundhnúksgígur, Iceland, Eruptions in 2024

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The Reykjanes peninsula, Iceland, has been experiencing unrest since 2019. Since Nov 2023 the activity has been focused along the fissure swarm of Sundhnúksgígur, with 6 major intrusive events of which 2 were eruptive. The events have caused heavy deformation within the town of Grindavík. The town is now mostly unoccupied, but with industrial activity. The eruptive fissure is about 2 km away from the Svartsengi geothermal power plant and the Blue Lagoon spa, a major tourist attraction, both currently open for activity. Evacuations, based on increased seismicity at the center of the activity, together with pressure signals on a borehole sensor within the geothermal field, have been issued as little as 30 minutes before the eruption. However, the pre-eruptive seismicity has been diminishing with each event, making alerts increasingly more difficult.

In late November 2023, a DAS interrogator was deployed in the peninsula, converting a 100-km-long telecommunication fiber cable crossing Grindavík into a dense array with 10,000 strain-rate sensors. Clear low-frequency signals are visible on the fiber more than 30 minutes before each eruption. We developed a warning system using the amplitude of low-frequency strain rate (LFDAS) on a quiet part of the cable near the center of the eruptive fissure. In hind-casting mode, the system would have issued a warning for the 6 large events, with no warnings associated with non-intrusive events, when data gaps are excluded. The alert has been running at the Icelandic Meteorological Office (IMO) since April 28th. Since then, two episodes of non-eruptive activity have been observed. The small amplitude of strain rate observed on the fiber, together with small pressure changes on the borehole pressure sensor, have caused the IMO to refrain from issuing a warning, demonstrating the immediate utility of the LFDAS observations.

In this presentation, we give an update on the results from the LFDAS monitoring of the ongoing Sundhnúksgígur sequence.

Seismic Velocity Changes Associated with the 2023-2024 Eruption Sequence on the Reykjanes Peninsula

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The intrusion of magma in a volcanic system often induces strain in the surrounding region, resulting in the opening and closure of microcracks in the vicinity of the intrusion. This change in the crack distribution can affect regional seismic velocities. In late November 2023, we deployed a fiber-optic seismic interrogator to convert a 100-km fiber-optic cable along the coast of Iceland's Reykjanes peninsula into a dense seismic array, which has run continuously to present. By measuring surface wave moveout with ambient noise cross-correlation, we observe significant changes in the phase velocity following eruptions in the peninsula's 2023-2024 sequence that are likely associated with magmatic intrusions into the eruption-feeding dike. As this signal exists across a wide frequency band, we may further invert for changes in the S wave velocity structure (dVs/Vs) at varying depths. The dVs/Vs signal allows us to infer volumetric strain change in the vicinity of the fiber, providing constraints on the extent of the dike laterally and with depth. As our array passes into the town of Grindavík, our result may help to characterize the structure of the dike beneath the town, a valuable result for hazard preparedness.

Urban Seismology

Oral Session • Thursday 10 October • 11:00 AM Local

Large-scale Monitoring of Urban Environments by Fiber-optic Seismology: Lessons from Eight Years of the Stanford DAS Project

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The capability of turning fiber-optic cables into seismic sensors has the potential of providing datasets that "illuminate" Earth processes in a way that would be impossible with data recorded by conventional seismic sensors. Fiber-optic seismology enabled by Distributed Acoustic Sensing (DAS) technology can produce continuous and densely sampled data recorded from difficult-to-access locations at an affordable cost. I will discuss the opportunities for leveraging ubiquitous telecommunication fiber cables with distributed acoustic sensing (DAS) to make cities more sustainable and resilient to climate change. We can use "dark fibers" in urban environments to monitor both human activities above the surface (e.g., vehicular traffic, urban noise) as well as possibly hazardous natural phenomena occurring in the subsurface (e.g., earthquakes, water intrusion, landslides). DAS data from dark fibers also enables cost-effective monitoring of the structural health of urban infrastructure such as bridges and tunnels. I will focus on the application of DAS recording of surface waves generated by vehicles transiting on urban roads to continuously monitor the subsurface under cities for possible hazards such as water intrusion and faults. I will also discuss how we can develop machine-learning methodologies to detect and analyze local seismicity from the massive amount of data generated by DAS systems.

Optimizing DAS Ambient Seismic Noise Interferometry Workflows for Efficient, High-resolution Investigation of the Urban Subsurface

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Local and regional characterization and monitoring of the urban subsurface is critical for safe energy production and storage and to assess geohazard risk. The application of interferometric analysis to human-generated ambient seismic noise recorded on unused telecommunication fiber-optic cables (dark fiber) using Distributed Acoustic Sensing (DAS) is becoming an attractive tool for high-resolution subsurface imaging and monitoring in urban areas. Still, this approach remains vastly underutilized due to the challenge of efficiently extracting coherent seismic energy from large-volume urban DAS data, characterized by complicated signal patterns resulting from the complex urban seismic noise field, unconventional array geometries and non-uniform cable coupling.

Here, we present an enhanced ambient noise interferometry workflow that identifies and optimizes coherent surface waves in complex DAS urban seismic noise data. We apply our workflow to 15 days of continuous DAS ambient noise recorded on an 11 km-long dark fiber in Berlin, Germany. Processing is applied to overlapping 1 km-long array segments to obtain a pseudo-2D shear-wave velocity model of the upper few 100 m of the subsurface. Following cross-correlation, a categorization scheme achieved through unsupervised clustering is applied to the resulting virtual shot-gathers (VSGs). This process is crucial for efficiently excluding transient and localized noise sources and retaining high-quality VSGs, which are subsequently stacked. A coherence-based enhancement approach designed for wavefield data recorded with large-N arrays is applied to the stack, further optimizing coherent surface wave content. Dispersion analysis of the enhanced stacks and subsequent 1D surface wave inversion yield 1D velocity models with reduced uncertainties and increased depth of investigation. Ultimately, this enhanced approach provides an efficient tool for improved, high-resolution imaging of the urban subsurface at the local to regional scale.

Building Health Monitoring Using Ambient Noise Interferometry Across Multistory DAS Arrays

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Distributed acoustic sensing (DAS) has gained significant traction in the oil and gas industry and shows promising potential for broader engineering applications, particularly in digital twins for smart cities. Digital twins create virtual replicas for smart cities, and DAS can provide complementary information for bidirectional communication between the virtual and physical worlds.

To explore the benefits of integrating DAS into digital twins for smart cities, our study designed a multi-story DAS array to recover building mode shapes through ambient noise interferometry. The impacts of weather parameters on building vibration modes were investigated. Our contribution leverages the ambient noise interferometry approach, utilizing a multi-story DAS array to enhance the depth and accuracy of building mode shape analysis. This method marks a significant departure from conventional practices by introducing a 3D perspective to structural health monitoring (SHM), a notable advancement over the 1D or 2D approaches typically employed.

By doing so, our work expands the toolkit available for SHM and opens new pathways for understanding the complex dynamics of buildings under various environmental influences. The inclusion of a DAS array facilitates a more nuanced capture of structural responses, promising improvements in the precision of monitoring and early detection of potential structural issues.

Data Augmentation Techniques to Improve Automatic Detection in DAS Records

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In addition to regional earthquakes, Mexico City is also affected by local seismic events. To better understand these local phenomena, it is important to monitor local earthquakes and create a comprehensive catalog that includes events with very low signal-to-noise ratios as well as those with higher amplitudes.

Using data collected during a DAS experiment conducted from May 2022 to June 2023, we have detected nearly a hundred local seismic events using classical algorithms such as STA/LTA. However, manual inspection of some records revealed that STA/LTA missed many low-amplitude events, likely due to the noise produced by the city.

To address the limitations of classical detection algorithms, we propose the implementation of a convolutional neural network (CNN), which has been proven effective in similar situations. The challenge, however, is that a labeled dataset of only a hundred samples is insufficient to properly train this type of neural network. To overcome this limitation, we performed data augmentation on the original dataset to generate several thousand labeled samples. The advantage of this approach is that it eliminates the need for simulations or modeling, which would be time-consuming and computationally intensive given the complexity of Mexico City's geology.

Once trained, the proposed CNN can process the entire 120 terabytes of data acquired during the DAS experiment in just a couple of days, enabling the detection of hundreds of seismic events each month.

Fiber Optic Seismology in Densely Populated Urban Areas Exposed to Seismic Hazard

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DAS and other photonic sensing technologies have led to a rapidly expanding area of research utilizing existing telecommunication fibers for urban seismology. With the significant spatial extent of these deployments, one is able to use one fiber to study multiple aspects of urban seismic hazard, from monitoring seismicity on local faults, to producing subsurface velocity profiles in even the densest population centers. Here, we present a summary of recent DAS experiments in urban areas exposed to significant seismic hazard, including Athens and Santorini in Greece, and Istanbul in Türkiye.

Within these urban experiments, we tackle multiple aspects of seismic hazard. We utilize dispersion measurements derived from ambient noise to constrain shallow subsurface velocity structure and demonstrate this method in a pilot study in Bern, Switzerland, as well as in a more extensive deployment in Athens, Greece. Obtaining high-resolution velocity information in the top tens of meters of the subsurface can reveal structural heterogeneities relevant for construction and seismic hazard mitigation. The same workflow is applied in Istanbul, Türkiye, with the addition of 2D full-waveform inversion updates to refine the final model. Our Istanbul acquisition recorded many of the February 2023 Turkey–Syria earthquakes, and we are able to clearly see the seismic waves propagating in the data, as well as areas of local site amplification. Our field experiments also reveal numerous small, local earthquakes not contained in network catalogs. We have developed several methods for detecting and locating seismic events and compare our event catalogs to those of regional networks. In spite of fairly linear fiber configurations in Athens and Istanbul, we are able to locate many detected events. However, in the more geologically complex submarine environment off the island of Santorini, solving for event locations proves to be extremely challenging. Such observations may indicate limits on the potential usability of DAS in particularly complex environments.

Poster Presentation Abstracts

Presenting author is in bold.

An Innovative Photonic Vision of Volcanoes and Geothermal Systems [Poster]

Poster Session • Monday and Tuesday

POSTER 1

Fine Scale Southern California Moho Structure Uncovered with Distributed Acoustic Sensing

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Moho topography can yield insights into the tectonic evolution of the lithosphere and the strength of the lower crust. The Moho-reflected phase (PmP) samples this key boundary and may be used in concert with the first arriving P phase to infer crustal thickness. The densely sampled station coverage of distributed acoustic sensing (DAS) arrays allows for the observation of the PmP phase at fine-scale intervals over many kilometers with individual events. We use the PmP phase recorded by a 100 km-long fiber that traverses a path between Ridgecrest, CA and Barstow, CA to explore the structural variability of the Moho in Southern California. With hundreds of well-recorded events, we verify that PmP is observable and develop a technique to identify and pick the relative arrival time between the first arrival and PmP with high confidence. We use these observations to constrain Moho depth throughout Southern California, and we find that low-wavelength variability in crustal thickness is abundant, with sharp changes across the Garlock Fault and Coso Volcanic Field.

POSTER 2

Time Varying Crustal Anisotropy at Whakaari/White Island Volcano

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Whakaari/White Island has been the most active New Zealand volcano in the 21st century, producing small phreatic and phreatomagmatic eruptions, which are hard to predict. The most recent eruption occurred in 2019, tragically claiming the lives of 22 individuals and causing numerous injuries. We employed shear-wave splitting analyses to investigate variations in anisotropy between 2018 and 2020, during quiescence, unrest, and the eruption. We examined spatial and temporal variations in 3499 shear-wave splitting and 2656 V_p/V_s ratio measurements. Comparing shear-wave splitting parameters from similar earthquake paths across different times indicates that the observed temporal changes are unlikely to result from variations in earthquake paths through media with spatial variability. Instead, these changes may stem from variations in anisotropy over time, likely caused by changes in crack alignment due to stress or varying fluid content.

Earthquake Characterization Using Fiber-optic Cables [Poster]

Poster Session • Monday and Tuesday

POSTER 3

Downhole DAS Array for Microseismic Event Characterization at FORGE Combining Direct and Converted Phase Picks from Machine Learning

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Microseismic monitoring is a vital reservoir management tool, offering insights into subsurface fluid-driven processes such as carbon sequestration, wastewater injections, and hydraulic fracturing in Enhanced Geothermal Systems (EGS), where precise event localization during reservoir stimulation is imperative for interpreting fracture activation and heat flow pathways. The FORGE site in Milford, Utah, dedicated to the study of advancing EGS, features an extensive geophysical monitoring network, including Distributed Acoustic Sensor (DAS) fibers. The downhole DAS array recorded a complete full wavefield of microseismicity, which occurred during the 2019 and 2022 stimulation, where clear P, S, and S-P converted phases can be identified. Notably, the S-P converted phase occurred at the granite contact, where the seismic velocity significantly changed. We developed an interactive tool to manually pick and interpolate phase arrivals on DAS wavefields for microseismic events during 2019 and 2022 stimulations. The phase picks with high signal-to-noise ratios are used to train a PhaseNet machine learning model (EQnet) using Pytorch to check the accuracy of predicted phase arrivals. We evaluate phase prediction results from our model and find good agreement with manual picks, especially for P-phases with the highest Precision, Recall, and F1 accuracy. The S-P and S phases show a relatively large residual from the manual picks, perhaps due to the trade-off at the contact interface. The importance of accurately predicting Converted Phase SP is its sensitivity to event depth, which can be used to better constrain event depths and relocate repeating events. Using the delay time between the S-P converted and P wave measured from DAS array, we identify multiplets occurring at different depth ranges and will further compare the multi-phase DAS event locations with geophone arrays. We will extend the cross-correlation workflow developed using geophone arrays to characterize microseismic event source properties and repeating earthquake evolutions.

POSTER 4

Source Parameter Measurement Validation Using DAS and Seismic Stations

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The stress drop validation project organized by Southern California Earthquake Center (SCEC) provides a comprehensive datasets of aftershocks during the Ridgecrest earthquake sequence. The Ridgecrest DAS array recorded a large number of aftershocks during the same time period, and offers a great opportunity to thoroughly evaluate the feasibility of using DAS to study source parameter variations. In this study, we identify three target events with adequate number of high-quality nearby smaller events that can be used as EGF (Empirical Green's Function) events.

We perform spectral ratio deconvolution using different multi-taper approaches, including: (1) MT-Deconvolve (Prieto, 2019) that optimizing both target and EGF events spectra simultaneously, and obtain spectral ratio and source-time-function (STF); (2) MT-Spec (Prieto, 2019) that optimizing individual spectrum; (3) Pmtm – the built-in algorithm from MATLAB. For each algorithm, we systematically vary the length of time window, frequency bandwidth, number of tapers, assumed source model (Brune or Boatwright) to evaluate the stability of spectral ratio inversion, and the relative moment ratio. We compare the stacked results from the DAS array, two nearby stations (SRT, CA03) and the averaged results from the SCEC seismic network.

We find that the DAS results are more sensitive to the time window length compared to the seismic stations, with longer time window decreasing the moment ratio at low frequency for the DAS, while seismic result tends to be more stable. The stacked result of DAS array is generally more stable than individual seismic stations, especially in source complexity characterization. All methods appear sensitive to the number of tapers, especially with shorter time window. For both datasets, careful selection of EGF events is needed to ensure stable results.

The detailed comparison demonstrates that DAS holds potential in routine network monitoring to resolve source parameters. Understanding the limitations and potential biases due to data processing using well-recorded dataset is crucial in future steps.

POSTER 5

A Waveform-Based Earthquake Detector for DAS Data

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Distributed Acoustic Sensing (DAS) offers significant advantages for microseismic monitoring due to its high spatial sampling. Unlike traditional geophones, which are sparsely distributed and sample the seismic field every ten to hundreds of kilometers, DAS provides dense sampling with 1-meter spacing and rates up to several kHz. This high spatial resolution allows for unprecedented mapping of seismic wave propagation but also produces TeraBytes of data daily. For this reason, traditional seismological processing techniques are not designed to handle such volumes and high spatial resolution. Consequently, new processing methods are required.

We propose an innovative waveform-based detection method exploiting the high temporal and spatial sampling of DAS data. Our algorithm is based on the calculation of a coherence matrix through the analysis of waveform coherence along hyperbolas with varying curvature and vertex positions (Porras et al., 2024). We then use a convolutional neural network to classify the coherence matrices, effectively distinguishing between seismic events and noise.

The residual neural network is trained on a dataset comprising coherence matrices derived from synthetic DAS data, which simulate events with varying locations and focal mechanisms. To validate our methodology, we applied it to data collected from a 90 km telecommunication fiber in the Pyrenees, France, and a borehole fiber in an enhanced geothermal system in Utah (FORGE experiment).

J. Porras, D. Pecci, G. M. Bocchini, S. Gaviano, M. De Solda, K. Tuinstra, F. Lanza, A. Tognarelli, E. Stucchi, F. Grigoli, A semblance-based microseismic event detector for DAS data, Geophysical Journal International, Volume 236, Issue 3, March 2024, Pages 1716–1727, https://doi.org/10.1093/gji/ggae016

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POSTER 6

Passive Seismology in Urban Environments Using Distributed Acoustic Sensing in Auckland, New Zealand

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We use data collected from two Distributed Acoustic Sensing (DAS) deployments in Auckland, New Zealand in conjunction with co-located and network seismometers to detect and explore regional and teleseismic earthquakes. We utilize unused network fiber (Dark Fiber) on the University of Auckland communication network in the Auckland City centre. Data are recorded on a 500 m long segment of the network that is co-located with an on-campus educational seismometer and compared with nearby network seismometer data. Our second deployment uses 1 km of directly emplaced tactical fiber in a horizontal array that is collocated with a broadband three-component seismometer in a semi-urban area. For the University of Auckland campus deployment, the DAS array acts as a point receiver on the scale of seismic wavelengths. Therefore, individual traces over the entire array are stacked to provide optimal SNR. This approach also inherently filters out near field effects from traffic, which are otherwise evident on the DAS data. Multiple regional and teleseismic earthquakes are recorded that are identifiable with DAS alone. Relatively poor P-wave arrivals are observed due to near-vertical incidence, though S-wave and surface wave arrivals are clear. Seismic beamforming will be undertaken to evaluate the effectiveness of these DAS deployments in this regard. The second deployment is currently underway, and data and results will be presented here.

POSTER 7

Using DAS and Seismometer Arrays to Analyze Strain for Explosion Monitoring

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We used Distribute Acoustic Sensing (DAS) and seismic array data to either measure or compute strain from earthquakes to enhance seismic monitoring. We repurposed the 2016 PoroTomo experiment DAS and geophone array datasets to compare the performance of array-based f-detector applied to 2 weeks of continuous data. We find that the detection performance from earthquake signals is similar using both sensor modalities; however, the wave propagation estimates are poor for DAS likely due to the fiber's broadside sensitivity limitations. We show with simulations that changing the array design will improve this limitation. We also found significant frequency dependent differences between array derived strain and DAS that may limit seismic methods that depend on signal coherency above 1 Hz.

We have applied a coda magnitude measurement method to DAS and found good agreement between DAS and co-located geophone magnitude estimates using PoroTomo and Sacramento Dark Fiber datasets. The coda waves recorded from regional earthquakes have similar envelope shapes between DAS and geophones. The benefit of the coda approach is the ability to measure precise earthquake magnitudes without complete knowledge of instrument and fiber response by using only a few prior calibration events.

We are performing a preliminary analysis of the 2023-10-18 Physics Experiment-1A (PE1A) explosion triggered aftershocks at the Nevada National Security Site. The 16.3-ton chemical explosion triggered 100's of microearthquakes within 24 hours only observed within ~500 m of the cavity and was recorded on DAS collected by the PE1 Experiment Team. A high percentage of approximately 650 aftershocks are singletons, i.e., not correlated with any other waveform templates, suggesting their source mechanisms may be from radial cracking in all directions observed in previous experiments (Ichinose et al., 2021). Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-864110.

POSTER 8

Resolving Asperity- and Barrier-like Fault Heterogeneity by Back-Projection of High-Frequency Signals

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Li et al. (2024) made a breakthrough in earthquake source characterization by using back-projections of high-frequency recordings of the 2021 Antelope Valley *M*w 6.0 earthquake to resolve subevents of the main rupture. A fully dynamic rupture model was able to reproduce the high-frequency signals as abrupt changes in the rupture speed caused by patches of frictional and normal stress heterogeneity along the fault. In this study, we extend the model to synthetic DAS signals to investigate the limit of what we can learn about the dynamic nature of fault heterogeneities through seismological observations. We compare synthetic DAS signals of rupture models that produce similar moment-rate histories in lower frequency but differ in the strength of the heterogeneity. In particular, we observe the sensitivity to changes in the qualitative behavior of the heterogeneous patches, from those that promote rupture propagation (asperity) to those that slow it down (barrier). The models further illuminate the mechanical origin of the high frequency signals and provide valuable information regarding the feasibility of a dynamic inversion.

POSTER 9

Unmasking Traffic Noise: Unsupervised Denoising for Distributed Acoustic Sensing (DAS) Data

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Recent advances in sensing technologies, particularly Distributed Acoustic Sensing (DAS) have enhanced the collection and analysis of seismological data, and DAS has emerged as a powerful method for detecting vibrations from earthquakes, subsurface phenomena, and other esoteric sources. However, the vast amount of data produced by DAS necessitate the use of sophisticated analytical methods to differentiate between signals of interest, such as those originating from earthquakes and vehicles.

We introduce a novel approach by extending the Noise2Self framework of Batson and Royer to effectively remove unwanted, structured coherent noise, particularly traffic signals, from DAS data. By creating a set of masks based on the first-order characteristics of traffic signals, we isolate and preserve earthquake signals while maintaining the denoising performance of the original Noise2Self approach, which efficiently reduces noise without requiring clean reference data. For a comprehensive evaluation of our approach, we employed synthetic data, which was generated using seismic recordings from closely spaced seismometers. We then applied our approach to data gathered from a DAS array located near Haast, New Zealand, adjacent to the Alpine Fault. For a comprehensive evaluation of our approach, we employed synthetic data, which was generated using seismic recordings from closely spaced seismometers, to validate our method under controlled conditions and afterwards applied this technique to data gathered from a DAS array located near Haast, New Zealand, adjacent to the Alpine Fault.

The results demonstrate that our model successfully removes traffic noise, as well as other non-coherent noise while maintaining the integrity of seismic signals, leading to an improvement in both Signal-to-Noise Ratio and waveform coherence. Evaluations on real-world DAS data further substantiate the robustness of our method, positioning it as a valuable tool for the analysis of large-scale DAS datasets across a range of geoscientific applications, working towards near or real-time monitoring.

POSTER 10

Detection of Cement Grouting Induced Events in Continuous Downhole Distributed Acoustic Sensing Data using Machine Learning

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Distributed Acoustic Sensing (DAS) is an innovative technology that transforms standard single-mode optical fiber into an array of virtual sensors, enabling the detection of acoustic signals along the entire optic fiber length. DAS provides high temporal and spatial resolution and is easily deployable in diverse environments. However, it exhibits distinct characteristics compared to traditional seismometers, such as unknown ground coupling. The Milun Fault Drilling and All-inclusive Sensing (MiDAS) Project in Taiwan aimed to investigate fault zone behavior; a hole was drilled approximately 700 meters deep, and a downhole optical fiber was deployed for DAS. Cement was promptly injected into the hole after deploying the downhole optical fiber for better ground coupling in DAS data. Several specific events occurred at different depths, observed by only a subset of DAS nodes. If these events were seismic, they should be detected by all nodes along the downhole fiber. Therefore, this study applies a machine learning method (YOLOv4) to downhole DAS data to identify such events. After identifying the time and locations (depths) of these events, it was discovered that they were related to grouting, with a notable reduction in these events after the cement solidifies. This underscores the advantages of DAS, characterized by its high temporal and spatial resolution, and signifies the first reported instance of DAS capturing tiny events during cement solidification.

POSTER 11

Shallow Imaging of the Alpine Fault Zone, New Zealand Using Distributed Acoustic Sensing (DAS)

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The Alpine Fault, which forms the boundary between the Pacific Plate and the Australian Plate, poses substantial seismic hazard to southern New Zealand, with magnitude ~8 earthquakes occurring on <300-year timescale, most recently in 1717 CE. The 800 km long oblique continental transform fault is divided into several geometrically-distinct segments with different kinematic and seismogenic characteristics. The fault zone architecture is of particular interest, as it is hypothesized to influence coseismic fault rheology and fluid-rock interaction, which in turn affects local fault slip rates, moment release, and rupture propagation patterns.

Resolving the fault zone architecture, including its geometry and velocity properties, requires high spatial resolution observations that can capture multiple length scales, from meter-scale fault core to kilometer-scale damage zone, and from the top few meters of the sedimentary layer to depths of several kilometers within the dipping fault. Distributed acoustic sensing (DAS), with its meter-spaced sensors spanning tens of kilometers of fiber optic cables, provides a unique opportunity to investigate and image the shallow fault zone architecture.

Here we present data and preliminary imaging results from SISSLE — the South Island Seismology at the Speed of Light Experiment — which made use of a DAS array running orthogonally across the surface trace of the Alpine Fault near Haast, South Island, New Zealand. Analysis of local earthquakes consistently reveals S-diffracted waves and P-wave multiples, consistent with a southeast-dipping fault zone with an estimated width of approximately 400 m. We also observe a strong surface wave coda, attributed to a sedimentary layer west of the fault. The shallow fault zone architecture is further delineated using correlation and waveform modelling techniques. This high-resolution view of the Alpine Fault zone architecture near a paleoseismologically recognized segment boundary enhances our ability to assess seismic hazards and inform mitigation strategies' late in the fault's typical interseismic phase.

POSTER 12

Construction of Horizontal Strain Array from DAS Sensor

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DAS (Distributed Acoustic Sensing) technology provides an economical way to deploy thousands of linear strain meters along the fiber cable. To fully utilize the information of the strain field, at least three linear strain meters are needed at the same site to obtain a horizontal strain tensor. Taking the opportunity by the redeployment of the surface fiber cable of the MiDAS (Milun fault Drilling and All-inclusive Sensing project) at the end of 2022, three components of fiber cable oriented at 0-45-90 degrees with cable length of 20 meters each were deployed on the surface. This allows us to compute the full strain tensor from the three arms of the fiber cable, rotating the surface strains into a radial-transverse coordinate system. Together with a collocated 3-axis seismometer and 3-axis rotation sensor, 10 components of the elastic wavefield can be achieved. In this study we merge the strain, rotation, and seismometer measurements at the same station and investigate if we could determine the direction of wave propagation and phase velocity for specific wave type from the combination of these measurements.

POSTER 13

Distributed Acoustic Sensing Data Denoising with Deep Learning

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Distributed acoustic sensing (DAS) data provide detailed strain information with higher spatial and temporal resolution compared to seismic sensors. Due to its large data size and the overlapping noise with the signal of interest, denoising using traditional approaches poses challenges, particularly in real-time monitoring applications. Here, we propose a deep learning 2D CNN U-Nets model for DAS data denoising based on real and synthetic DAS data. We test this approach using the PoroTomo DAS data set, employing one week of continuous DAS data for model training. Once trained, the model processes groups of DAS time series data as 2D images, significantly reducing computation time. Our results show that the model can learn the spatial and temporal coherence of DAS data, which enhances the SNR of noisy channels. Comparison of our results with those derived from co-located geophones demonstrates good agreement. Furthermore, our preliminary analysis of the model generalization test with the Physics Experiment-1A (PE1) chemical explosion data set from the Nevada National Security Site (Myers et al., 2024) shows that the model is generalizable and can be applied to other DAS data sets without significant transfer learning.

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POSTER 14

PYROS: A Python Framework for Modeling DAS Data

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The advent of fiber optics technology for seismic data acquisition marks a pivotal moment in contemporary seismology. Nowadays Distributed Acoustic Sensing (DAS) is becoming widely employed in different seismological contexts and applications such as passive seismic imaging, characterization of seismic sequences, and induced seismicity monitoring, especially concerning Enhanced Geothermal Systems (EGS) and Carbon Capture Storage (CCS) operations, among others. The main advantage of DAS consists of its capability to collect data in logistically challenging sites such as volcanic areas or the sea bottom and/or in adverse environmental conditions (such as deep geothermal borehole installations) that are prohibitive for the deployment of conventional seismic sensors. Although promising, DAS technology poses new challenges to the seismological community, the main one is related to the massive data volumes it generates, posing practical obstacles for current data storage and analysis infrastructures. Also for this reason, public domain datasets remain relatively limited compared to classical seismological datasets, being an obstacle to the development of dedicated data analysis methodologies able to exploit the characteristics of DAS data. To address this challenge, we propose a methodology developed within the Pyrocko framework to generate synthetic DAS data. Our approach essentially consists of adapting the reflectivity method (e.g., QSEIS) for 1D Green's functions generation to compute synthetics strain or strain/rates traces, simulating DAS acquisition for different geometries. We first compare our results with the synthetics generated using other commercial software. Finally, we compare our synthetics with the real DAS recordings collected at the Forge EGS site in Utah (USA). To enhance the realism of our synthetics, we stochastically simulate the DAS noise characteristic of the Forge site and add it to the synthetic traces. This method will facilitate the development and testing of novel methodologies for DAS data analysis.

POSTER 15

Evaluation of Passive Source DAS Methods on the Source Physics Experiment Phase II

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Distributed Acoustic Sensing (DAS) is an emerging technology capable of recording the acoustic wavefields at unprecedented spatial resolution. However, this new tool requires significant refinements before it becomes operational for explosion monitoring objectives. Recent studies have shown significant development of array processing with DAS data. In this contribution we explore three such array processing methods: including DAS strain-rate data versus geophone measured ground motion, beamforming for event parameters, and machine learning based denoising. We first validate the methods on published results and then apply them to high SNR data from the Source Physics Experiment Phase II. We further investigate these methods as a function of DAS array design and SNR through the use of synthetic signals and noise.also investigate DAS array design by applying these methods to synthetic signals and noise.

The Source Physics Experiment (SPE) would not have been possible without the support of many people from several organizations. The authors wish to express their gratitude to the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development (DNN R&D), and the SPE working group, a multi-institutional and interdisciplinary group of scientists and engineers.

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POSTER 16

Numerical Investigations of the Potential of Joint Source-Structural Full Waveform Inversion (FWI) Using DAS Arrays

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In the context of inverse problems, the high spatial density of DAS measurements significantly enlarges the data space, potentially allowing for the estimation of larger parts of the model space while keeping the inverse problem well-constrained. Although Full Waveform Inversion (FWI) is naturally formulated with both earthquake source parameters and structural parameters as the model space, such a formulation is usually not well-constrained. In practice, inversions target either structural or source parameters, with the other estimated separately and kept constant throughout the inversion. However, this approach could introduce non-linear errors in the inverted parameters.

Leveraging the increased data space, we investigate the possibility of performing joint FWI of both source and structural parameters. We generate a synthetic dataset that includes DAS recordings of two events in a representative regional seismology scenario. The DAS array consists of two surface linear fibers, one surface circular fiber, and two boreholes, each 2 km deep. The underlying 3-D Earth structure includes lateral variations. As a starting model, we only use a 1D version of the velocity model, and no information about the sources.

We use an L-BFGS-based FWI to jointly invert for the source parameters of two earthquakes and for the 3-D structure. We use the phase misfit as the objective function and, to maximize the data space, we add a normalized envelope misfit to it. The scale differences between the parameters are addressed by using a diagonal approximation for solving the secant equation of L-BFGS instead of the commonly used scaled identity matrix. Due to the low number of simulated events, we can only aim to recover an effective velocity model that will improve the estimation of location, origin time, and moment tensor of the events. Using the proposed algorithm, we achieve a reduction of more than 70% in the errors of the source parameters compared to the initial estimations. This study can be expanded for inversions with a higher number of events to estimate structural parameters.

POSTER 17

Downhole DAS for Induced Seismicity and Reservoir Monitoring in the Groningen Gas Field

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Monitoring induced seismicity and reservoir properties are critical for managing seismic risk and production in various subsurface operations, including oil and gas exploration, geothermal energy, and CO2 sequestration. Downhole Distributed Acoustic Sensing (DAS) is an emerging, cost-effective, and long-term monitoring tool. Previously applied in microseismicity monitoring for hydraulic fracturing, DAS is now being explored for large-scale reservoir monitoring.

This study presents a DAS measurement conducted in the Groningen gas field, Netherlands. We interrogated an optical fiber partially cemented behind the casing along a deviated well (~3,800 meters), using a 10-meter gauge length and 1-meter sampling spacing. In this configuration, most traces achieved a low self-noise floor between 0.1 and 30 Hz.

We developed a frequency-wavenumber domain event detector that successfully identified events with local magnitudes (ML) as low as 0.6 at an epicentral distance of 9 km and the furthest event at 30 km with ML 1.1. Smaller uncataloged events are also detected.

Analyzing those events suggests that the amplitude difference between upgoing and surface-reflected waves is influenced by well deviation geometry,event azimuths, and incidence angles. This indicates that amplitude changes may be useful for earthquake characterization. Notably, we observe no clear signal amplitude or noise level changes from cemented to uncemented well sections. Moreover, comparing strain rate amplitude with P-wave velocity data from well logs revealed a clear anti-correlation,suggesting the possibility of deriving seismic properties from DAS amplitude measurements. Additionally, we applied hybrid noise interferometry between seismometer and DAS channels, retrieving signals that hold promise for reservoir monitoring.

Real-Time Monitoring and Warning with Fiber Optic Seismology [Poster]

Poster Session • Monday and Tuesday

POSTER 18

Earthquake Location With Distributed Acoustic Sensing (DAS) Using Beamforming and Phase Arrival Time Differences

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Beamforming is a well-established method to identify the direction (back-azimuth) and slowness of seismic waves relative to a seismic array. DAS is essentially a very dense and potentially large-aperture array whose measurements exhibit unique features compared to conventional arrays. Namely, commercial optic fibers tend to have linear geometries, resulting in ambiguous back-azimuth results. Here we show an earthquake epicenter location method, using beamforming and phase arrival times differences, both calculated on the DAS native strain-rate data. We divide a 66 km-long fiber into shorter overlapping segments (~5 km) and perform segment-wise beamforming in the time domain quantified using semblance, a cross-channel coherency measure. Each segment produces a single beam of back-azimuth estimate. We demonstrate that even if a single beam indicates ambiguous results, the directional ambiguity is resolved by the intersection of many single beams originating from various orientations relative to the source. Furthermore, we show that the semblance-driven beamforming can be used as a phase picker, constraining the distance to the source using P to S phase arrival time differences. We validate the method using DAS records of several local earthquakes. This work demonstrates that a sufficiently large aperture fiber, divided into segments, facilitates earthquake location via the intersection of several beams, combined with phase arrival times difference. The proposed time-domain beamforming implementation is easily applicable for earthquake early warning to both detect and locate earthquakes.

POSTER 19

Developing Local to Near-regional Distance Explosion Monitoring Capabilities Using Distributed Acoustic Sensing (DAS)

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The high-fidelity, and broadband measurements provided by Distributed Acoustic Sensing (DAS) over an extended spatial domain has been shown to be capable of characterizing both traditional seismic sources such as earthquakes, as well as aerial sources such as bolides. DAS measurements can provide seismic observations which rival those of traditional seismic arrays, while simultaneously providing enhanced constraints on both the atmospheric acoustic and infrasound wavefield, making these measurements uniquely well suited to examine near-surface seismo-acoustic sources such as volcanic eruptions and chemical explosions. In this study, we analyze DAS data collected at local to near-regional distances (e.g., ~12 km) from a near surface chemical explosion test series which occurred in May 2024 near Socorro, NM, and consisted of 4 one-ton TNT equivalent shots followed by a 10-ton TNT equivalent shot. The one-ton shots occurred in two pairs separated by several hours, and with each shot comprising a pair occurring with a spatial separation of <100 m and a time delay of several minutes. The 10-ton shot occurred a few hours later at a location several kilometers away from the 1-ton shots. The DAS data captured both seismic and acoustic waves from all the explosions. This experiment provides a crucial demonstration of the capabilities and constrains of DAS to record surface explosions at local to near-regional distances.

POSTER 20

Machine-Learning Based Techniques Enabling Real-time Monitoring of Induced Seismicity in Offshore CO2 Sequestration Sites

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Safe carbon sequestration requires a cost-effective and robust monitoring system that can detect induced seismicity and track the CO2 plume in the subsurface. The largest proposed CO2 sequestration sites are located offshore in marine settings. In such environments, distributed acoustic sensing (DAS) offers a low-cost alternative with added advantages of higher spatial sampling, real-time data acquisition and processing capabilities, and better offshore azimuthal coverage compared to land-based seismometers. The high spatial resolution of DAS allows for distinguishing between seismic events and cultural noise, but leads to a high volume of data being recorded. High sensitivity requirements for monitoring CO2 sequestration in presence of significant cultural noise render traditional techniques like STA/LTA impractical for detecting earthquakes.

In this study we show significant advancements in earthquake and microseismic event detection using a novel machine learning based approach on subsea DAS data. We use cable-specific advanced denoising techniques and a three-class classification neural network to detect and differentiate between seismic events, cultural noise, and background noise. Due to a lack of labeled data, we start from a pre-trained ImageNet model and fine-tune a fraction of the weights. Our ML approach involves active learning to improve our models over time by iteratively detecting and adding more labeled training data in each class. Our detection system exhibits enhanced sensitivity in detecting faint earthquakes along with a dramatic reduction in false positive triggers. We further tested our system on another subsea fiber, with both different geology and natural seismicity rates, without retraining the ML model. Our preliminary results show that the detection system trained on one fiber can be used to detect new events on a different fiber and jumpstart the active learning process. Furthermore, the system can be deployed remotely with consumer grade hardware enabling a cost-effective, real-time detection system.

POSTER 21

Integrating DAS Seismic Data into the National Earthquake Monitoring at the Swiss Seismological Service

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We explore the integration of Distributed Acoustic Sensing (DAS) seismic data into the standard processing system used by the Swiss Seismological Service (SED) for national monitoring. Using temporary DAS deployments across Switzerland, we have incorporated DAS data in the existing monitoring infrastructure based on SeisComP to enhance the accuracy and efficiency of seismic monitoring across the Swiss national network. Our approach is based on spatial and temporal decimation and the conversion of native data into strain and velocity data in miniseed format with associated metadata in FDSN station-XML format ready for integration alongside existing seismic data in SeisComP. We will present examples of standard manual event analyses, demonstrating how DAS data can be effectively used alongside traditional seismic data. We discuss our approach for DAS channels for picking, locating and magnitude estimation. These examples will demonstrate the improved resolution capabilities offered by DAS technology. Additionally, we will discuss the results of real-time processing tests that include both DAS data and traditional data from the Swiss national network. The presentation will conclude with a discussion of the challenges encountered during the integration process and future steps for further improving the use of DAS technology in seismic monitoring, with a view towards EEW.

POSTER 22

Toward Automatic Avalanche Detection With Distributed-Acoustic-Sensing, Leveraging Telecommunication Infrastructure

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Snow avalanches pose significant threats in alpine regions, leading to considerable human and economic losses. The ability to promptly identify the locations and timing of avalanche events is essential for effective prediction and risk mitigation. Conventional automatic avalanche detection systems typically rely on radars and/or seismo-acoustic sensors. While these systems operate successfully regardless of weather conditions, their coverage is often confined to a single slope or a small catchment (distances < 3 km).

In our study, we demonstrate the feasibility of detecting snow avalanches using Distributed Acoustic Sensing (DAS) through existing fiber-optic telecommunication cables. Our pilot experiment, conducted over the 2021/2022 winter, involved a 10km long fiber-optic dark cable running parallel to the Flüelapass road in the eastern Swiss Alps close to Davos. The DAS data reveal distinct evidence of numerous dry- and wet-snow avalanches, even when they do not reach the cable, as confirmed photographically. We show that avalanches can be distinguished from other signals (e.g., vehicle traffic) using a frequency-dependent STA/LTA attribute, enabling their detection with high spatiotemporal resolution. These findings pave the way for cost-effective and near-real-time avalanche monitoring over extensive distances, leveraging existing fiber-optic infrastructure.

POSTER 23

Assessing Distributed Acoustic Sensing Strain-Rate Waveform Statistics for Improving Earthquake Early Warning

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DAS seismology offers new opportunities for earthquake early warning (EEW) as existing "dark fibers" are used as dense linear arrays of strain meters. Here, we examine the statistical features of DAS measurements of the first few seconds after P-wave arrivals from small-to-moderate local earthquakes for applications to EEW. Our data are from a 15-km long fiber onshore between Arcata and Eureka near the Mendocino Triple Junction in Northern California, where a M6.4 occurred about 30 km away, near Ferndale, on December 20, 2022. We analyze 5 months of local seismicity following the 2022 Ferndale event, including 12 M>4 events and one M5.4 on January 1, 2023. We calculate DAS waveform statistics before and after P-wave arrivals for the purpose of designing a DAS-based "tripwire" alert mechanism for EEW for nearby large earthquakes, thus expanding EEW coverage wherever dark fibers are available. We identify 70 two-minute-long DAS records of local earthquakes using the Comcat event catalog and an automatic phase picker (PhaseNet-DAS; Zhu et al., 2023), and analyze their statistical features in both time and frequency domains in the ten seconds before and four seconds after a P wave is detected across a spatial segment of the fiber. We find that some features correlate with catalog magnitude including continuous wavelet transform coefficients, short-term average/long-term average (STA/LTA) ratios, and strain-rate amplitudes, and are largely independent of distance and azimuth. We suggest that near-field terms which are thought to be characteristic of large, but not small, rupture processes, may help broadly distinguish between large and small earthquakes on DAS fibers, thus improving our ability to characterize potentially hazardous earthquakes in a timely and effective manner.

POSTER 24

Utility of Distributed Acoustic Sensing for Locating Seismic Events Over Multiple Distance Ranges

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Two of the big advantages of Distributed Acoustic Sensing (DAS) systems stem from its use of fiber optic cables that are either purpose-deployed (in boreholes, mines, surface trenches, buildings, etc.) or pre-existing (e.g., unused telecommunication or "dark" fiber) and its ability to make observations along many kilometers of these cables with sensing separations as small as one meter. An important question for seismologists is to what degree DAS systems are useful for monitoring seismic events. We examine various cases of DAS for locating seismic events over multiple distance ranges, from hundreds of meters to thousands of kilometers. Some of the cases we examine include determining seismic event locations at a geothermal field and in an aftershock sequence at scales from hundreds of meters to tens of kilometers and estimating wave arrival azimuth and incidence angle at near regional, far regional, and teleseismic distances. Even for non-ideal geometries, DAS arrays show promise for contributing to seismic event monitoring over multiple distance scales.

POSTER 25

Real-Time Monitoring of Centrifuge Operational Status and its Impact on Surrounding Structures Using Distributed Acoustic Sensing (DAS)

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Monitoring large indoor equipment like centrifuges, which are dynamic vibration sources, is crucial for assessing their operational status and the effect on surrounding structures in real-time. Traditional methods, which utilize numerous built-in sensors, can impede equipment performance. In this study, we introduce a Distributed Acoustic Sensing (DAS)-based method to monitor a basement-located centrifuge in real-time. We conducted an indoor experiment where the centrifuge's rotational speed was controlled in a step-wise manner: starting at 100 rpm and increasing through steps of 200, 350, 450, to a peak of 580 rpm, before sequentially reducing back to 100 rpm and halting. The monitoring utilized a three-dimensional DAS array with a 1.2 km fiber-optic cable that spanned the building from a concrete raft foundation in the basement, through the courtyard buried beneath the surface, and up to the roof, secured along building floors with plastic tapes.

Spectral analysis of the DAS data pinpointed key dynamics of the centrifuge and responses of the building structure. As the rotational speed increased, corresponding elevations in fundamental frequencies (calculated as rpm/60 Hz) and their harmonics (integer multiples of the fundamental frequencies) were observed, becoming more pronounced at higher speeds. These observations are crucial as they indicate increased energy outputs and complex vibrational behaviors at elevated operational speeds. Additionally, a notable frequency folding effect at 1000 Hz highlighted the limitations of the sampling rate, resulting in the mirroring of frequencies that exceed this threshold.

These findings underscore the effectiveness of DAS techniques not only in monitoring the health of equipment like centrifuges but also in providing critical data on how such equipment impacts building vibrations. The ability of DAS to capture high-resolution data across a large spatial array makes it an invaluable tool in both industrial applications and structural health monitoring, potentially leading to more proactive and predictive maintenance strategies.

Sensing Technologies and their Latest Developments [Poster]

Poster Session • Monday and Tuesday

POSTER 27

Calibrating Strain Measurements: A Comparative Study of DAS, Strainmeter, and Seismic Data

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Distributed Acoustic Sensing (DAS) measures strain along an optical fiber at specific intervals. Although converting DAS strain into ground units seems straightforward, practical implementation can result in coupling and instrument response errors. To address this, we compared DAS strain measurements with total strain from an optical fiber strainmeter (OFS) within the same cable. We also simulated strain using single-point velocity measurements from a nearby broadband STS2 seismometer.

Our study includes both field and lab experiments. In the field, DAS and OFS were deployed together on Whidbey Island, Washington, on land and beneath a shallow waterway. We used a teleseismic event recorded by DAS and converted it to total strain by stacking recordings from each channel. The integrated DAS strain data were then compared with OFS measurements, showing highly similar waveforms, nearly identical amplitudes, and a correlation coefficient above 0.95. Strain simulations from seismic velocity also showed consistency with offshore recordings, though with an amplitude factor of ~2.5, suggesting imperfect coupling between the fiber and the ground.

In the lab, we introduced a new method for evaluating DAS amplitude response using DAS and OFS. This method employs a piezoelectric sensor to generate ground truth strain, avoiding biases from natural earthquakes. Lab findings indicated a -3.2 dB decrease in DAS recorded amplitude at low frequencies (0.01 Hz), emphasizing the need for amplitude calibration in such studies.

Our investigation of underwater signals revealed a strong correlation with tide speed, with signals concentrated around slope turning points on the eastern side. This localization was achieved by calculating the coherence between DAS and OFS recordings, providing insight into the unknown source of these underwater signals.

POSTER 28

Monitoring Blasting Operations at the Sanford Underground Research Facility (SURF) Using a Three-dimensional Distributed Acoustic Sensing (DAS) Array

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At the Sanford Underground Research Facility (SURF) in Lead, SD, we deployed a three-dimensional Distributed Acoustic Sensing (DAS) array at the 4550-foot level, with sections extending from the 4100-foot level towards the 4850-foot level using the old mine's ramps and shafts. In May 2022 and February 2023, we illuminated the array with an OptaSense ODH-4 interrogator. Over the two deployments, we recorded seismic signals from up to 100 blasts triggered while the facility constructed three utility caverns for Physics experiments at the 4850-foot level. Those seismic records captured the effects of different blasting charges and sequences, directivities of sources, attenuation, and different rock-to-fiber couplings. As the location and characteristics of the blasts advance across the utility caverns, we interpret the signals to characterize the blasting operations and qualify how a three-dimensional DAS array can evaluate mining and excavation operations.

POSTER 29

Quaternion Processing of 3C Rotational Motion Based on FOGs

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Among the various types of rotational seismometers, fiber optic gyroscopes (FOG) have become the most widely used and promising rotational seismometers due to their portable size, high sensitivity and wide measurement frequency range. At present, the main processing method for three-component FOG data is to process each component separately. However, this approach ignores the correlation between the components, which may lead to loss of some vector wavefield information. Thus, there is an urgent need for multi-component vector methods to process different components simultaneously, which can fully utilize the inherent correlations in different components, better preserving the vector wavefield characteristics of the signal. Quaternion, as an excellent mathematical tool, can fully express the linear and nonlinear characteristics of multi-component data. By placing the three components of FOG onto the three imaginary parts of pure quaternion and then using quaternion algebra, it is possible to achieve joint vector processing of 3C rotational seismic data.

When analyzing the low-frequency passive source signals from different types of FOG, it is observed that there is a prevalent presence of strong harmonic noise in three components. Analysis reveals that the fundamental frequency of this harmonic is positively correlated with the mean of the data, suggesting that it may be caused by the modulation process of the FOG. These harmonic noises will interfere the identification of seismic events. In order to suppress harmonic noises, various denoising methods are attempted, among which the quaternion vector filter methods have shown better performance and the higher efficiency.

POSTER 30

Ocean Space Surveillance Using Distributed Acoustic Sensing on Submarine Networks

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Technology developments have realized long-range distributed acoustic sensing (DAS) that can coexist with transmission in submarine telecommunication networks. The fiber optic cable measurements can be used for multiple purposes contributing to enhancing environment and hazard monitoring, and resilient societies. The seismology community has rapidly adopted the technology to improve earthquake monitoring and early warning capabilities, and the enhanced marine data coverage is advancing ocean sciences.

In this presentation we will focus on surveillance using submarine cables. We have carried out long-term monitoring on a Southern North Sea telecom cable. During a three-year period, we have detected and analysed regional impulsive source events from sources located in the water column, onshore and in the air. The recordings show clear arrivals of seismic, hydroacoustic and infrasound waves. The long propagation range and sensitivity on the fiber optic cable measurements show that by instrumenting only a few cables, it is possible to achieve a coastline-scale surveillance capacity.

The observations from underwater detonation of ordnance, and onshore blasts show that it is possible to augment the seismometer-based networks for regional explosion monitoring. The signal characteristics also show how it is possible to determine the type of source to quickly assess an event and contribute to situational awareness.

We discuss how a real-time processing system can extract important event parameters. Source localization is limited by the single-component nature of the data. However, curvature in the cable path can be exploited since cable sections with different orientations are sensitive to different parts of the wavefield. Moreover, it is feasible to instrument multiple cables thereby achieving area coverage from simultaneous and coordinated interrogation on linear cables.

POSTER 31

Full-Waveform Inversion with Distributed and Integrated Strain Sensing for Complex Cable Geometries

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Full-Waveform Inversion (FWI) is a powerful imaging technique with the potential to produce high-resolution models, typically on the basis of traditional seismometer recordings. The emergence of fiber-optic sensing opens the opportunity to capture the seismic wavefield with meter-scale channel spacing. However, as fiber-optic sensing measures one-dimensional strain over a line segment instead of displacement, the forward and adjoint formulations in FWI need adaptation.

This study presents theoretical and computational developments for FWI applied to distributed acoustic sensing (DAS) and integrated strain sensing in 3D for complex cable geometries. We perform numerical simulations using Salvus, a spectral element wave propagation solver that accounts for surface topography, water layers and visco-elastic/acoustic rheologies. In addition to arbitrary cable geometries, our forward modelling accounts for the gauge length, as well as direction- and curvature-dependent sensitivity.

To solve inverse problems, we present the formulation for adjoint sources for strain measurements. Using a synthetic dataset with coherent noise, we jointly invert waveforms measured on a curved DAS-interrogated cable placed on strong topography for seismic source parameters and the 3D wave speed distribution. Initially, we iteratively update the source location, time, and moment tensor to enhance the time-frequency phase misfit. Subsequently, we utilize the recovered source solutions to invert for the wave speed structure. By extending the gauge length to the complete cable length, we can apply the workflow to integrated strain sensing, and we present results for a similar setup.

In addition to the developments, we present real-data inversion results from various settings, including the Bedretto-Lab, the ice-covered volcano Grímsvötn, and a submarine cable connecting the Greek islands Santorini and Ios.

POSTER 32

Monitoring of Seismic Surface Waves in Trackside Dark Fibers Using High-Fidelity Distributed Acoustic Sensing

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Distributed Acoustic Sensing (DAS) is a fiber-optic sensing technology that transforms optical fiber telecommunication cables into arrays of thousands of broadband strain meters. The emergence of DAS has spurred numerous developments in a wide range of scientific domains, including geophysics and seismology, hydrology, and engineering. Modern DAS systems allow spatial resolutions of several meters, a range of several tens of kilometers, a sensitivity below 1 nε, and a sampling rate of up to several kHz. In seismology, these performances enable high-resolution detection of seismic waves originating from events such as earthquakes (both local and teleseismic) and local microseismic vibrations induced by trains or vehicles.

DAS has been used in railway monitoring for tracking vehicles and assessing rail conditions. Owing to its spatial and temporal density, DAS has significant potential for monitoring and control in high-speed railway systems. In this work, we use methods borrowed from array seismology to visualize seismic surface waves generated by trains and other vehicles passing close to a trackside dark fiber in detail. The relatively simple methodologies used here efficiently extract and characterize surface waves propagating along the railway superstructure.

The DAS data collected in trackside fibers can provide a significant amount of information about terrain features and railroad superstructure. These results highlight the capabilities of DAS systems in monitoring seismic surface waves and superstructure conditions in pre-installed fibers. The evolution of this information over time may provide significant insights for infrastructure owners, particularly in critical scenarios such as high-speed railway infrastructure. Moreover, the local dispersion relation for surface waves can reveal additional features and details of the superstructure that could be relevant for preventive maintenance.

POSTER 33

Comparison of DAS Recordings With a Calibrated Underground Strain Meter Array

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The power of distributed acoustic sensing (DAS) lies in its ability to sample deformation signals along an optical fiber at hundreds of locations with one interrogator only. While the interrogator is calibrated to record 'fiber strain', the properties of the cable and its coupling to the rock control the 'strain transfer rate' and such how much of 'rock strain' is represented in the recorded signal. We use DAS recordings in an underground installation (BFO observatory) colocated to an array of strainmeters in order to measure the 'strain transfer rate' in situ. A tight-buffered cable and a standard loose-tube telecommunication cable are used, where a section of both cables covered by sand and sandbags is compared to a section, where cables are just unreeled on the floor. The 'strain transfer rate' is largely independent of frequency in the band from 0.05 Hz to 1 Hz and varies between 0.15 and 0.55 depending on cable and installtion type. The sandbags show no obvious effect and the tight-buffered cable generally provides a larger 'strain transfer rate'. The noise background for 'rock strain' in the investigated band is found at about an rms-amplitude of 0.1 nstrain in 1/6 decade for the tightbuffered cable. This allows a detection of the marine microseisms at times of high microseism amplitude. We recently cemented a "naked" optic fibre into the concrete floor of the observatory and the collected data will be presenred, which should give new insight into the cable coupling an sensitivity limits of the DAS recordings.

POSTER 34

Amplitude Calibration for Distributed Acoustic Sensing

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Distributed Acoustic Sensing data is increasingly used to characterize near-source and far-field signatures of anthropogenic and natural sources. However, conversion from strain rate to particle velocity can be challenging in environments where near-field elastic properties and fiber coupling affect the recorded DAS signal. Calibrated signal amplitudes are critical for wavefield modeling efforts and quantitative interpretation of DAS data. We compare amplitudes of controlled-source signals, ambient noise, explosions, and earthquakes recorded on co-located fiber optic and nodal instrumentation and discuss optimal approaches for converting strain rate to ground motion. Variations in fiber geometry, emplacement, and signal frequency are analyzed to derive transfer functions between fiber and geophone data for different fiber arrays and source types. We show that while empirical relations for converting strain rate to acceleration are useful as a first order approximation, using a gradiometry-derived strain rate provides a more useful comparison. These results will inform future applications where well-calibrated amplitudes are required. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

POSTER 35

The Potential of DAS to Detect Long-Period Signals

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Compared to conventional seismometers, the unique capability of DAS to measure strain opens the door to observing long-period (> 100 s) signals, such as fault movements, tsunamis, ocean internal waves, and tides. Detecting signals is challenging at long periods because the self-noise of DAS increases almost linearly with period. Therefore, the signal and noise levels of DAS at long periods need to be evaluated for accurately detecting and analyzing long-period signals. To evaluate the ability to record long-period signals, we analyze DAS data at a variety of geological settings, from a volcanic region (Iceland) to the ocean bottom (offshore central California) and ice sheet (South Pole), where we observe both transient signals such as volcano eruptions and persistent signals like tides. We also discuss the different sources and levels of noise on DAS at these different settings and our efforts to reduce noise. Our results show the potential of DAS to complement existing geodesy and early warning (e.g., tsunamis and volcanic eruptions) instruments because it can leverage existing telecommunication fibers and has high spatial resolution.

POSTER 36

Distributed Acoustic Sensing (DAS) Calibration in a Laboratory Wellbore System

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Wellbore monitoring using Distributed Acoustic Sensing (DAS) is an emerging technique in the unconventional oil/gas industry and Carbon Capture

Utilization and Storage (CCUS). Calibrating the DAS measurements to accurately recover the wavefield during these processes, regardless of fiber geometry and coupling issues, is critical for field interpretation and operation. To explore the DAS calibration, ultrasonic waves were excited in a laboratory dual wellbore systems using monopole and dipole sources in a one wellbore, mimicking a production well. DAS data were collected using both armored and unarmored optic fiber cables in the adjacent monitoring wellbore. For comparison, we also deployed PZT sensor arrays in this system. Additionally, finite difference simulations were conducted to calculate the full waveform acoustic signals in this laboratory wellbore system. The DAS experimental data are calibrated using both simulated wavefields and the acoustic signal recorded by PZT sensors.

The use of both armored and unarmored optic fiber cables, along with the comparison to PZT sensor arrays, provided a comprehensive understanding of the DAS response. The findings highlight the potential of DAS for reliable wellbore monitoring in unconventional oil/gas and CCUS applications, emphasizing the importance of proper calibration to mitigate fiber geometry and coupling issues. This approach can significantly enhance field interpretation and operational decision-making in real-world scenarios.

Exploring the Frontier of Environmental Processes using Fiber-optic Sensing [Poster]

Poster Session • Wednesday and Thursday

POSTER 1

What Does free-floating fiber in a River Record? Insights from a DAS Deployment in Clear-Creek Colorado

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Fluvial seismology has the aim of using the seismic wavefield to infer parameters such as sediment transport and turbulence. A persistent challenge has been trying to untangle the different sources of seismic energy to be able to interpret the seismic data in terms of fluvial parameters. Using DAS to accomplish this goal introduces new opportunities and challenges, especially if the cable is free-floating. A free-floating cable is in direct contact with the flowing water and thus can be expected to be sensitive to the character of the flow. At the same time, the movement of the cable in the water will be a large source of the strain signal. Here, we describe the data recorded by a free-floating DAS cable in Clear Creek, Colorado. We find that different segments of the cable have distinct signatures in both the time and frequency domains. This is evidenced in the time-domain correlation matrix whose "blocky" character suggests distinct segments of the cable; with traces within each segment being much more similar to each other than to those in the adjoining segments. Segment boundaries correspond to locations where cable movement is restricted. In the frequency domain, a spatial spectrogram reveals distinct regions, that partially correspond to those defined by the correlation matrix. The most eye-catching feature of the spectrogram shows symmetrical spectral gliding in a part of the data dominated by high-frequency impulsive signals. Time-domain analysis and simple modeling strongly suggest that this is caused by the fiber hitting the bed with the resulting wave propagating along the cable and reflecting from pinned cable locations that correspond to segment boundaries. Sonorization of the data additionally reveals bubble-like signals in some segments of the cable. These are characterized by being high-frequency, nearly monochromatic signals recorded in individual channels. This study provides insights into what to expect in a free-floating DAS deployment. Future studies under more controlled conditions can build on these results to optimize data acquisition strategies.

POSTER 2

Using Co-Located DAS and Nodal Data to Interpret Flow Hydraulics and Sediment Transport During Flume Experiments

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One focus of environmental seismology studies has been to instrument river systems for the purpose of characterizing hydrological and sediment transport processes. Seismic data recorded along rivers include a range of signals, including from water turbulence and bedload transport. Using seismic records can be challenging because the various processes generate signals across wide frequency ranges, and we often have limited datasets to identify the right frequency bands for each process in natural systems. As a pilot project in spring 2024, we collected seismic and DAS data during controlled flow experiments within an outdoor flume at UT-Austin to capture seismic signals associated with hydraulic bore-style floods, turbulent water flow, and bedload transport. For the DAS data, we installed 214 m of cable both within and adjacent to the concrete flume and used an OptaSense ODH4+ interrogator from the UT-Austin NHERI group to collect data sampled at 10 kHz with a spatial sampling interval of 1.02 m and a 2-channel gauge length. We also installed a set of eight high frequency (5 Hz corner, 2000 Hz sampling) three-component nodal seismographs adjacent to the flume structure. DAS cable installation methods (caulk, tape, burial) varied depending on location within the flume, on concrete or in grass adjacent to the flume. We present data to demonstrate frequency ranges that dominate for each flow process as well as provide comparisons between the DAS recordings and data from the adjacent buried nodes to highlight variations in deployment techniques.

POSTER 3

Detection of an Artificial Meteoroid Via Distributed Acoustic Sensing

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On September 24, 2023 the OSIRIS REx space capsule returned through the earth's atmosphere, crossed over California and Nevada, and landed in Utah. Along its path, the capsule generated infrasonic signals. The entry provided an excellent opportunity to develop and test a rapid deployment of fiber-optic cables to be sensed with distributed acoustic sensing (DAS) interrogators. We deployed 12 km of optical fiber at two locations in Eureka, Nevada, chosen for its proximity to the predicted point of highest heating. At each location, we deployed three co-located seismometers and infrasound sensors to inform interpretation of DAS data. For nearly the entire fiber length, we placed the fiber directly on the ground without any trenching or weights to increase ground coupling. We used three different interrogators to sample the fibers at the two locations: an AP Sensing sampled 4.5 km of fiber at the Eureka Airport and a Silixa and an Optodas sampled 7.5 km of fiber in nearby Newark Valley. Two different types of optical fiber composites were utilized, one with an armored jacket, and one with a polyurethane jacket. We observed a noticeable difference in the signal quality between the two locations and between the two optical fiber composites. Furthermore, since the optical fiber could not be feasibly buried, we have observed signatures of both acoustic and ground-couple seismic signals generated from the space capsule. Signals from the space capsule were successfully captured in both locations, and the DAS data revealed phases that would otherwise be difficult to distinguish with traditional point sensors. These results will aid in developing rapid deployments of DAS systems in remote environments for unique events.

POSTER 4

Forecasting Coastal Cliff Collapse Using Distributed Sensing

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Coastal erosion is widespread and for cliff coasts, much existing protection is expected to be abandoned (1). Cliff-top communities will have to live with increased erosion risk, making it crucial to understand erosional processes, including how and when they might threaten cliff-top buildings and other infrastructure, to facilitate sustainable management of defences and other resources. Local authorities are trying to address this challenge. However, it is currently difficult to forecast where and when hazardous collapses will occur, rendering management and mitigation of the risk extremely challenging.

Traditional methods of subsurface monitoring are restricted in either time or space. Distributed Sensing is a new technology that utilises optical fibre. Our system includes a distributed acoustic sensor (DAS), distributed strain sensor (DSS), and distributed temperature sensor (DTS). In Summer of 2023, we deployed 2 km of fibre optic cable on the North Norfolk Coast to monitor coastal processes with this suite of interrogators.

Using machine learning techniques, we are constructing a database of nano-earthquakes associated with subsurface cracking with a view to develop a real-time map to show regions that are more seismically active and therefore more likely to see movement. Combining DAS signals with drone-based differential photogrammetry, we are also creating a local magnitude scale for rockfalls that reflects the volume of rock affected. This can be used to alert local residents, landowners and managers of emerging hazards.

To elucidate mechanisms of cliff weakening and failure, we are using strain and temperature profiles and ambient noise from the nearby crashing waves to tomographically monitor the geomechanical properties of the subsurface as they evolve. We hypothesise that dessication cracking and groundwater flow play significant roles in modulating cliff retreat.

(1) Committee on Climate Change, "Managing the coast in a changing climate" (2018).

POSTER 5

Automatic Monitoring of Rock-Slope Failures Using Distributed Acoustic Sensing and Semi-Supervised Learning

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Distributed Acoustic Sensing (DAS) represents a leap in seismic monitoring capabilities. Compared to traditional single-seismometer stations, DAS measures seismic strain at meter to sub-meter intervals along fiber-optic cables thus offering unprecedented temporal and spatial resolution. However, the effective use of the wealth of information provided by DAS for natural hazard and in particular mass movement monitoring remains a challenge.

We propose a semi-supervised neural network tailored to screen DAS data related to a major rock collapse on 15 June 2023 and precursory failures near Brienz, Eastern Switzerland. Besides DAS, our dataset from 16 May to 30 June 2023 includes Doppler radar data for ground-truth labeling. The proposed algorithm is capable of distinguishing between rock-slope failures and background noise, including road and train traffic, with a detection precision of over 90%. It identifies hundreds of precursory failures and shows sustained detection hours before and during the major collapse. Moreover, we have identified key performance dependencies: event size and signal-to-noise ratio (SNR). As a critical part of our algorithm operates in an unsupervised way we suggest that it is suitable for general monitoring of gravitational hazards.

The major collapse is characterized by strong low-frequency signals between 0.01 and 0.03 Hz across multiple channels of the cable's trajectory-parallel section. Most of this low-frequency energy arrives after the high-frequency signal. Our initial hypothesis is that the low-frequency signal relates to a bulk mass moving downslope. However, the Doppler radar does not fully capture this movement, possibly due to radar insensitivity immediately following the collapse. Further investigation will focus on force-history inversion to study the seismic source mechanisms during the major collapse.

POSTER 6

Characterizing Environmental Noise in Hypersonic Object Detection: Insights from a Fiber Optic Cable Deployment

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Infrasonic and seismic signals generated by hypersonic objects transiting Earth's atmosphere provide critical information to classify the arriving object as natural or anthropogenic. Historically, these sound waves have been recorded by permanent arrays of widely separated seismometers and infasound instruments. During the 24 September 2023 reentry of the OSIRIS-REx space capsule, a total of 12 km of fiber optic cable was deployed at two sites in Nevada, which each sampled the capsule's acoustic wavefield with high spatiotemporal resolution by utilizing Distributed Acoustic Sensing (DAS) technology. A straight-line cable array and a T-shaped array were deployed during the span of a few days directly onto the surface, exposing the cable to environmental forcings which may have induced signal distortion. Three separate Interrogator Units (IU's) were used to capture DAS data, and multiple seismometers and infrasound sensors were co-located along the cable to inform our interpretation of DAS data and environmental noise sources. Here, we sample portions of the dataset recorded prior to the capsule arrival to investigate environmental sources affecting signals in the 5-100 Hz range which vary with the time of day, such as temperature, solar exposure, and wind speed. We quantify the signal distortion frequency range, intensity, and triggering factors to identify which noise sources may have impacted the spectral signature of the capsule arrival data. Finally, we compare the variations in noise captured by the three IU's to determine which systems performed best given the most significant noise sources. Our results have implications for mitigating the impact of environmental noise sources in DAS datasets to better constrain target signals. Characterization of these noise sources will also aid in efforts to advance future design and operation of DAS in remote and extreme environments where large temperature and wind variations affect signal acquisition.

POSTER 7

Local Variations in Microseisms Recorded off the Coast of Sicily

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Microseisms induced by ocean waves define a unique interaction between the sea and solid Earth, with associated seismic surface waves dominating global ambient seismic noise records. The use of fibre optic sensing provides a new exciting way for detailed characterisation of microseism signals at an unprecedented spatial resolution. For instance, an improved understanding of microseism sources and signals, not only benefits seismic passive imaging and monitoring of active processes in the marine environment, but can also help track storm events. In November 2023, DAS (Distributed Acoustic Sensing) data were recorded on two cables from the INFN-LNS submarine infrastructure located offshore Catania and Capo Passero in the Western Ionan Sea. Long-term trends in the DAS data on specific channels along each cable show continuous microseism noise but also the presence of short-term high frequency (>1Hz) events which seem connected to the wind wave activity in the area. Tremors from Etna observed during acquisition overlap those signals and need to be taken into account for a better characterisation of microseism sources. In addition, whereas the wind waves' signature is limited to the shallower sections of the cables, we observe that microseisms are present over the whole length of each cable, with their energy fluctuating as a function of water depth but also cable coupling with the seafloor. Taking advantage of the dense spatial sampling of the DAS data, f-k analysis applied for shorter time windows enables both ocean waves and seismic wavefields decomposition (e.g. landward vs seaward separation of signals) over different sections of the cables. Despite the two cables being geographically close (~150km apart), the microseism signals recorded offshore Catania show more complexity compared to Capo Passero. This observation implies a change in the local microseism sources but also highlights the influence of significant local site effects (e.g. water depth, sub-seafloor velocity structure) on the recorded seismic surface waves which vary over short regional distances.

POSTER 8

Looking into a Disappearing Glacier: An Active Source DAS Experiment on Langjökull Ice Cap

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The rate at which glaciers lose ice mass is highly controlled by properties within the ice and at the base, such as temperature, composition and mechanical strength of material at the basal interface, and presence of meltwater within the glacier. With the seemingly accelerating disappearance of glaciers in response to climate change, insight into this process is necessary. However, this information is buried under hundreds of meters of ice. Therefore, indirect methods such as seismology give us a non-invasive way to probe the base of glaciers. While traditional geophone arrays can help recover these properties, the short wavelength heterogeneity expected in ice cannot be resolved and, in harsh environments, deployments become increasingly difficult. Distributed Acoustic Sensing (DAS) provides a logistically simpler deployment alternative suited for glacial environments as well as high density coverage for meter-scale resolution.

Langjökull is a quickly disappearing ice cap in Iceland, losing an estimated 11% of its mass from 1997-2010. The ice cap is also known to host surge events at its southern outlet glaciers where the terminus can advance by over a kilometer in a season, making it a potential hazard to the surrounding communities. Radar techniques have been unable to provide constraints on the rock properties at the base making the origin of these surges unclear, though the proximity to the volcanic zone could indicate porous rock which may be conducive to sliding. In May 2024, we performed an active source survey on a DAS array at Langjökull Glacier. Using a combined plow-deployment system, we are able to deploy the cable without the need for manual trenching. The active source data collected helps us to learn about the feasibility of a short-term DAS glacial deployment, as well as the englacial and subglacial properties which help control glacial mass loss and surge behavior.

POSTER 9

DAS Observations of Ice-Wedge Cracking in Utqiagvik, Alaska

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Ice wedge polygons are among the most distinctive landforms in permafrost regions. Conceptually, they form when freezing ground undergoes thermal contraction cracking during winter, followed by crack filling during the spring snowmelt. However, there is a lack of field observations hindering the understanding of cracking dynamics. In this study, we report over two thousand strong seismic signals throughout the winter months identified in the continuous recordings of yearly-deployed distributed acoustic sensing (DAS) system. These signals are characterized as short-duration events, with center frequencies ranging from 5 to 30 Hz. The events present body wave arrivals closely followed by surface waves, indicating a source near the installed fiber. We found a strong correlation between the daily occurrence of these events and periods of extremely low ground temperatures. Consequently, we interpret these events as cryoseisms originating from the permafrost. During periods of intense cold, thermal stress within the frozen ground can induce tensional fracturing, resulting in the sudden release of stress in the form of seismic waves, known as frost quakes. Through analysis of each event's move-out, we were able to distinguish the relative source locations. Our findings reveal distinct seismicity patterns between wet tundra and dry tundra environments. Finally, we modeled elastic wave propagation to examine the source mechanisms and compared several potential mechanisms for generating local seismicity within the permafrost with the observed waveforms. This research presents an innovative method by using DAS for monitoring and analyzing the dynamics of thermally fracturing frozen ground in the changing Arctic environment.

POSTER 10

Correlation of DAS Strain Data and Oceanographic Variables in the North-East Atlantic

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DAS recordings close to the coast are influenced by pressure signals from land- and seaward ocean surface gravity waves. The amplitude and period of the signal can be interpreted as a proxy for the sea state. Measurements along the cable at larger water depths show secondary microseisms related to the sea state away from the shore. The significant wave height (SWH) and ocean currents along the cable can be evaluated continuously during the experiment, resembling a dense sampling array of closely spaced buoys. However, in order to provide serviceable results, the measurements have to be calibrated with existing buoy or wave model data.

In October 2023, the GeoLab dark fibre off Madeira Island in the Atlantic was fitted with a DAS interrogator under a project by ARDITI and the Oceanic Observatory of Madeira. As a pilot site, the experiment is linked to the SUBMERSE project that is trying to establish continuous DAS monitoring along fibre-optic cables at multiple locations around Europe.

We use a one-week recording in late 2023 to show changes in the DAS data close to the shore where the water depth is small, and temporal variations of the secondary microseisms further along the cable. Spectrograms of individual channels and f-k spectra of different time intervals show effects of varying sea states, such as currents on the dispersion curves between land- and seaward waves.

To calibrate the measurements, the data are compared with measurements from a buoy located close to the coast and the DAS cable. In addition, we use model data from the Atlantic-Iberian Biscay Irish-Ocean Wave Analysis and Forecast model (0.05 x 0.05 deg; Toledano et al., 2022), which shows good correlation with the buoy data.

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POSTER 11

Distributed Acoustic Sensing of Debris Flow Dynamics at Illgraben, Switzerland

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We explore the possibility of using distributed acoustic sensing (DAS) for debris flow monitoring in the Swiss Alps. Data were obtained during the summer months of 2022 at the Illgraben debris flow observatory maintained by the Swiss Federal Institute of Forest, Snow and Landscape Research WSL in the Rhône valley. We connected a Silixa iDAS interrogation unit (1000 Hertz sampling frequency, 2 meters channel spacing, 10 m gauge length) to a pre-existing 450 m long dark fiber. This fiber belongs to a telecommunication network connecting households of Illgraben's inhabited debris cone and locating within a few tens of meters of the torrent. On September 8th 2022 we acquired, to the best of our knowledge, the first DAS record of a full-scale debris flow.

The debris flow had an estimated total volume of about 9000 cubic meters and a maximum discharge of about 20 cubic meters per second. We were able to detect debris flow signals 4 kilometers away from the dark fiber when the debris flow was mobilizing in Illgraben's upper catchments. The seismic record is characterized by high frequency (> 1 Hz) signals commonly attributed to particle-ground impacts. In addition, we detect low frequency (< 0.1 Hz) signals, which we interpret as the elastiostatic ground deformation resulting from the weight of the moving mass of the debris flow. Further, we observe flow instabilities commonly termed "roll waves" in our DAS data. Using low frequency (< 0.1 Hz) elastiostatic signals produced by roll waves, we

can trace individual roll waves along the cable and determine their velocities as a function of flow depth.

Our study benefits from various point measurements along the torrent, including flow depth gauges, basal force plates and velocity sensors. The combination with distributed measurements, in our case DAS data, demonstrates that existing fiber-optic infrastructure can enhance monitoring and warning capabilities, offering novel insights into the dynamics of debris flows difficult to capture with conventional sensors.

POSTER 12

Fiber-optic Observations of Wind-induced Gravity Waves in Lake Ontario

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The Great Lakes region lacks in-situ observations during the winter season due to surface instrument withdrawals (e.g., buoys) to avoid damaging them from extreme weather. As a result, there is a critical observational gap during a large period of the year. To circumvent that, we propose to use Distributed Acoustic Sensing (DAS) measurements using telecommuting fiber-optic cable at the bottom of the lake as it can help acquire year-round observations in the lakes. Here, we installed a DAS interrogator along a telecom infrastructure between Toronto and Lockport to measure strains in the first 50 km of the underwater cable. The DAS array has nearly 5000 channels with 10-m spacing measured between May 2023 and March 2024. The preliminary results show that the DAS detected distinct signals from wind-induced gravity waves, including microseisms and infragravity waves. Especially, amplitudes of the microseisms between 0.2 and 2 Hz correlate to water level heights observed in Toronto and Olcott. In addition, the high-resolution measurements from this dense array also depict details of the wave motions, such as wave propagation, dispersion, and wave-wave interactions in the lake, providing unique observations for understanding the dynamic processes of the wind-driven waves. Such signals can further be utilized to monitor massive waves generated by storm surges, seiches, meteotsunamis, among others.

POSTER 13

Long-Term Analysis of Cryoseismic Events and Earthquakes at the South Pole Using Distributed Acoustic Sensing

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Polar and glacial seismology plays a crucial role in exploring the dynamics of the cryosphere and lithosphere, and in studying their impacts on, and responses to, climate change. However, the understanding of Antarctic seismicity remains limited due to the lack of field observations from dense seismic networks, as logistical challenges hinder the deployment and maintenance of seismic stations in Antarctica's remote and harsh environments. For instance, the Quiet South Pole Antarctica (QSPA) station is the only permanent seismic station within a 12-degree radius of the South Pole. In this study, we deployed a long-term distributed acoustic sensing (DAS) array along a pre-existing fiber optic cable between the Amundsen-Scott South Pole Station and the QSPA station. This 8-km optical fiber was converted into a dense array of thousands of strain sensors, recording continuously since January 2023. Utilizing one year of data from the South Pole DAS and the QSPA station, we built a seismic activity catalog for the South Pole region. We identified local cryoseismic events, including ice quakes and firn quakes. We documented swarms of firn quakes that exhibited strong correlations with local weather. We also detected regional tectonic earthquakes up to hundreds of kilometers away. By applying array processing techniques to the DAS data, we enhanced the characterization of these earthquakes. Our findings highlight the potential of DAS to advance the detection and understanding of seismic activity in polar and glacial regions.

Filling the Data Gap: Ocean-bottom Sensing with Fiber-optic Cables [Poster]

Poster Session • Wednesday and Thursday

POSTER 14

How Cable Architecture Influences Distributed Fiber Optic Sensing Along a Submarine Cable Offshore Catania

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Seismological sensors are predominantly found on the 30% of the Earth's surface that is on-land. Distributed Fibre Optic Sensing (DFOS) using submarine telecom cables offers a means to bridge this observational gap. Cables come in different designs, where fibers sit in gel (loose fibers) or are layered with an acrylate coating (tight fibers). The design can change the energy transfer from the surface of the cable to the fibers, impacting the measurements. We examine this effect using the 6 km-long FOCUS cable located 29 km offshore Catania in 2 km water depth. This prototype cable contains three tight fibers at its center and two loose fibers coiled around them. One loose and two tight fibers are connected in series and loop in the cable allowing one interrogator to sample the same location using the different fiber configurations. We compare the performance of the loose and tight fibers as a strain rate sensor using DAS data collected in November 2023. With a local ML 3.3 earthquake we show that, on average, the energy transfer is greater on the tight fiber and is frequency dependent: 25% more energy is transferred to the tight fiber compared to the loose fiber in the 0.1-2.5 Hz range, but this decreases to 13% in the 10-12.5 Hz range. This previously unreported result shows how cable structure affects DAS records. We perform a similar analysis for static strain using a BOTDR interrogator on the same cable, recording since October 2020. We have observed one natural deformation (causing ~40 $\mu\varepsilon$), bag drops on the cable (~200 $\mu\varepsilon$), and an abrupt pulling of the cable end (~400 $\mu\varepsilon$). Strain measured along the tight fibers was two to ten times larger than that measured on the loose fiber. Controlled loading experiments in a laboratory on the FOCUS cable confirm these observations as the tight fiber consistently deforms 200% more than the loose fiber. In tight fibers, amplitude loss is 0.26 db/km vs the 0.19 db/km in loose fibers, reducing the coverage of DFOS by 40 km. However, better energy transfer favors tight fibers over loose fibers for sensing both strain and strain rate.

POSTER 15

Application of Distributed Acoustic Sensing for Fin Whale Calls Detection and Localization

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Detecting and locating marine mammals such as fin whales is critical to understanding their behavior and protecting their habitats. Traditional methods of monitoring using visual observations and tagging are limited in coverage and can be usefully complemented by acoustic methods. Fin whales are well suited for acoustic monitoring because males produce a stereotypical, 1-second, 20-Hz, down-swept chirp that is incorporated into songs associated with breeding and observed in non-song vocalizations in migratory groups. However, the deployment of dedicated hydrophone arrays is expensive. Distributed Acoustic Sensing (DAS) is an emerging technology that shows promise for passive acoustic monitoring of marine mammals in real

time. DAS uses fiber optic cables as sensors by exploiting Rayleigh scattering, allowing continuous monitoring over distances of up to ~100 km with an unprecedented resolution of tens of meters. For 4 days in November 2021, a public domain DAS dataset was collected on the two submarine cables of the Ocean Observatories Initiative Regional Cabled Array that extend offshore Pacific City, Oregon. This experiment took place during the fin whale breeding season, and tens of thousands of 20 Hz calls are present in the data. The dataset includes DAS measurements on three fibers extending 65-95 km with 2 m channel spacing. In this study, we demonstrate a scalable example of detection and localization. Different detection techniques have been explored, from classical methods such as matched filtering and spectrogram cross correlation, to image processing, exploiting the new possibilities of DAS time-space representations. Due to the performance of spectrogram correlation, the final detection combines Gabor filters on the recorded wave field envelope and single channel matched filtering. This provides a set of detection times for automated localization using the time difference of arrival method. Scaling these techniques to the full dataset for tracking the whales and inferring their behavior will also be discussed. [Work supported by ONR].

POSTER 16

SeaFOAM : A Permanent Offshore DAS Deployment in Monterey Bay, California

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Seafloor Fiber-Optic Array in Monterey Bay (SeaFOAM) is a permanent offshore DAS deployment in Monterey Bay, California, with the purpose of seismic monitoring and beyond. We apply DAS to a 52-km long submarine cable maintained by Monterey Bay Aquarium Research Institute (MBARI), starting from August 2022. We have explored the dataset for seismic and ocean waves, subsurface structure, and relative instrument response.

We have recorded a large number of local and teleseismic events with broadband observations. A workflow has been developed to detect and characterize earthquakes in real-time for the purpose of earthquake early warning, including a machine learning-based phase picking model and an integrated methodology that synergizes DAS with traditional seismic stations onshore. We also observed scattering waves from offshore San Gregorio Fault zones and resonance effects from underwater basins. We analyzed infragravity waves recorded during strong winter storms at different water depths. A coherency analysis in frequency domain is applied to explore characterization of frequency-dependent instrument responses of individual DAS channels. We show that this unique submarine DAS array can enhance local earthquake and fault monitoring as well as offer new insights into mechanisms of both oceanic processes and ocean–solid earth interactions.

POSTER 17

Feasibility Study: Integrating Fiber Optic Sensing into the NEPTUNE Cabled Observatory for Enhanced Ocean Monitoring and Earthquake Early Warning

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Ocean Networks Canada's NEPTUNE Cabled Seafloor Observatory offers an excellent opportunity to enhance ocean-bottom monitoring and Earthquake Early Warning (EEW) through fiber optic sensing, including Distributed Acoustic Sensing (DAS), Distributed Strain Sensing (DSS), and Distributed Temperature Sensing (DTS). The observatory consists of an 800 km cable loop off Vancouver Island, B.C., Canada. We will explore three strategies for integrating fiber optic sensing with NEPTUNE: (1) utilizing the existing cable loop, (2) deploying a dedicated sensing cable along the offshore subduction zone, and (3) laying a dedicated sensing cable from the Port Alberni shore station. The first strategy is limited by the shore station in Port Alberni being 70 km inland, reducing DAS effectiveness to the first repeater at approximately 100 km (30 km offshore). The second strategy involves a custom-designed cable for comprehensive sensing (including pressure, temperature, and DAS) positioned based on scientific needs. Despite high scientific potential, this approach is costly and relies on emerging technology. The third strategy could offer detailed tsunami warnings for Port Alberni, a region with a history of destructive tsunamis.

Our primary goal is to investigate the technical feasibility, costs, and funding opportunities for these options and to identify scientific use cases. Integrating fiber optic sensing with NEPTUNE would complement existing offshore seismometer networks, geodetic instruments, and oceanographic capabilities, and would enhance EEW for Canada's west coast. It would also be strongly synergistic with parallel efforts to implement fiber optic sensing on the Ocean Observatories Initiative Regional Cabled Array offshore central Oregon.

We aim to facilitate discussions on feasibility, scientific benefits, and future directions, leading to well-informed and competitive funding proposals.

POSTER 18

Potential and Challenges in Body Wave Travel Imaging From an Offshore Telecommunication Fiber in Southern Alaska

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Strain data recorded along telecommunication fibers with Distributed Acoustic Sensing (DAS) have been shown to capture the full extent of the seismic wavefield. Seismic interferometry, which extracts the propagation surface waves between seismic stations, has been used to provide high-resolution images of the shear-wave velocity of the shallow subsurface below fiber-optic cables. Nevertheless, additional constraints on the 3-D structure could be obtained from P- and S-wave travel times from earthquakes. We probed 50 km of a telecommunication fiber deployed offshore Cordova, Alaska, and recorded continuous data for four months in 2022. We pick direct P- and S-wave arrival times from regional earthquakes recorded along the fiber with a 10 m spacing. We combine the travel time measurements with ten years of travel time picking from the Alaska regional network near the region of interest. We invert the measurements by using the fast-marching tomography (FMTOMO) approach to build a new 3-D velocity structure. We discuss our preliminary results as well as the advantages and limitations of the proposed inversion method to improve regional seismic velocity models using DAS.

POSTER 19

Trans-dimensional Inversion of Multi-mode Dispersion Curves From Ocean Bottom Distributed Acoustic Sensing

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The development of the Distributed Acoustic Sensing (DAS) technology with the acquisition of high spatio-temporal seismic data along fiber-optic cables provides an opportunity to achieve high-spatial resolution imaging of the subsurface. Generally, imaging the shallow crust and sediment layers can be difficult using passive seismic approaches, especially offshore due to the lack of station coverage. This study takes advantage of continuous strain data recorded in 2022 along 50 km of a telecommunication fiber deployed offshore Cordova, Alaska. We use two weeks of data to compute cross-correlation functions along the cable and extract Scholte-wave dispersion data. We quantify the shear-wave velocity profile of the sediment layers and shallow crust to ~2 km below the seabed from the inversion of high frequency Scholte-wave dispersion curves. From the data collected between May 04 and May 15, 2022, we extract the fundamental and higher modes phase velocities and invert these jointly with a trans-dimension model. The approach quantifies parameter uncertainties and data errors. The results provide new constraints on the sediment characteristics and origins in this region. We will discuss the implications in terms of sediment transport and mixing but also the potential of underwater landslides associated with these sediments.

POSTER 20

Wavefield Reconstruction of Distributed Acoustic Sensing: Compression, Wavefield Separation, and Edge Computing

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Distributed Acoustic Sensing (DAS) is a new seismic observation method. DAS dramatically expands the ability of dense seismic observation and has been used for ocean observation, sub-surface imaging, volcano monitoring, and earthquake characterization. While the high rate of data benefits research analysis, they are problematic for data transmission and storage and limit the real-time or large-scale application of DAS. Data compression algorithms accelerate the transmission by transforming the raw data into smaller sizes, however, at the cost of more computing time and data distortion.

In this study, we explore wavefield reconstruction using Deep Learning (DL) methods for wavefield compression, reconstruction, and separation. We test SHallow REcurrent Decoder (SHRED) that generalizes over space and time for a single optical fiber with 20% decimated channels for the reconstruction. Despite good performance in reconstructing long-wavelength features, our model does not reconstruct transient earthquake wavefields at shorter wavelengths, limiting its usability for seismic data transmission. Nevertheless, we leverage wavefield reconstruction of ocean waves to separate them from the seismic wavefield and improve seismological use cases for earthquake detection and Earth imaging. At last, we evaluate the model accuracy, adaptivity, computing expense and generalizability on the Cook Inlet DAS experiment.

POSTER 21

Denoising Offshore Distributed Acoustic Sensing Using Masked Auto-encoders to Enhance Earthquake Detection

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Offshore Distributed Acoustic Sensing (DAS) has emerged as a powerful technology for seismic monitoring, expanding the capacities of cable networks and coastal seismic networks to monitor offshore seismicity. However, DAS data often combine signals unfamiliar to seismologists, including new types of instrumental noise, fiber cable coupling issues, and ocean signals that overprint those from tectonic sources, all of which hinder seismological research. We develop a self-supervised deep learning algorithm, a Masked Auto-Encoder (MAE), to denoise DAS data for seismological purposes. The model is trained on randomly masked DAS channel recordings of local earthquakes in the Cook Inlet, offshore Alaska. To demonstrate the benefits of denoising for seismological research, we conduct the most fundamental steps to any earthquake catalog building: seismic phase picking, signal-to-noise ratio estimates, and event association. We leverage the generalizability of ensemble deep learning models with cross-correlation to predict phase picks with sufficient precision for post-processing (e.g., earthquake location). The signal-to-noise ratio (SNR) of the denoised testing DAS data increased by 2. The MAE denoised DAS data allows manyfold more S picks than the original noisy data for smaller regional earthquakes. The results demonstrate that our self-supervised MAE holds significant potential for enhancing seismic monitoring with rapid earthquake characterization.

POSTER 22

Mapping Ocean Surface Gravity Waves in the Coastal Ocean with Distributed Acoustic Sensing from Seafloor Fiber Optic Cables

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Distributed Acoustic Sensing (DAS) provides a novel opportunity to turn coastal seafloor fiber optic cables into high-resolution surface wave measurement arrays. A DAS interrogator connected to the shoreward end of a submarine cable records strain or strain-rate of the cable, which responds to variations in seafloor pressure (as well as acoustic and other waveforms in the water column). Strain can be measured on meter-scale spacing over 10s to 100s of kilometers, which enables the cable to act as a series of thousands of seafloor pressure sensors. Studies so far use empirical methods for conversion of DAS strain spectra to pressure spectra, which can then be used to calculate surface wave parameters. Comparison between six DAS datasets ranging from nearshore to continental shelf regions in Alaska, Hawaii, Massachusetts, North Carolina, and Oregon provides insight into the fundamental controls on submarine strain. The raw strain recorded in each experiment varied over 4 orders of magnitude. Variations between sites could not be explained by water depth, wave conditions, or interrogator settings alone, and suggest that cable characteristics and burial depth are the most important factors controlling strain magnitude and measurement quality. The empirically-calculated correction factors varied over 10 orders of magnitude, yet the site-specific empirical calibrations provided accurate calculations of wave height and period. With a simple calibration, DAS can provide a particularly appealing method for observing spatial and temporal changes in wave conditions in regions with high spatial gradients. We provide two examples of such high-gradient environments: the seasonally ice-covered Arctic shelf, and a mid-latitude surf zone. DAS can be used to produce maps of wave processes such as reflection and attenuation that provide new insight into the physics of the coastal system.

POSTER 23

Near-coast Subsurface Imaging with Distributed Acoustic Sensing and Double Beamforming

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The high cost of active surveys and the scarcity of underwater passive instruments hinder seismic imaging in oceanic environments Ocean-bottom Distributed Acoustic Sensing (OBDAS) along telecom infrastructure is an alternative and economical approach to illuminate the subsurface at unprecedented resolution and over distances of tens of kilometers. In this study, we utilize OBDAS data along a 50-km cable perpendicular to the coast of Oregon to image the continental shelf subsurface using ambient seismic field (ASF). First, we extract surface waves propagating both landward and seaward via ASF noise cross-correlation and coherent stacking. Then, we apply a 1D double-beamforming (DBF) workflow to measure the phase velocities of surface waves across different array subsections and to improve the quality of the dispersion curves in the 0.2-3 Hz band. Afterwards, we use a Density-Based Spatial Clustering method to extract multi-modal dispersion curves from each beam. Finally, we adopt a perturbational-based inversion scheme to reliably invert for S-wave velocities over the first 200 meters of the sediment underlying the fiber-optic cable. Our results demonstrate the applicability of the DBF method on the OBDAS dataset and illustrate the enhanced spatial resolution of this approach.

POSTER 24

Event Detection Threshold on Submarine Fiber Optic in the Arctic

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Distributed Acoustic Sensing (DAS) is increasingly leveraged for event detection at local, regional, and teleseismic scales for both earthquakes and anthropogenic sources. Despite the abundance of telecom submarine fiber optic, a very limited number are accessible to the event monitoring research community. In Alaska, we interrogate a segment of submarine dark fiber optic cable, approximately 37 km, extending northward into the Beaufort Sea from Oliktok Point. Since 2023, this cable has enabled us to continuously monitor seismic events, capturing hundreds of events ranging from local to teleseismic epicentral distances. Preliminary analyses indicate that this system can reliably detect teleseismic events of magnitude 4 and higher and local events down to magnitude 1 across a variety of back azimuths. Variations in cable depth beneath the seafloor and the presence of ocean surface ice do not have a significant impact on signal recovery. However, the cable's geometry affects the signal amplitude for specific back-azimuths, distances, and hypocenters, particularly across the change in fiber orientation from N-S to NNW to SSE approximately 5 km offshore. We observe significant signal attenuation beyond 35 km distance along fiber, likely due to scattering and other nonlinear effects. Additionally, a one-way repeater at the end of interrogatable section of fiber will not allow signal recovery from the backscattered light and acts as a hard limit for detection along the fiber. This research demonstrates that DAS data recorded on submarine fiber optic can be used to monitor both natural and anthropogenic signals from local to teleseismic distances, demonstrating the potential to bridge data gaps in regions currently lacking coverage from conventional arrays. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

POSTER 25

Advanced Monitoring Techniques for Mitigating Induced Seismicity in Offshore Subsurface Energy Projects: A Case Study from the CASTOR Gas Storage Site

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The scientific evidence of climate change has led to new energy policies aiming for a carbon-neutral economy by mid-century. Renewable energies, energy storage systems, and carbon footprint reduction are crucial for these goals. Subsurface fluid injection is common in these projects, including green hydrogen storage in salt caverns and CO_2 storage in porous rock formations. Offshore geothermal energy production also involves deep underground water injection. Induced seismicity is a global concern in fluid injection projects, necessitating risk assessments for future operations. Fluid injection changes crustal stress, generating earthquakes whose frequency and magnitude vary with the injection rate. Long-term monitoring plans are essential for these multi-decadal, capital-intensive projects. Mitigating induced seismicity involves addressing four major issues: studying natural seismicity to evaluate fault activity, preventing injection-triggered faults, ensuring underground storage integrity, and managing moderate induced seismicity to prevent social alarm. Offshore storage sites, though challenging for seismic monitoring, reduce risks by being far from populated areas.

Effective monitoring integrates optical fiber cables with Distributed Acoustic Sensing (DAS) systems and AI algorithms for seismic detection, analysis, and location. This technology provides high-density seismological records, being an unparalleled tool to unravel the active tectonics of a target region. This approach was tested at the CASTOR offshore gas storage site, where significant induced seismicity occurred in 2013 due to gas injection. The facility, now in a phase of hibernation, was monitored for three months in 2023 using DAS on a telecom fiber optic cable connecting the offshore platform with the land facility. We recorded and located low-magnitude earthquakes under the platform, undetected by the national seismic network. This successful implementation highlights the potential of advanced monitoring technologies in ensuring the safety and viability of critical energy projects.

POSTER 26

Mining Ocean Bottom Distributed Acoustic Sensing data with 2D Scattering Network

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Distributed Acoustic Sensing (DAS) data provide unprecedented 2-D spatio-temporal information about the seismic wavefield. While a large variety of signals from both natural and anthropogenic sources has been identified in DAS data in various environments, new signals and/or hidden patterns are still likely to be discovered due to the vast amount of data generated by the technology. Deep scattering networks, which are equivalent to convolutional neural networks with convolutional filters restricted to wavelets, have been shown to be a very powerful tool to discriminate complex seismic signals recorded by seismometers (i.e., Seydoux et al., 2020). In this work, we extend the 1-D scattering network approach to two dimensions to incorporate the spatio-temporal information from DAS data. The 2-D scattering network approach, which takes advantage of 2-D wavelets, is applied to time-distance images of DAS data to accurately represent the variations of the signals propagating across the array with different frequencies. Independent Component Analysis (ICA) is then used to capture the most significant features provides by the 2-D scattering representation of the data and hierarchical clustering is applied to group similar signals in an unsupervised manner. We apply the clustering technique to five months of continuous DAS data recorded offshore Cordova, AK, and show that a large variety of transient signals (i.e., earthquakes) and slow water movements from the water column can be clustered.

POSTER 27

DeepDAS: Earthquake Phase Picker from Submarine Distributed Acoustic Sensing Data

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The EU-INFRATECH funded SUBMERSE project will establish continuous monitoring of several oceanic telecom cables for landing sites in Portugal, Greece, and Svalbard. We develop tools for the automated analysis of these upcoming data sets as well as other submarine DAS data. Employing DeepLab v3, a cutting-edge deep neural network architecture renowned for its exemplary performance in semantic segmentation, this project aims to develop a specialized machine learning model for the detection of earthquakes and the identification of P and S waves using submarine DAS data. The inherently two-dimensional nature of our input data mandates the adoption of DeepLab v3.

Confronted with the distinctive challenges posed by submarine DAS data, which encompass varied oceanic noise environments and a spectrum of operational parameters including cable length, configuration, channel spacing, deployment conditions, and geographic diversity, we have chosen to implement a more expansive model to enhance detection capabilities. This project exclusively utilizes submarine DAS seismic records, now encompassing nearly three million earthquake records from multiple international locales. This approach ensures that our model is more effective to the unique characteristics of the submarine environment.

Our findings corroborate the model's good capacity to detect seismic events and accurately categorize P and S waves using single-component multi-channel DAS data—a notable feature considering the absence of the three components typically essential for wave discrimination in conventional seismology. The model proficiently differentiates between P and S waves, even in scenarios where the order of these waves is reversed or their amplitudes are markedly altered, indicating that the model discerns complex patterns and features inherent in seismic data beyond mere amplitude analysis.

How to Scale Up [Poster]

Poster Session • Wednesday and Thursday

POSTER 28

DAS Fiber Optics in Brazil, Why We Are Not Using It Yet

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This work presents an analysis of potential areas in Brazil for the application of Distributed Acoustic Sensing (DAS) technology with optical fiber, highlighting the difficulties of support from foundations and the private sector, thus proposing solutions to promote effective collaborations. In the last 10 years, Brazil has not yet explored the use of DAS with optical fiber. This study aims to identify promising regions for implementation, characterize the main difficulties encountered and suggest strategies to overcome these obstacles, facilitating the advancement of technology in the country.

POSTER 29

Enabling Access to DAS Earthquake Data with FiberSense's DigitalSeismic Platform

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A screenshot of the global fiber telecom network map motivates the photonic seismology community to scale up what is possible in earthquake seismology, but the effort required to execute any single DAS experiment on this network is extraordinary. Many potential photonic seismologists are frustrated by high barriers to entry like fiber access, interrogator cost, interrogator configuration and know-how, security, and terabyte-per-day data management. Scientific understanding in this field (and many others!) would accelerate if only we could make DAS data as accessible as satellite-based earth observation data. FiberSense is addressing this problem through the development of a new data collection, storage, processing, and retrieval platform. Earthquake waveform data and metadata are collected from telecommunications fiber networks using FIberSense DAS systems and streamed in real time to the cloud, where they are stored and processed at scale, and from which they can be retrieved on demand. Seismology data products such as peak ground acceleration values, P- and S-wave arrival times and waveforms, waterfall diagrams, and digital map overlays with local surface geology are generated at time of data collection and stored for retrieval. We are currently working in several major earthquake zones in the Western US and New Zealand supporting local geophysics groups.

POSTER 30

Lossless and Lossy Compression for Distributed Acoustic Sensing Using Inter-channel Predictions

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Distributed Acoustic Sensing (DAS) offer unique advantages to extensive monitoring initiatives due to its long-distance, high-density arrays of real-time acoustic sensors. However, high-resolution and long-term applications generate a large amount of data, on the order of hundreds of terabytes per year, presenting challenges for processing and storage. As a result, leveraging innovative data compression techniques is essential for scaling up DAS monitoring. DAS arrays are composed of multiple channels carrying highly correlated and coherent signals. These redundancies allow to exploit inter-channel compression, which use predictions from consecutive channel signals and achieve a higher compression ratio compared to compressing each channel separately.

In this work, we propose a novel coding scheme for DAS data that improves state-of-the-art compression. Encoding follows a pipeline composed of intra-prediction, inter-prediction, transform and entropy coding. For lowly correlated channels, intra-channel prediction is realized by means of Linear Prediction Coding. For inter-channel prediction, we propose three different methods: (1) prediction by warping and scaling the signal from the consecutive channel, (2) a linear predictor is learned over many channels and (3) wavelet transforms are used to disentangle data signals of different frequency, allowing fine-grained prediction. Entropy coding is done by a combination of adaptive arithmetic coding and run-length coding. The implementation is divided into an encoder and a decoder. The encoder uses bitrate optimization for decisions on the prediction methods and parameter values and can be tuned for either speed or high-compression modes. In addition, we explore lossy quantization by adding tunable quantization of the transformed signal, which we observe to achieve significantly higher compression at the expense of quantization noise. The designed algorithms and the provided implementation facilitate the deployment of long-term DAS monitoring.

POSTER 31

Developing Standards and Building Capacity for Photonic Seismology Data

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Existing facilities for storing and distributing traditional geophysical data are a logical repository option for DAS and related data. While there are many similarities between these geophysical observation types, the differences represent some significant challenges to managing and exchanging DAS data. First, and most widely recognized, the volume of data produced by DAS observations is often orders of magnitude larger than traditional geophysical data. Already the volume of DAS experiment data over the last few years has surpassed the total collected volume of geophysical data sets in facilities handling traditional data over the last 40 years. Second, multiple DAS-specific metadata fields are required. Third, the usage patterns of DAS data often require large volumes that are more akin to dense array, nodal, or refraction processing. When considering these issues, EarthScope has concluded that traditional geophysical data and metadata formats are insufficient to meet the needs of facilities and researchers.

To address these challenges, EarthScope is working with international peers to develop strategies and standards for DAS. An early conclusion is that the adoption of object storage is important to support the large volumes needed in a flexible and cost effective manner. A new metadata specification based on the work of the DAS Research Coordination Network recommendations is being developed and will support the specialized needs of these experiments and allow open exchange of metadata. The data container will be based on TileDB and designed to work well in object storage environments while supporting analysis-ready access at scale. One of the goals of this effort is to submit specifications for DAS data and metadata formats to the International Federation of Digital Seismograph Networks for adoption as a broadly recognized standard. EarthScope is also developing systems that will allow users to conduct their research computing near the stored data, removing the requirement to transmit such large volumes over the internet.

Urban Seismology [Poster]

Poster Session • Wednesday and Thursday

POSTER 32

A Corpus of Signals From a 12-month DAS Experiment at Southern Methodist University

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Since August 2023, we have been continuously experimenting with DAS capabilities on the Southern Methodist University (SMU) campus using 2-10 km long commercial dark fiber with an OptaSense QuantX Strain Interrogator Unit (IU). During this period, we have recorded a variety of seismoacoustic signals, including natural events (e.g., earthquakes, thunderstorms) and anthropogenic signals (e.g., rotary subwoofer, vehicular movements, building demolitions, football games). All these records are well recorded in a wide frequency range of 0.01-250 Hz at a spatial spacing of 1-2 m with a gauge length of 4-16 m. The recorded signals are clearly visible in Frequency-Wavenumber (F-K) transform plots that are utilized to calculate apparent velocities. For several events, infrasound and conventional broadband measurements were made alongside the DAS measurements, enabling us to explore coupling effects. This presentation summarizes the variety of signals we have detected and explores some applications of the signals for exploring source and path.

POSTER 33

Characterizing Near-surface Velocity Structure and Site Responses at the MIT Campus Using Telecommunication Dark Fibers with DAS

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Dark fibers in the telecommunication network can be useful tools for urban site characterization with Distributed Acoustic Sensing (DAS). In 2022, we collected 5 days of continuous strain-rate data from the dark fibers on the Massachusetts Institute of Technology (MIT) campus in Cambridge, Massachusetts. The cables are buried 2 – 5 feet below ground, lying horizontally in an air-filled conduit. We performed a tap test with a hammer to locate the channels along the cable. The fiber captured environmental signals from human activities such as traffic, passing trains, and construction. We use ambient noise surface waves to investigate the shallow shear-wave velocity structure (Vs). To extract surface waves from ambient noise, we remove large transient signals and calculate cross-coherence between channel pairs using a 1-minute time window. We manage to extract coherent Rayleigh waves at two segments on the cable (40% of the total available length) after stacking in time and bin-stacking coherograms according to the inter-station distance. We use the dispersion relation of Rayleigh waves to invert for Vs structure on the top ~120 m. The resolution is constrained by (1) the length of the target cable segment and (2) twice the gauge length, which place bounds on the longest and shortest wavelength we can reliably resolve, respectively. The velocity profiles show low Vs (0.1 – 0.3 km/s) materials overlying a hard bedrock (1.5 – 1.8 km/s), which results in a strong impedance contrast at 75 m –95 m. Our results agree with previous studies on nearby sites using well logs, active and passive seismic surveys. The transfer functions simulated by the 1D Vs profile show resonance peaks at 0.6 – 1 Hz, which is important to consider for improving the seismic resistance of local buildings.

POSTER 34

Detection and Location of Operational Activity at the Sanford Underground Research Facility

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We use data collected with a 3D distributed acoustic sensing (DAS) array at the Sanford Underground Research Facility to test the potential of using DAS data and arrays to detect and locate facility operations (e.g., drilling, ventilation fans, conveyor systems, and personnel and cart movements). Traditional seismic detection and geolocation techniques are often designed for a single energetic impulsive signal (e.g., blasts and earthquakes), in which the background noise is stationary. Contrarily, machine operations generate continuous, low amplitude, and spectrally discrete seismic signals. We demonstrate a technique that is effective in identifying changes in specific regions of the power spectral density (PSD) to monitor anthropogenic activity using DAS data. This PSD-based detector identifies events with distinct frequency signatures, even in cases where signals overlap in time or exhibit dynamic frequency content. We also evaluate amplitude attenuation with distance in the fiber data to estimate the locations of underground sources. This method successfully determines a source region in a cluttered environment for facility monitoring, and it is ideal for the high spatial sampling and array geometry of the 3D DAS array. Amplitude variations in DAS can result from cable coupling, so we also assess the effect of fiber emplacement in the attenuation of signals with distance.

POSTER 35

Urban Seismic Monitoring on Spatiotemporal Relative Velocity Changes with Seismic Interferometry and Distributed Acoustic Sensing

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Urban areas, particularly those with high seismic rates and unique geological structures like Mexico City, face significant seismic risks. However, monitoring seismic activity in such environments is a formidable task, often leading to inadequate and imprecise quantification of seismic hazards. This challenge is primarily due to the difficulties associated with installing and maintaining traditional seismic instrumentation in populated and asphalted areas. In contrast, Distributed Acoustic Sensing (DAS) offers a unique solution. By harnessing existing telecommunication fiber optic cables as seismic arrays, DAS provides an unparalleled spatiotemporal resolution, revolutionizing urban seismic monitoring.

On May 6th, 2022, we conducted a DAS experiment using a telecom fiber along a subway line in Mexico City. This setup covered a 29-kilometer sublinear path between the south and the north of the city, offering the equivalent of 2266 seismic channels and, therefore, the largest seismic experiment ever conducted in the region. During our experiment, a Mw7.6 earthquake struck Michoacán on Sep 19th, 2022, approximately 450 km from the city. The DAS system captured high-quality data from this event, enabling an investigation of site responses in city areas.

In this study, we applied seismic interferometry on the ambient noise field of DAS data and the stretching method to monitor seismic velocity changes in Mexico City. Our findings, which demonstrate the daily velocity variations along the fiber, have significant implications. The analysis reveals varying degrees of velocity reduction following the 2022 Mw7.6 earthquake, providing crucial insights into the city's seismic response. This work underscores the efficacy of DAS in spatiotemporal monitoring of velocity variations in urban environments, thereby offering invaluable information for urban hazard assessments and mitigation strategies.

POSTER 36

Spatiotemporal Models of Pedestrians and Vehicles Using Machine Learning and Back-projection

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The high spatial and temporal resolution of Distributed Acoustic Sensing (DAS) allows for the recording and analysis of signals typically considered a nuisance with unprecedented fidelity. Here, we focus on two such nuisance signals: pedestrians and passing vehicles. Given the large volume of data generated by DAS, employing machine learning (ML) methods to such urban seismology settings allows for the analysis of these signals, providing information about the human community near the fiber. Many studies have used convolutional neural network (CNN) models with a binary classification (noise, signal), generally focusing only on walking signals.

We leverage modern advancements in ML to characterize the waveforms and higher order data products to distinguish walking and vehicle signals from each other and from background noise. We find two approaches, k-nearest neighbors and CNN, both perform significantly better than a simple amplitude threshold detection method. We associate detections into events using a Gaussian Mixture Model (GaMMA; Zhu et al., 2021) and locate moving sources through time with back-projection. Back-projection estimates can locate the sources to within ground truth GPS accuracy when the source is within ~20 meters of the fiber.

The detection threshold is dependent on several factors including: the impact force, the local geologic attenuation of the soil, the sensitivity of the sensor, and the incidence angle between the source and the fiber. We compare a theoretical treatment of detectability from Tsai et al., (2012) and our empirical observations of detection finding a close match between theory and application. This suggests that transportability of this test will vary based on local conditions and provide a potential method of characterizing local geologic structure relevant to urban and environmental applications using readily available, traditionally nuisance, sources.

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POSTER 37

Assessing Impact of Preprocessing Techniques for DAS Ambient Noise Survey in Urban Environments

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Distributed Acoustic Sensing along dark fiber has become a common place way to increase sensor density in urban environments. A common challenge for these surveys is noise characteristics. Fiber coupling along the conduit hosting the fiber unknown and often results in varying sensor quality along a fiber. Moreover, temporal changes in noises sources, either continuous or impulsive, can hinder analysis where specific noise assumptions are needed. Here, we present an initial analysis of different preprocessing techniques to improve data quality for ambient noise DAS survey conducted along a dark fiber located in New Mexico. Seven days of data was collected along a seven-kilometer-long dark fiber adjacent to a heavily used truck route which has distinct and temporally varying noise characteristics. We implement different techniques to identify and improve signal quality for noisy gauges, account for time-varying noise sources, and locate and remove impulsive events. We show how each of these techniques improves the correlation of ambient noise between gauges and improves our ability to detect transient velocity changes between sensors. Even though the survey target is urban environments, since most telecom fiber is installed adjacent to roads, we suggest our findings will also be applicable rural areas as well.

POSTER 38

Characterizing Low-yield Mining Blasts Using Distributed Acoustic Sensing (DAS)

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Distributed Acoustic Sensing (DAS) has been shown to be a reliable method in the detection of various seismic sources from megathrust earthquakes to small-magnitude explosive sources. As Lior et al. (2023) showed, DAS can be possibly used for real-time magnitude estimation and ground motion prediction. Here we report the DAS recordings of mining blast events from the Six Mile and Shawville mines approximately 25 kilometers northwest of Philipsburg, Pennsylvania, and 50 kilometers northwest of the FORESEE DAS array using telecommunication fiber-optic cables beneath the Pennsylvania State University campus in the city of State College, Pennsylvania. Our DAS array detected 325 of 808 recorded blasts, 234 of which lay outside our monitoring period between 2019-2021, for a 57% detection rate and observed 99 more events than The Pennsylvania State Seismic Network (PASEIS). Observed explosive tonnage ranged from 6,156 to 57,780lbs (lowest to highest yield source observed) at 19 and 70-foot hole depths respectively. Using pre-detected events, we use template matching to search for hidden blast events. Our final goal is to assign magnitude estimates to the observed blasts by using the methods described in Yin et al. (2023). If this approach proves to estimate earthquake magnitude of low-yield explosive sources reliably and rapidly, we propose incorporating this method into geohazard early warning on the seismically vulnerable east coast of the United States.

POSTER 39

On the Spatial Subsurface Localization of Seismic Velocity Changes in Mexico City Using DAS

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This study examines the impact of subsoil velocity changes in dispersion curves from DAS records in Mexico City. In recent years, Distributed Acoustic Sensing (DAS) technology has become a popular tool for investigating subsurface properties in urban environments. DAS records have been successfully used to extract dispersion curves and perform tomographies. From May 2022 to July 2023, we conducted a DAS experiment in Mexico City, well-known for its complex geology and underground water reservoirs that result in low elastic velocities under most of the city. A preliminary study has successfully measured dv/v velocity changes by stretching the coda of the correlation (Urban Seismic Monitoring on Spatiotemporal Relative Velocity Changes with Seismic Interferometry and Distributed Acoustic Sensing, also presented in this conference). They show that the highest velocity changes are restricted to a narrow time-frequency band and are present in a limited area along the fiber. They also show the main waves contributing to the dv/v, however, it is not clear which depth is inducing these changes. Some theoretical sensitivity kernels have been proposed in the literature to investigate the horizontal regions of influence on dv/v changes, but determining the depth of contribution is still challenging. Attempts to see velocity changes in the tomographic procedures usually involve high velocity media. We show that the low velocity media of Mexico City enhance the sensitivity to seismic velocity changes and we aim to reveal the depth of the dv/v changes through a 4D tomographic inversion.

POSTER 40

Imaging the Urban Subsurface Using Thunderquakes

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Thunderstorms generate abundant acoustic disturbances that interact with the ground, creating rich sources of seismic energy in urban environments where large-scale seismic surveys can be especially challenging. We recorded and analyzed thunderstorm-induced seismic events, “thunderquakes,” and their potential for urban seismic studies using a distributed acoustic sensing (DAS) array. The array is repurposed from a dark telecommunications fiber beneath urban State College, PA, as part of the Fiber-Optic for Environmental Sensing (FORESEE) project. Thunderquakes seen by the DAS array have already been used to locate their lightning-strike sources, and a novel DAS-specific amplitude analysis technique showed that thunderquakes contain significant Rayleigh wave energy. This allows us to use classical Rayleigh wave dispersion analysis on over one hundred high-quality thunderquake signals. The dispersions are fed through a Monte Carlo inversion algorithm to derive shear wave velocity profiles for the State College area, which we compared with profiles obtained from hammer-strike geophone studies at collocated sites. The results from these two methods align, revealing local geology and demonstrating a novel approach for urban near-surface seismic velocity characterization.

POSTER 41

Addressing Challenges of Accurately Measuring Earthquake Ground Motions Using Commercial Dark Fiber in an Urban Environment

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Seismic monitoring using conventional broadband seismometers can be challenging in urban environments due to limitations of land access. To evaluate the use of fiber optic sensing in urban environments, we interrogate ~95 km-long pre-existing dark fiber in an area with heavy traffic in Dallas, Texas, using a strain Interrogator Unit. To compare with traditional seismometers, we deployed 10 three-component broadband seismometers at different locations along the fiber cable and tested the Distributed Acoustic Sensing (DAS) on different configurations. We observed some known and unknown challenges with using the commercial dark fiber to retrieve reliable estimates of ground motion. These include the presence of aerial fiber sections, slack fiber in handholes, and varying fiber cable coupling with the ground. We have provided a computational-based solution for the identification of sections of fiber that cannot be used to retrieve reliable ground motions. In addition, we provided a criterion for using the Frequency-Wavenumber (F-K) transform technique to convert the DAS strain to ground velocities with different ground coupling conditions. Using a modified F-K transform technique, we have reliably matched the earthquake ground velocity records of DAS with seismometer recordings.

POSTER 42

Innovative Applications of Distributed Acoustic Sensing in Railway Monitoring

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Distributed Acoustic Sensing (DAS) is increasingly being used in various applications, gaining particular importance in rail and train monitoring. When integrated with existing optical fiber infrastructure, DAS offers a reliable, continuous and cost-effective monitoring solution. This technology can complement or even replace conventional rail monitoring techniques. Additionally, DAS is a powerful tool for understanding underground geological processes and managing geologic hazards.

This technical presentation aims to demonstrate how standard telecommunication fibers along the railtrack, known as “dark fibers,” can be employed for a variety of applications, including monitoring of railtrack condition, various human activities and potentially hazardous natural phenomena.

By integrating DAS technology with optical fiber cable infrastructure along railways, we achieve a scalable solution for continuous monitoring. Beyond monitoring track and rail conditions, DAS-equipped railway networks have potential applications in earthquake monitoring and near-surface characterization, enabling real-time geological process monitoring. Several case studies illustrate the deployment of DAS along different railway tracks, capturing seismic wave arrivals with high spatial and temporal resolution. Additionally, the presentation will focus on utilizing trains as seismic sources. Real-life examples will demonstrate the efficiency of fiber optic DAS technology for near-surface monitoring beneath railways, providing high resolution and reliability. This innovative approach enhances railway infrastructure resilience, facilitates preventive maintenance, and helps prevent safety hazards.

POSTER 43

Deep Learning Models Applied to Localization of Mexico City Microseismicity Recorded with DAS

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Localizing earthquakes is not always easy. In particular, we show that most of the localizations of local earthquakes in Mexico City can be seriously questioned. Although the seismic network has been densified for the 20 past years, the highly heterogeneous media in the city and the rapidly evolving ratios Vp/Vs through depth (about a factor of 100 in the first 80m of depth and then about 1.7 at 1km depth) make obsolete the general tools for localization. Worst, the first observed shear arrival does not always follow a direct path, and phase identification with a scattered seismic network in such a geological context is uncertain.Then, the high spatial and temporal resolution measurements in Mexico City, such as the ones associated with Distributed Acoustic Sensing (DAS) technology, are of significant interest. We experimented from 2022 to 2023 and detected a hundredth of local earthquakes. We show that it is easy to follow several phases through a large number of channels. However, DAS measurements conducted with dark fibers in urban environments don’t allow for observation of compressional wave.

We will also show that localizations can be improved by considering more than the direct P and S arrivals. However, identifying each phase is out of the question. Instead, we would apply convolutional neural networks (CNN), which are well-suited for this task due to their ability to capture spatial and local patterns within the data. The CNN architecture was designed to include multiple convolutional layers with appropriate kernel sizes to extract features from data, followed by fully connected layers to map these features to the 3D coordinates. Data preprocessing involved denoising, normalization, and segmentation of DAS signals to focus on relevant temporal windows associated with microseismic events. The model was trained using a supervised learning approach, where the known positions of microseismic events served as ground truth. A comprehensive evaluation using a separate validation set was conducted to assess the model’s performance and generalization capability.

POSTER 44

Detecting Potential Sinkholes Using Distributed Acoustic Sensing Array

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Sinkholes are most common in karst landscapes and can cause serious geohazard if they occur in densely populated areas. In urban region, Distributing Acoustic Sensing (DAS) with pre-existing telecom fiber-optic cables can record high-fidelity seismic wavefields with great spatiotemporal resolutions. This gives an invaluable tool to develop cost-effective seismic methods to characterize underground space. In this study, we demonstrate to use spatially-dense DAS recordings from the Fiber Optic foR Environmental SEnsEing (FORESEE) array in State College PA to detect potential sinkholes. We used ambient noise interferometry method for traffic signal recorded by DAS array to obtain Noise Cross-correlation Functions (NCFs). From the dispersion spectrums of NCFs, we discovered the unique inverse dispersion phenomenon of surface waves (i.e., phase velocities increase with increasing frequencies), which is typically caused by the low-velocity half space. Theoretically, the low-velocity half-space model will produce leaky surface waves corresponding to the complex roots of dispersion function. We demonstrated to practically use the leaky surface-wave dispersion curve inversion for detecting low-velocity half spaces by searching the complex roots in the complex-velocity plane. Using all NCFs along the FORESEE array, we reconstructed the 2D underground shear-wave velocity map and found obvious low-velocity anomaly regions. These anomalies imply the fractured dolomite and limestone formations with karst features (cavities and sinkholes) due to the groundwater dissolution and erosion of limestone/dolomite. This study demonstrates the important role and potential use of DAS for urban geohazard prevention.

POSTER 45

Physics-Informed Deep Learning for Bridge Displacement Estimation Using DAS Data

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Bridges are vital components of urban infrastructure, crucial for human livelihoods and economic prosperity in city centers. Monitoring bridge displacement is essential for assessing the structural health of bridges. However, achieving long-range, continuous, and high-precision monitoring of structural displacements still remains a significant challenge. In this study, we developed a distributed acoustic sensing (DAS) system and millimeter-wave radar on a highway bridge for collecting dynamic responses of structure. We trained a Physics-Informed Neural Network (PINN) to convert DAS data into bridge displacements based on governing equations for bridge dynamics, using radar data as the ground truth for displacement. A mode shape guided method was adopted to adjust the overall response of the whole bridge, resulting in high-precision displacement data for the entire bridge. Additionally, we analyzed the sensitivity of unarmored and armored fiber optic cables for structural dynamic acquisition. It has been discovered that armored fiber optic cables can reduce the signal-to-noise ratio by 6-9dB in the primary observation frequency band, with this influence diminishing as frequency increases. It provides insights for the industrial application of DAS. The study confirms the strong potential of DAS for monitoring critical urban infrastructure.

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