ITINERIS

Distributed Acoustic Sensing (DAS) for high resolution and high scale geophysical imaging

Distributed Fibre Optic Sensing (DFOS) – Overview

- Athena Chalari

SILIXA
A LUNA company

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR- Mission 4 "Education and Research" - Component 2: "From research to business" - Investment 3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani

Overview DAY 1

17 MARCH

Time	Duration	Training Module - Topic	Speaker
09:00 – 09:30	0h30m	Welcome and housekeeping, Introductions attendees/speakers	Athena Chalari/ Fabio Meneghini?
09:30 – 10:30	1h00m	Silixa introduction technology overview DAS DTS applications Case studies	Athena Chalari
10:30 -10:45		***Coffee Break***	
10:45 -12:00	1h15m	Fibre optics basics - DAS principles - DTS principles: light transmission and fibres common to both technologies DAS-specific physics DTS-specific physics	Jack Maxwell/ Athena Chalari
12:00 -13:00		***Lunch Break***	
13:00 – 14:00	1h00m	Carina and XT DTS demo (split in 2 groups)	Jack Maxwell/ Kyriaki Mitsopoulou
14:00 -15:00	1h00m	Suitable cables- fibres/cable deployments	Athena Chalari
15:00 – 15:15		***Coffee Break***	
15:15 – 16:40	1h25m	DAS Configuration parameters/best practices/Geophone comparison	Jack Maxwell
16:40 -17:00	0h20m	What to ask in a tender Questions/Answers	Athena Chalari

Outline

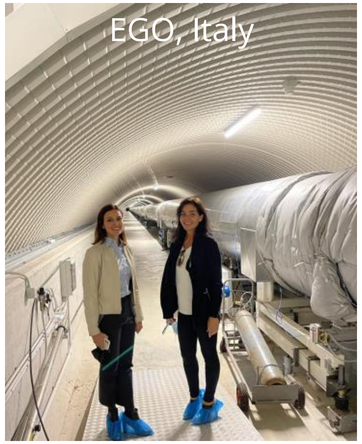
- Meet the team
- Silixa introduction
- Technology overview
- Applications & Case Studies
  - CCUS
  - Geothermal
  - Natural hazards monitoring
  - Living labs
  - Marine Acoustics

Athena Chalari (E&S Business Unit)

- BDM – Environmental and Earth Sciences

- Joined Silixa in 2012 and has been involved in activities ranging from field installations and surveys, project management, technical sales and business development of geoscience applications.
- Currently acts as Business Development Manager looking after the Natural Environments sector including geoenergy observatories, natural hazards monitoring and research collaborative projects.
- Holds a master's degree in Environmental Oceanography and a PhD in Marine Geology and Geophysics
- Silixa client from 2008 to 2010 (met with Michael and Mahmoud in a CTEMPS workshop in Denmark 2009)

- Grew up in Athens, Greece. Enjoying travelling around the globe and swimming in the Mediterranean sea



Jack Maxwell (Technology – DAS)

- Lead Development Engineer

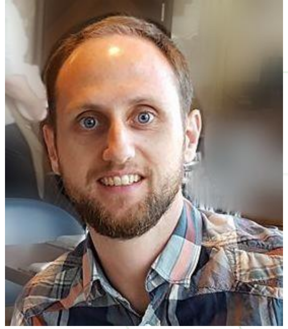
- Joined Silixa in 2019 and is currently a Lead Development Engineer in the technology team.
- Is the product owner for DAS interrogators and represents Silixa at conferences, joint-industrial events, and technical field trials.
- Has worked on development engineering projects for Silixa DAS interrogators as well as client engagement activities, and currently leads product and hardware development projects.
- Holds a PhD in optics and photonics from Imperial College London and a masters in theoretical physics.
- Plays the trumpet and owns a dog.


Facility demo, Netherlands


Mt. Etna


The Blues

Andy Clarke (Technology)



Head of Product Management

- I joined Silixa in 2010 as an Acoustic Development Engineer after graduating from Southampton University with an MEng in Acoustic Engineering.
- Over the years I've dabbled in geophysics and led the development Silixa's seismic acquisition solution as Seismic Product Champion, with the help of OGS. I spent a couple of weeks at Piana di Toppo in 2013 (with Fabio!) acquiring some very early DAS seismic. I had more hair then.
- My focus now is creating the best hardware and software products for our customers across every type of fibre optic sensing in all our different markets.
- But I fondly remember when I used to get to go to the field more and do experiments!

- If I'm not working, you'll probably find me trail running, skiing or bikepacking

Kyriaki Mitsopoulou (E&S Business Unit)

- Technical Sales Engineer

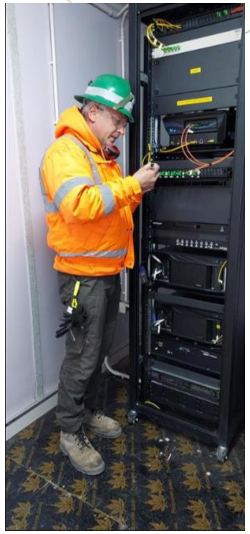
- Joined Silixa in 2024 as a Technical Sales Engineer in the Natural Environments sector.
- Graduated from the Dept. of Electrical and Computer Engineering, with a 5-years Diploma (Master's Equivalent).
- Have field experience in supervising the installation of power networks (underground power cables), fibre optics and earth networks.

- Grew up on Rhodes island. Outside of work I love travelling and being by the sea.

Plamen Atanassov (E&S Business Unit)

- Field Engineer

- Plamen joined Silixa in 2011 as a subcontractor/consultant and has been a Field Engineer since 2019. He has 13 years of hands-on experience with fiber optic sensing systems and field installations, working on and managing projects across the oil & gas, mining, geothermal, and CCUS sectors.
- He holds fiber optic cabling and various safety certifications.
- Originally from Bulgaria, Plamen enjoys playing the guitar and is passionate about fitness and bodybuilding.



Silixa Introduction

Awards

Institute of Physics Innovation Award 2015

World Oil Award for The Best Deepwater Technology 2020

World Oil Award for New Horizons Idea 2020

Queen's Award for Innovation: Enterprise 2021

Accreditations

ISO 9001 QUALITY MANAGEMENT

UKAS MANAGEMENT SYSTEMS 0015

Parent Company

LUNA

End of 2023

Operational Footprint

- Silixa
- Agent

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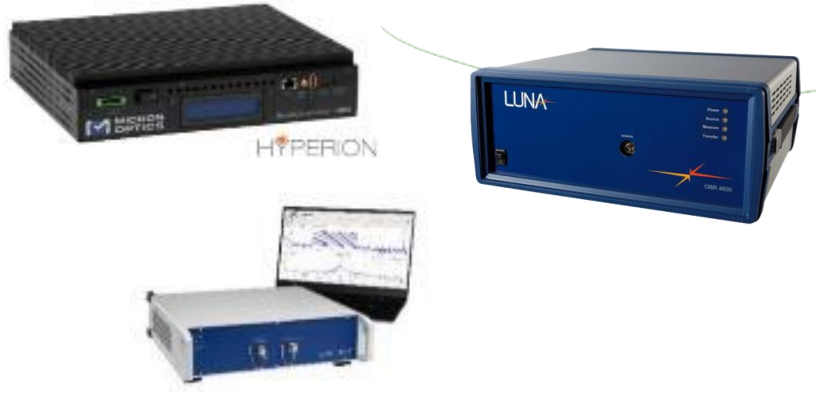
Distributed Fibre Optical Sensing

Distributed Temperature Sensing (DTS)

Distributed Strain Sensing (DSS)

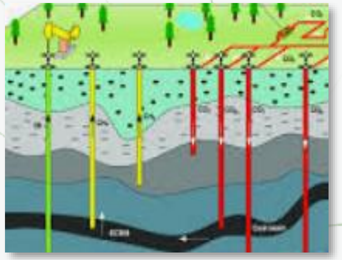
Distributed Acoustic Sensing (DAS)



Fiber Optic Sensors & Measurements

Luna Sectors

ITINERIS

	Midstream	Security (Perimeter & Fire)	Utilities (Cable Monitoring)	Upstream	Scientific & Environmental
					
Competitive Differentiation	*Algorithms for leak detection* *Reliable instruments* *Longest range (100km)*	*Fully certified products for fire detection (VDS, FM, UL)* *Track record and MTBF >40 years* *Fully integrated software*	*Longest range for both instruments* *Proprietary algorithms developed (RTTR, DoB)*	*Constellation™ Fiber (better signal, low noise, and industry leading data quality)* *Customized solutions for in-time decisions*	*Multiphysics based characterization and monitoring* *EDGE software platform enabled application solutions* *Customized monitoring systems* *Advanced Geophysics*
Key Benefit	*Total cost of ownership as less instruments needed for long range applications*	*Range and track record certificates*	*Total cost of ownership as less instruments needed for long range applications; cost avoidance to deploy a full solution*	*Monitoring solution with proactive recommendations for improved oil recovery* *Improved efficiency with cost avoidance, small footprint & reduced operational interrup tion*	*Measurements with the greatest repeatability, accuracy, and precision enable the most advanced applications*

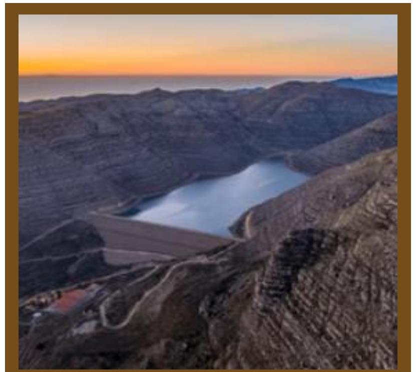
Providing Solutions and Services whenever it is meaningful

Application Sectors – Systems and Units

Natural Environments

Protect and extend the life of critical assets through proactive risk-based monitoring

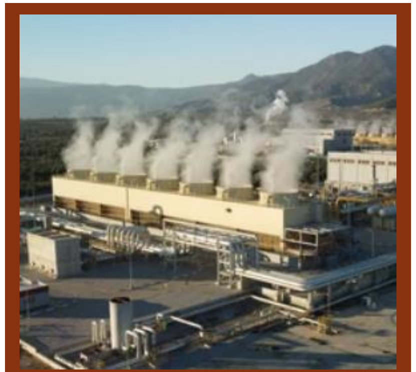
- Hydrology and hydrogeology
- Glaciology
- Marine and shoreline
- Earthquake Seismology
- Near surface



Infrastructure

Protect and extend the life of critical assets through proactive risk-based monitoring

- Embankment dams
- Earthen structures
- Industrial process plants
- Mining
- Landfill monitoring



Energy

Monitor new projects and mature infrastructure on and offshore to secure an affordable and sustainable future

- Oil & Gas Conventional
- Oil & Gas Unconventional
- Geothermal
- EGS
- Geothermal

CCUS

Enable reduced atmospheric carbon emissions through continuous subsurface monitoring

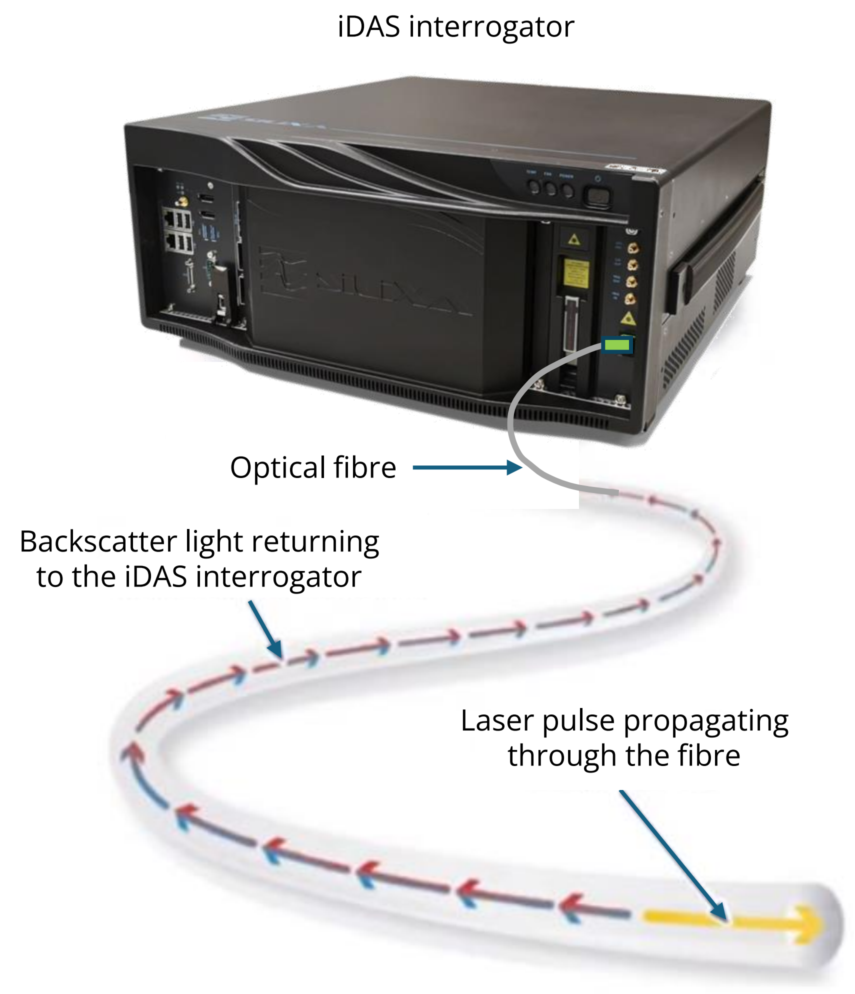
- Site characterization
- Sequestration integrity
- Plume monitoring
- Induced seismicity monitoring
- Regulatory compliance

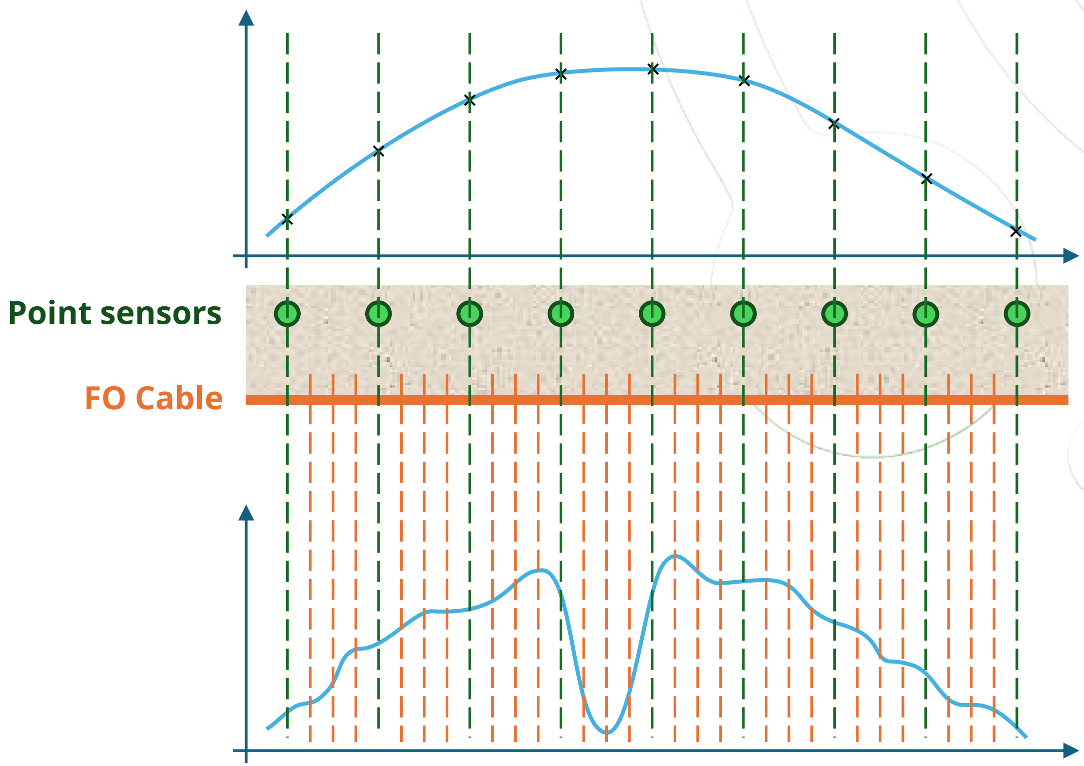
Defense

Extend situational awareness and perform tactical asset monitoring on land and at sea

- Custom monitoring systems
- Dense, long sensor arrays
- High sensitivity and precision
- Harsh environments
- Subsea

The advantage of true distributed measurements





Large numbers of traditional sensors are required to monitor large volumes of interest.

Information might not be representative of the actual conditions.

Fibre optics help recovering complex signals.

Fibre optics require no electronics at point of measurement.

DFOS: Optical Time Domain Reflectometry

- A laser light source generates a pulse that is coupled into an optical fiber.

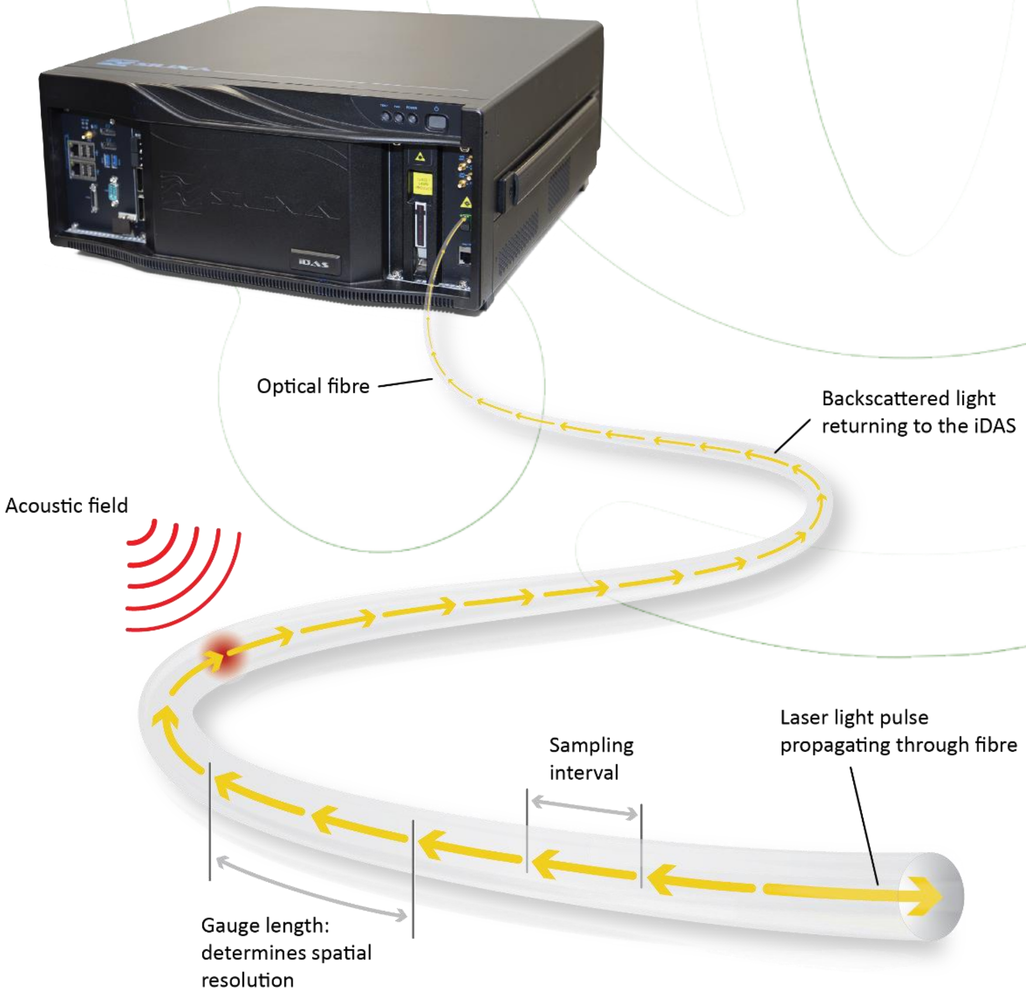
- The backscattered light signal is sampled in time. The signal measured over a time sample corresponds to a spatial sampling interval, which is equivalent to the two-way pulse width.

- The measured signal is spatially distributed from using optical time domain reflectometry (OTDR).

- Spatio-temporally continuous data over many tens of kilometers of optical fibre.

Distributed Optical Fiber Sensing Technology

- Cable containing optical fibre is placed at the measurement location
- Fibre is the sensor which requires no power and can extend to 10's km – effectively giving 40,000 sensors which are interrogated simultaneously
- Laser pulse is injected into the optical fibre
- Tiny reflections caused by interactions with the fibre structure return to the interrogator unit
- The reflections are affected by localised temperature or acoustics and these physical properties can be reconstructed by our technology.
- The time taken by the reflections to return is accurately measure and provides the position along the fibre to within a few centimetres

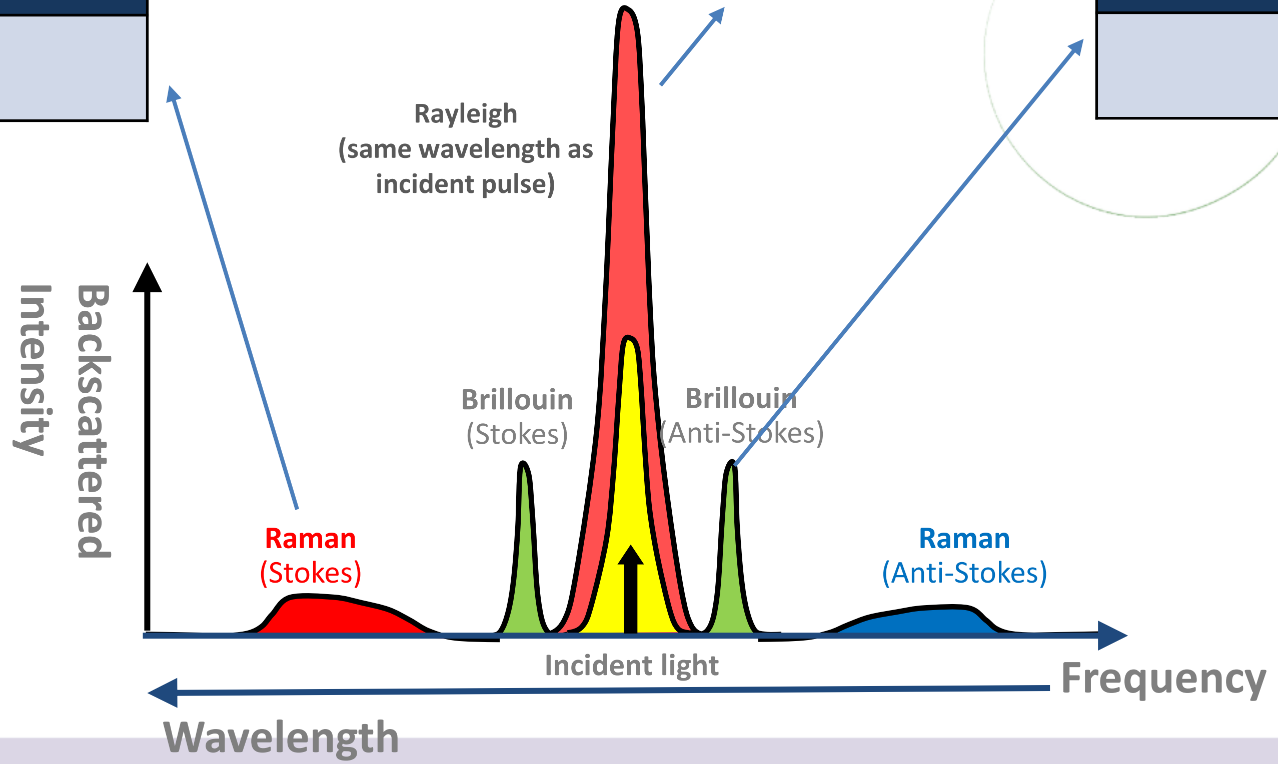


Silixa Distributed Sensing


MK2 Ultima	MK2 XT
Temperature (DTS) 0.01°C Resolution	

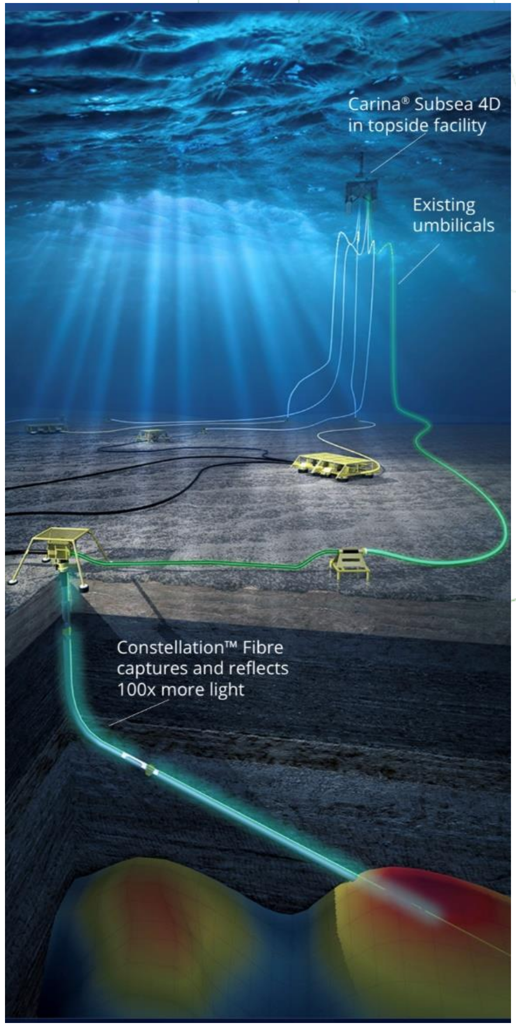

IDAS MG	CARINA
Acoustics (DAS) >120dB Dynamic range	

iDSS
Strain (DSS) 1 με Resolution

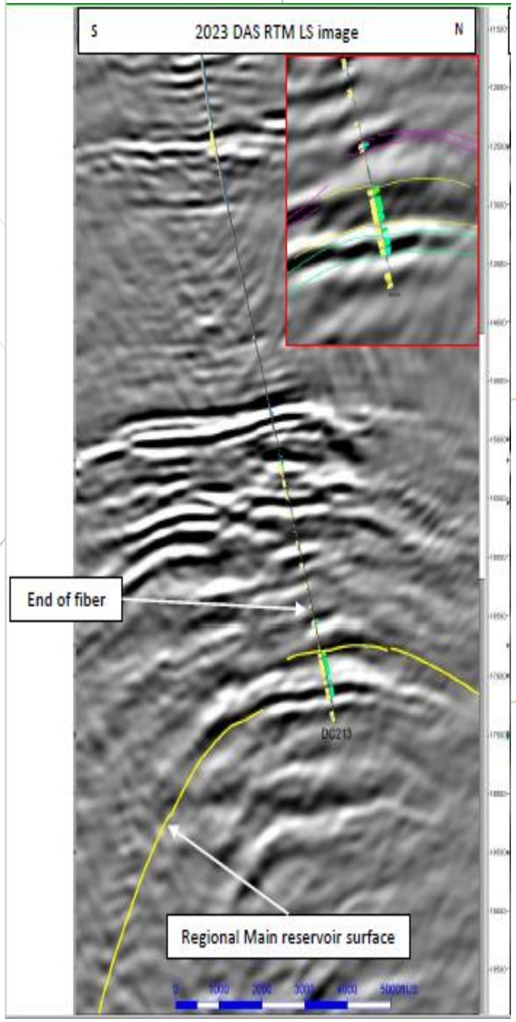


Competitive Advantage given by Carina® Sensing System

- **20dB additional optical budget**
  - High tolerance to splice and wet-connect losses
- **20dB reduction in required seismic source energy**
  - Monitoring in urban or environmentally sensitive areas; reduced source cost
- **Equivalent to 100x fewer seismic shots**
  - Reduces cost, time and environmental impact
- **20dB Improved signal to noise ratio (SNR) allowing detection of events unseen by other DAS systems**
  - Carina reveals hidden signals, for example an expected ~10x more microseismic events
  - Noise floor reaches below sea state zero ambient noise
- **Enhanced SNR enables resolutions (gauge lengths) down to 25cm**
  - High sensitivity dynamic strain
  - Low density flow measurement arrays



US Patent No. 10883861
EP Patent No. 3265757

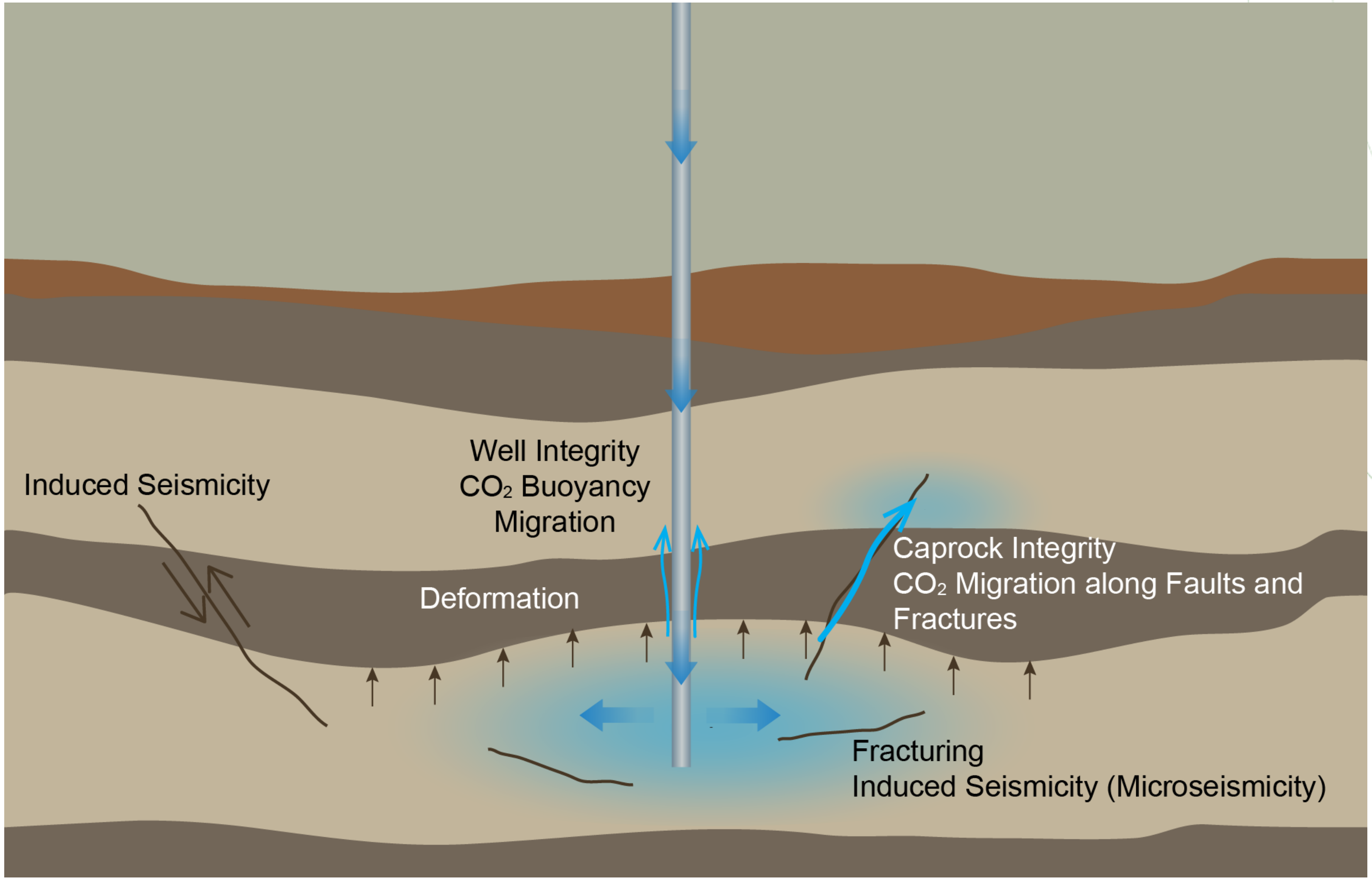


CCUS Monitoring

Silixa Sample CCUS Projects:

LBNL, USA **2012**, Multiple Sites; **CO2CRC**, Australia **2012**; **PTRC** *Aquistore* Canada **2013**; Archer Daniels Midland, Decatur, Illinois; **CIUDEN**, Spain; Research Institute of Innovative Technology for the Earth (**RITE**), Japan; Korea Research Institute of. Geoscience & Mineral Resources (**KIGAM**); **ACT SUCCEED**, Reykjavik, Iceland; Zorlu Energy, Turkey; **ACT DIGIMON**, **CaMI** FRS site , Alberta, Canada; **SINTEF** Svelvik, Norway; Midwest Regional Carbon Sequestration Partnership (**MRSCP**) **BATTELLE**, Otsego County Michigan, CARBON Utilisation and Storage Partnership (**CUSP**), **Shell Quest** CCUS, Red Trail Energy CCUS, New Mexico Tech **CarbonSafe, JOGMEC, Japex** Japan**, INPEX** Japan**, ADNOC** Middle East **, PERENCO** UK

CO2 Storage Risks – MMV Requirements



Source: Silixa, Carbon Capture and Storage Monitoring with Distributed Fiber Optic Sensing, March 2022. Prepared for EERC and the PCOR Partnership.

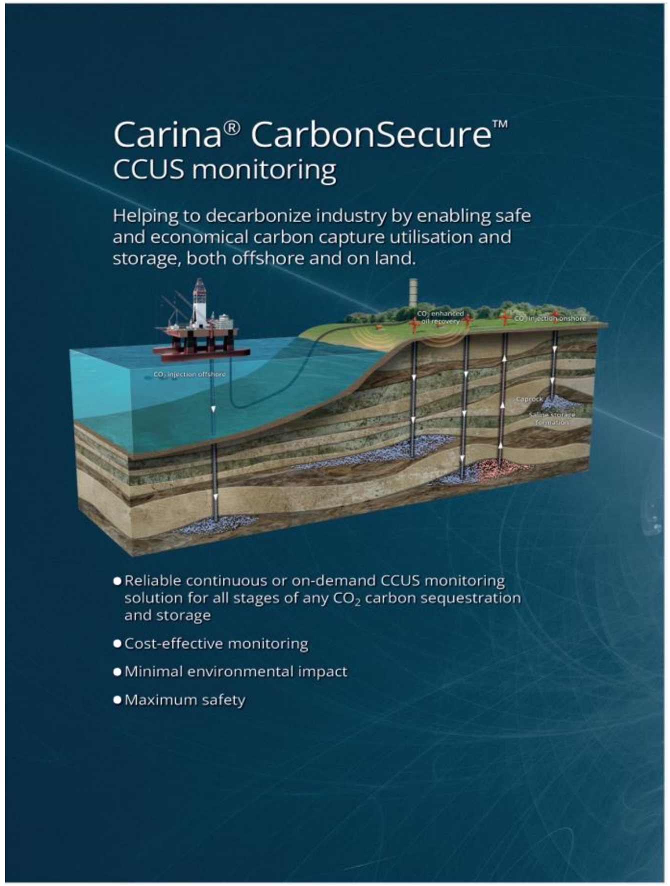
- **Well Integrity:**
  - Leakage
  - Deformation
- **CO_2 plume containment:**
  - Migration along faults and fractures zones
- **Induced seismicity**

Containment: MMV data to trigger timely controls

Conformance: MMV data to predict long term behavior

Confidence: MMV data to maintain license (also storage closure)

Real-time, online, modular, Edge Monitoring Platform



Remote operation

- System set up
- Data QC
- Remote Support

Cloud storage & computing

- Customer platforms for analysis
- Data Integration
- Dashboard visualisation

Full-bandwidth streaming to off-site servers

- Requires high-speed network
- Data analysis and/or archiving

Benefits

Cost-Effective Solution:

- Low maintenance
- Online remote operation
- Permanent and smaller seismic sources

High-quality data:

- Repeatability
- Full well coverage
- High-spatial resolution
- Continuous, real-time, or on demand monitoring

Minimal environmental impact:

- Low energy consumption
- Low carbon emission
- Small footprint

Improved Safety:

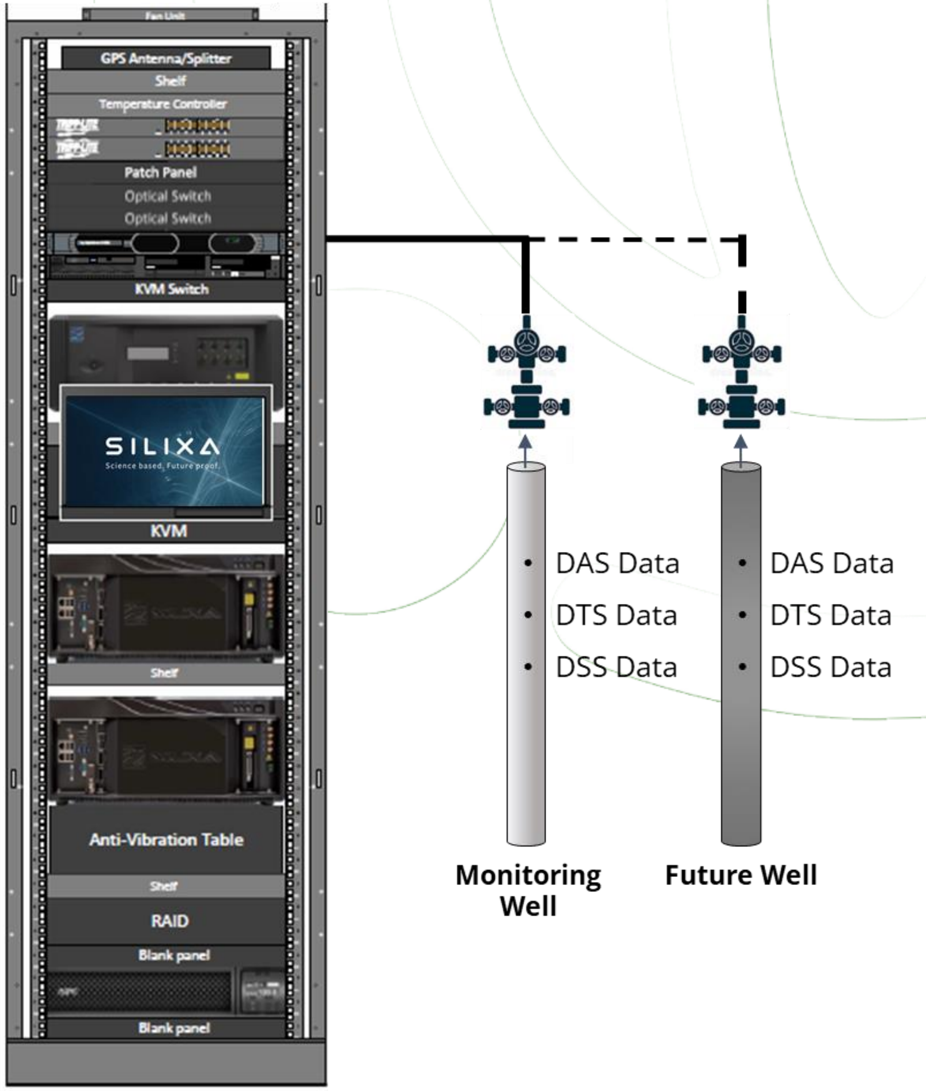
- Reduced mobilizations
- Reduced personnel onsite

CCUS permanent monitoring

https://silixa.com/sectors/industrial-digitalisation/co2-storage-monitoring

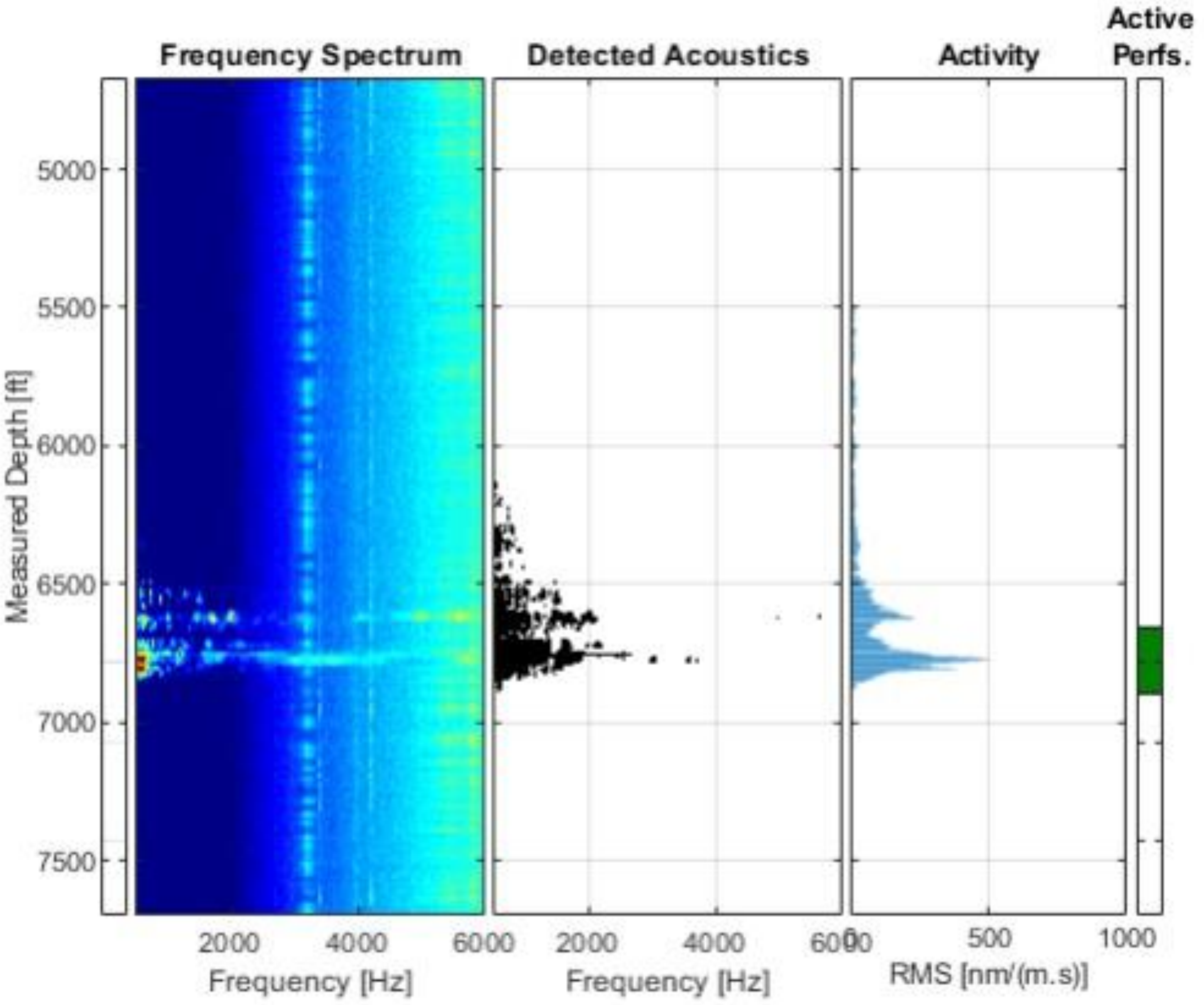
Project Progression for CCUS

Feasibility study	1-2 months
Well design and component procurement	6 months – 2 years
Fiber optic cable deployment	1 month + reporting
Fiber optic cable surface termination	1 week
Perforation and injectivity test monitoring (SRT)	1-2 weeks + reporting
DAS-VSP baseline survey	1-2 weeks + reporting
Baseline monitoring prior to injection	Up to a year + reporting
Long-term monitoring of CO2 injection	5+ years + reporting
DAS-VSP timelapse for CO2 distribution	1-2 weeks + reporting



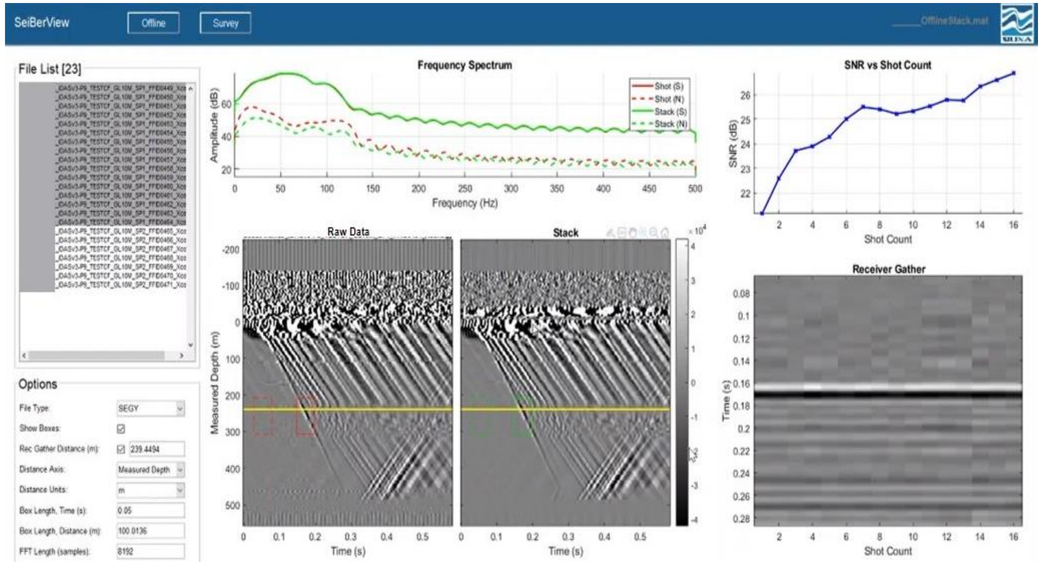
Perforation and Injectivity Test

- Displays frequency content of acoustic energy at perforation zone
- Detects spatial distribution of acoustics during perforation
- Correlated with external pressure and temperature gauges
- Demonstrates that fluid is being allocated where it should be and not at untargeted depths

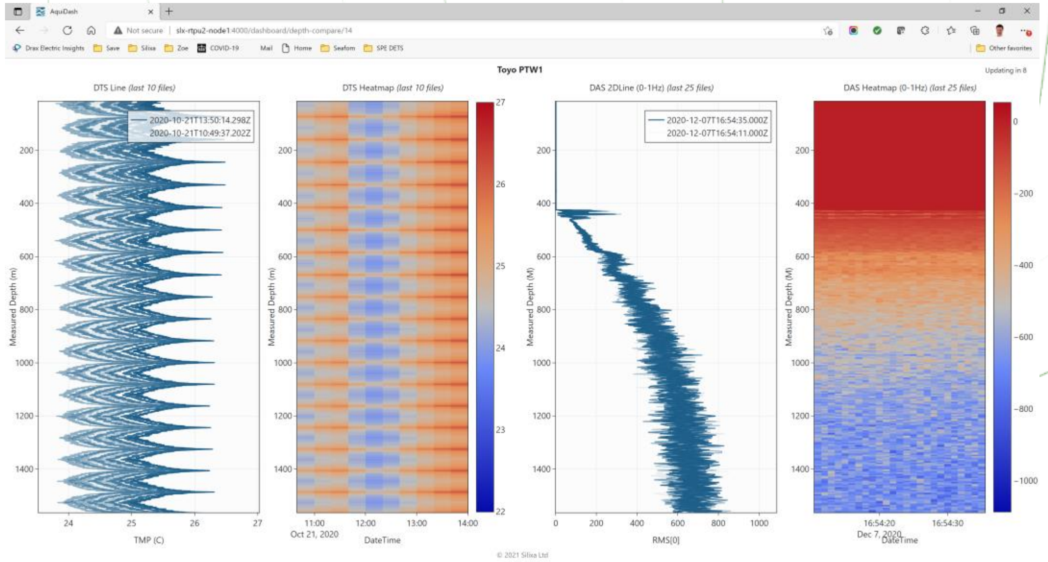


Real-time, modular Edge Platform

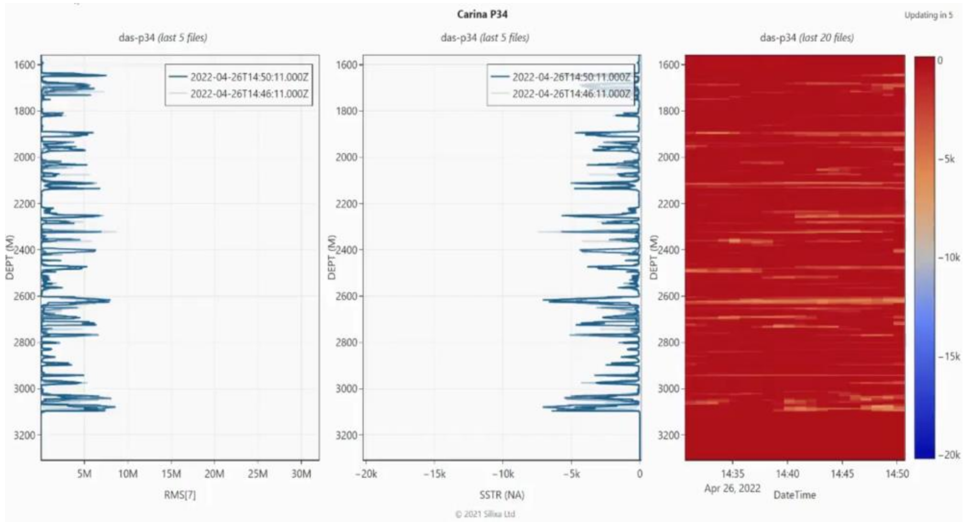
VSP (DAS)



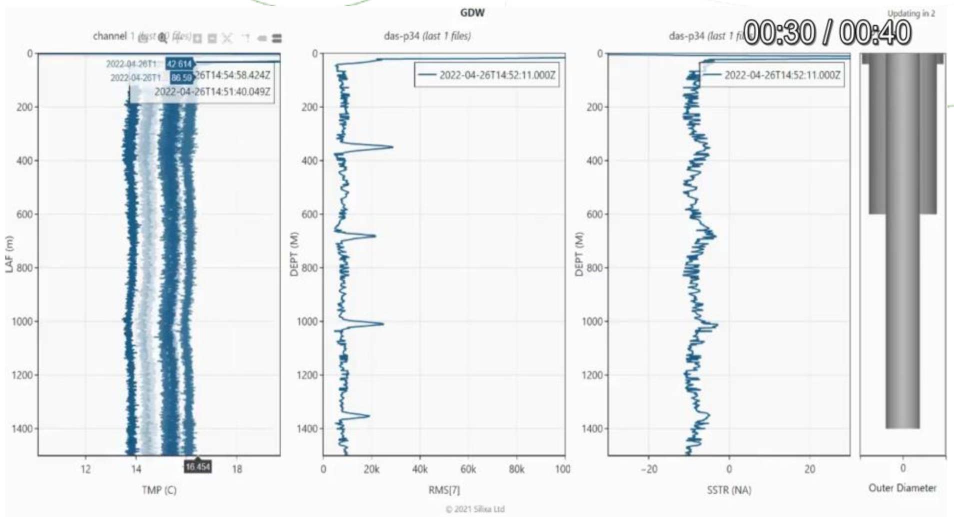
Thermal Profiling (DTS)



Continuous Acoustic (DAS)

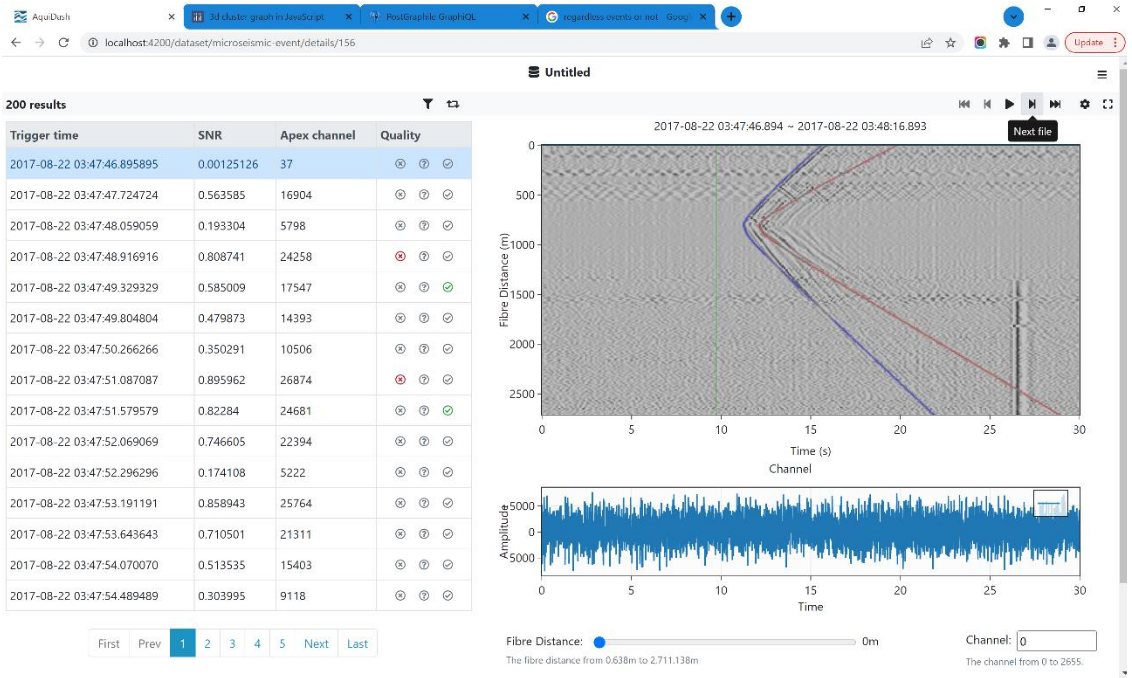


Casing Integrity (DAS, DTS)



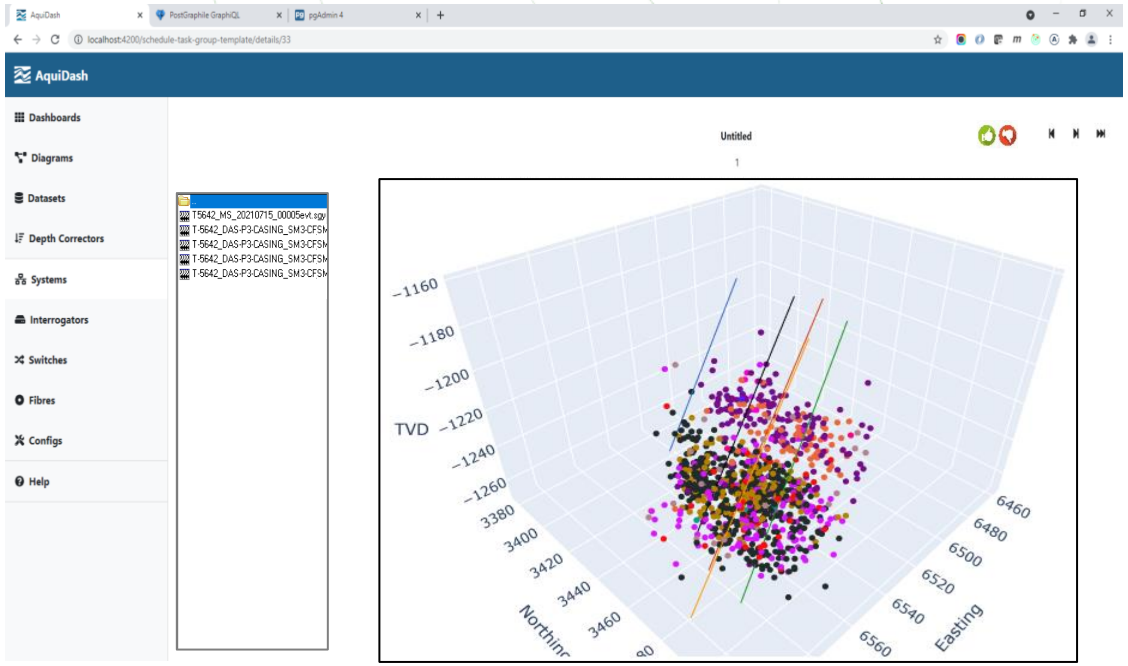
Microseismic Monitoring

Detection Module



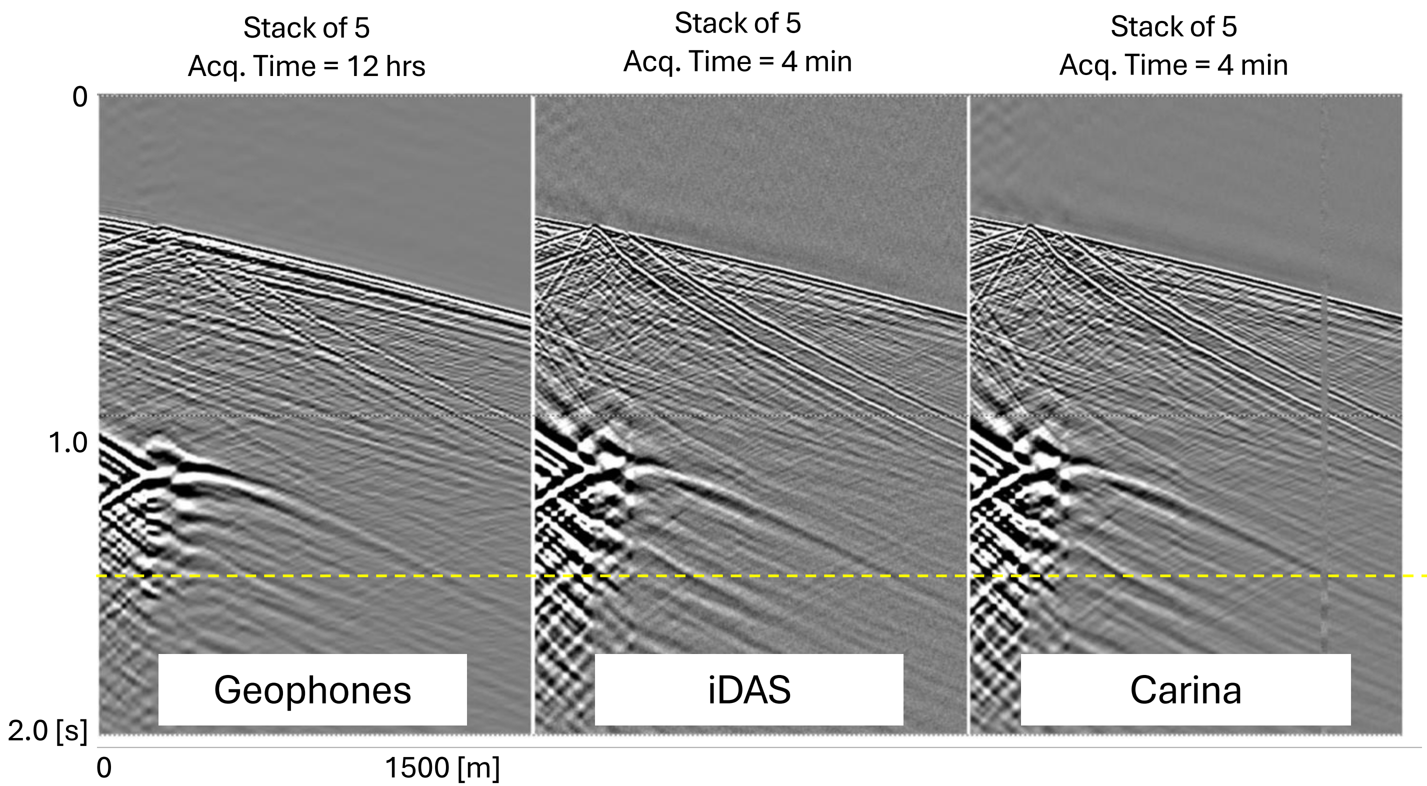
- Event detection catalogue.
- QC/QA on SNR and arrival times.

Location Module



- Event location catalogue.
- Magnitude calculations.
- SEGY output.
- 3D Visualization.

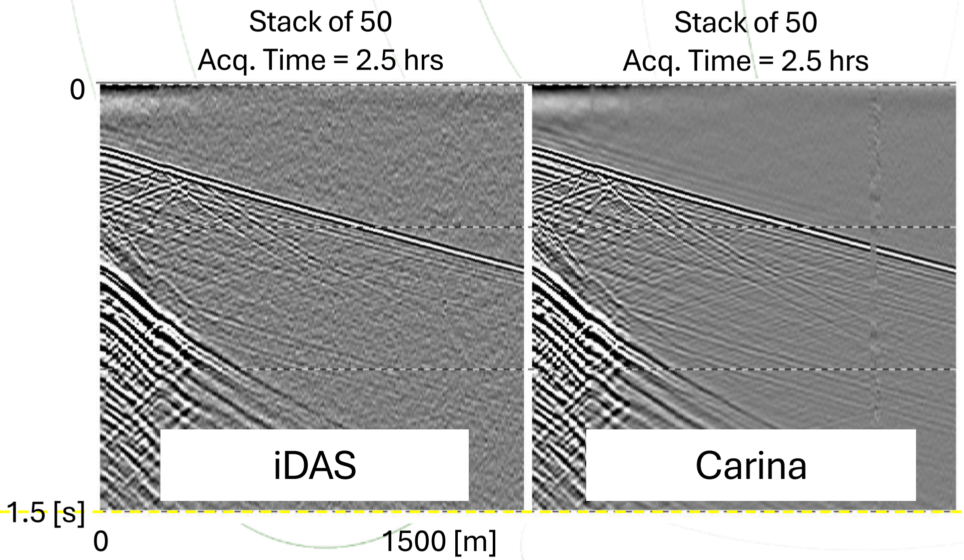
Geophone vs DAS



VSP with Vibe truck

High-cost, high environmental impact, non-continuous

Correa et al. 2019 US-DOE/NETL



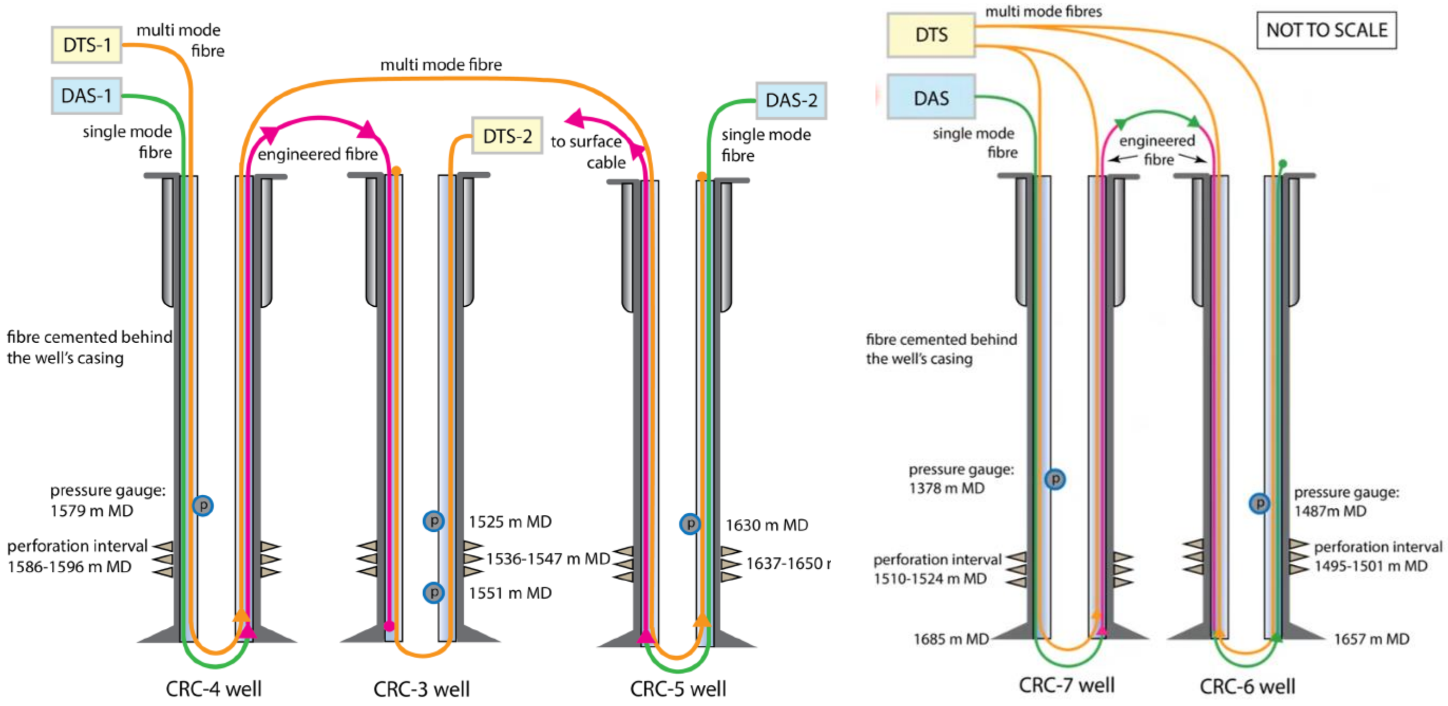
VSP with SOV 80 Hz

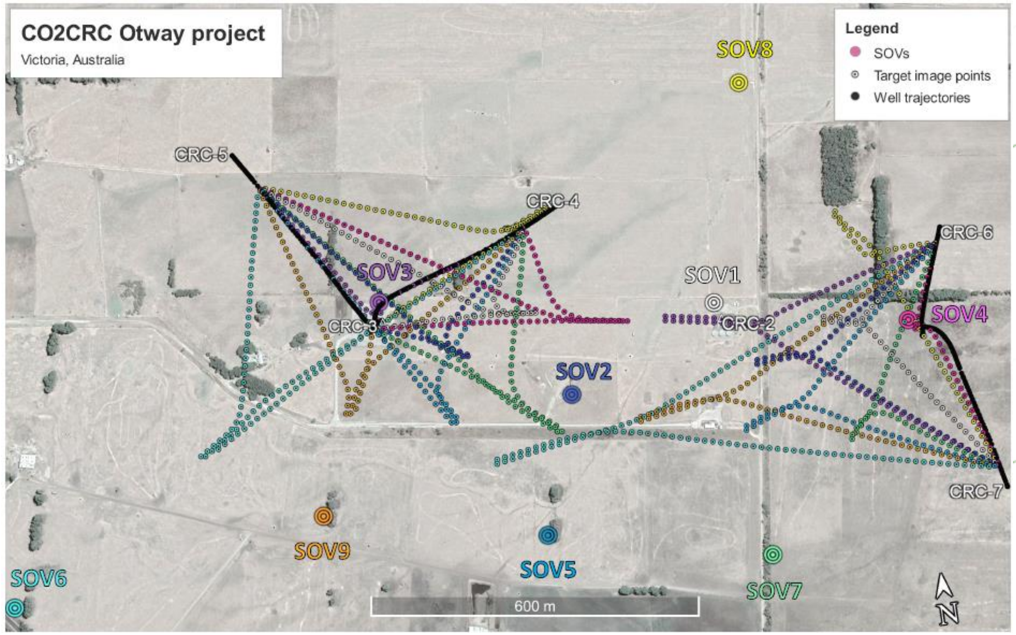
Low-cost, low environmental impact, continuous

Data courtesy of Curtin University

DAS-VSP Surveys – CO2 Plume Mapping (Otway, Australia)

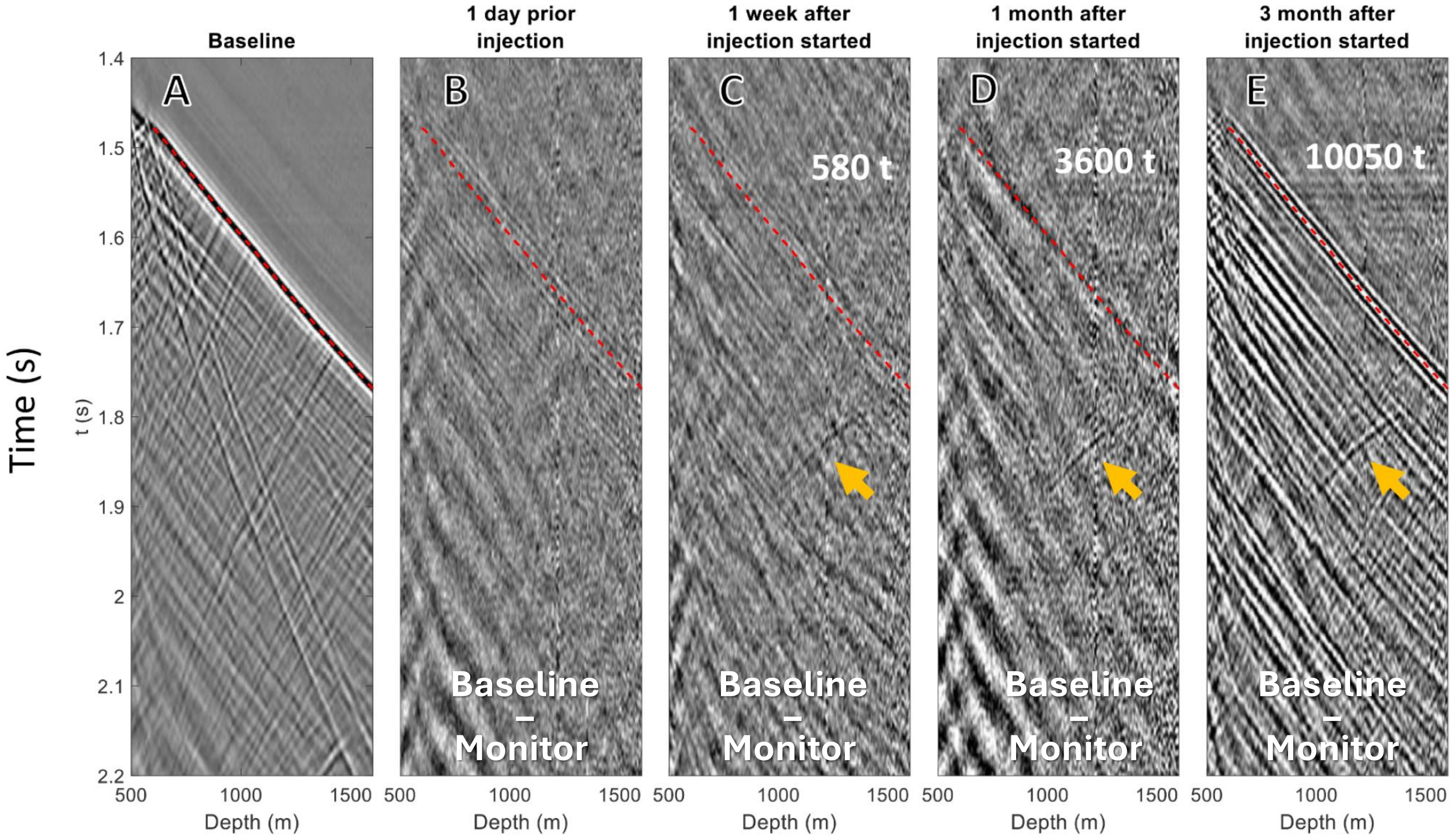
Cable Layout





Sidenko et al. 2022 Intl Journal of Greenhouse Gas Control

DAS-VSP Surveys – CO2 Plume Mapping (Otway, Australia)

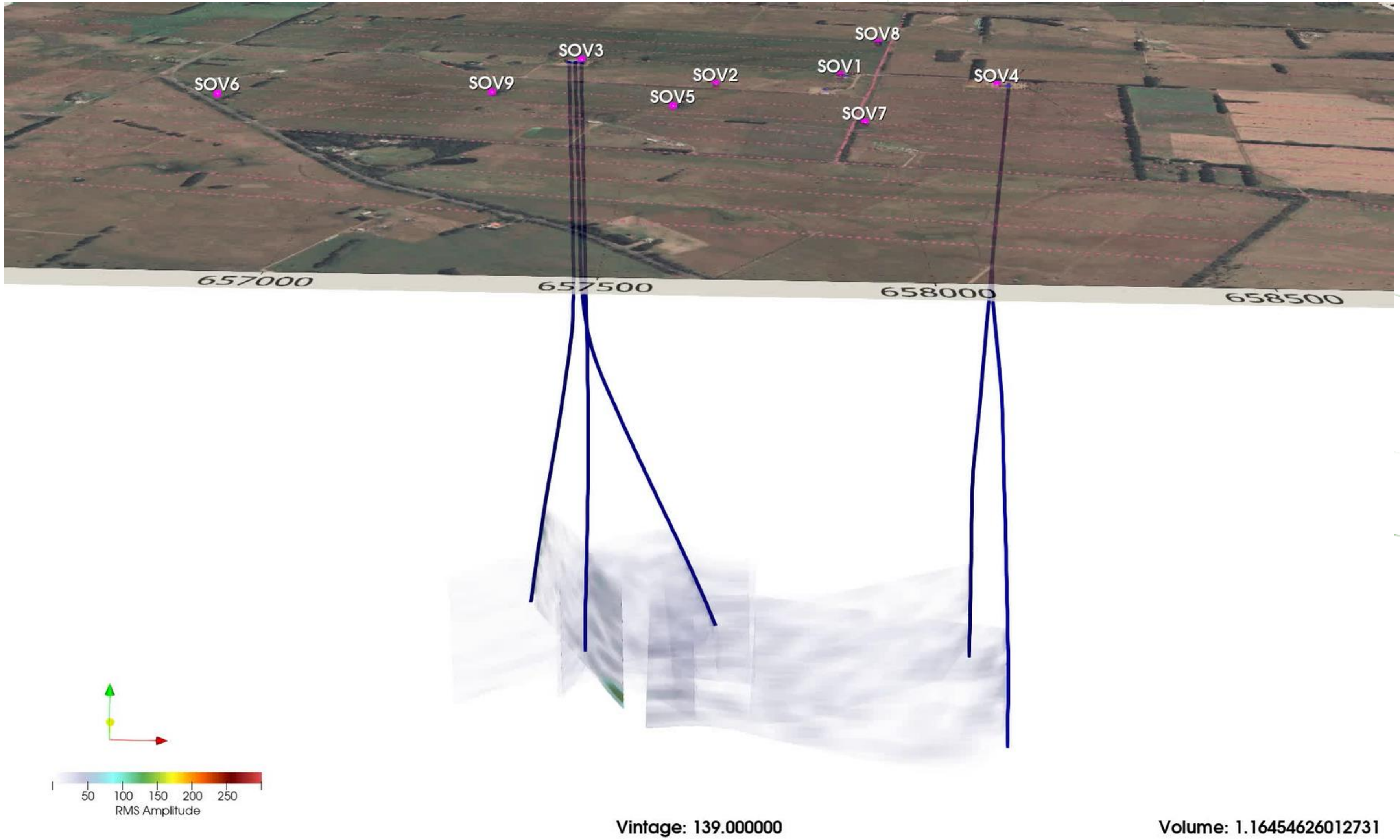


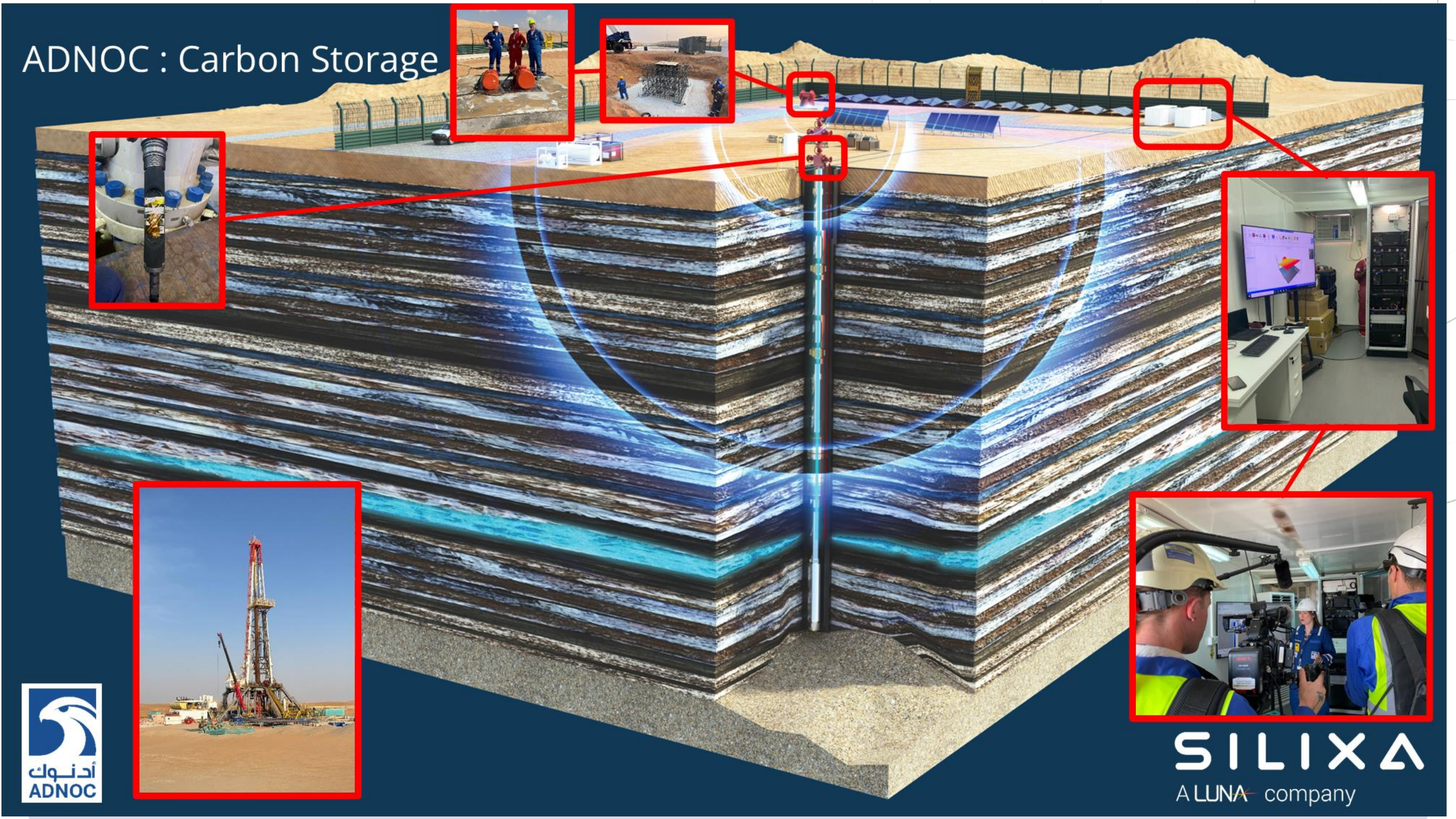
Incremental injected CO_2 in [tons]

Growing seismic signature of the CO_2 plume

Pevzner et al. 2021 Intl Journal of Greenhouse Gas Control

Continuous plume monitoring using permanent sources




ADNOC : Carbon Storage
أدنوك
ADNOC
SILIXA
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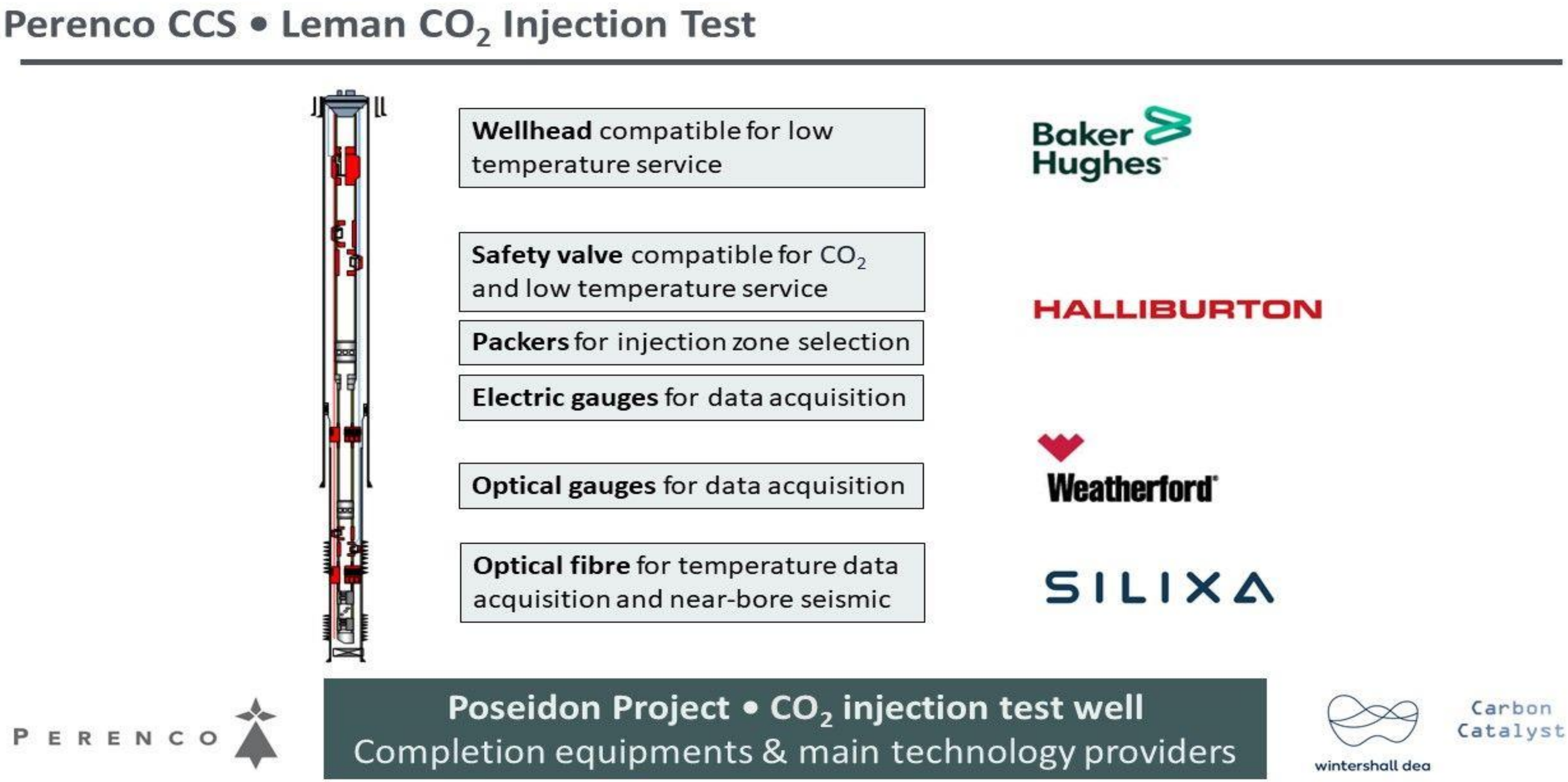
Perenco : Offshore North Sea Carbon Storage



[Perenco CCS - Deploying cutting edge technologies - YouTube]

Case Study: Gas Hydrate Research Project

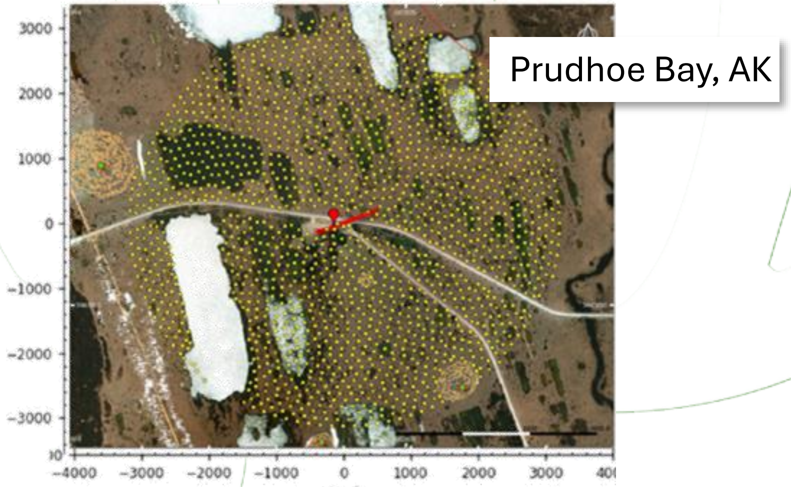
Objectives:

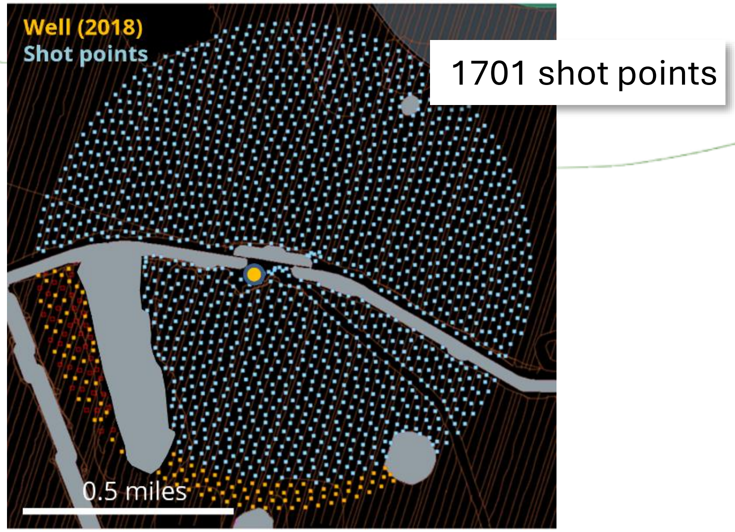
- Acquire scientific data on long-term production behavior
- Verify mitigation technologies against possible technical issues such as sand production and excessive water production
- Identify operational issues associated with long- term production

Project outline:

- Joint R&D: JOGMEC, US-DOE/NETL, USGS
- Scientific well drilled in 2013 (USGS)
- Stratigraphic Test Well drilled in 2018 (BP Exploration AK, US-DOE/NETL)
- Largest known onshore 3D DAS-VSP survey
- 3D VSP used to detect distribution of faults around the R&D well pad
- Monitoring and production wells are being drilled
- DAS, DTS & DSS to be used to understand the well condition to achieve sustained production, and identify production anomalies

AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) | JOGMEC | NETL NATIONAL ENERGY TECHNOLOGY LABORATORY | USGS science for a changing world

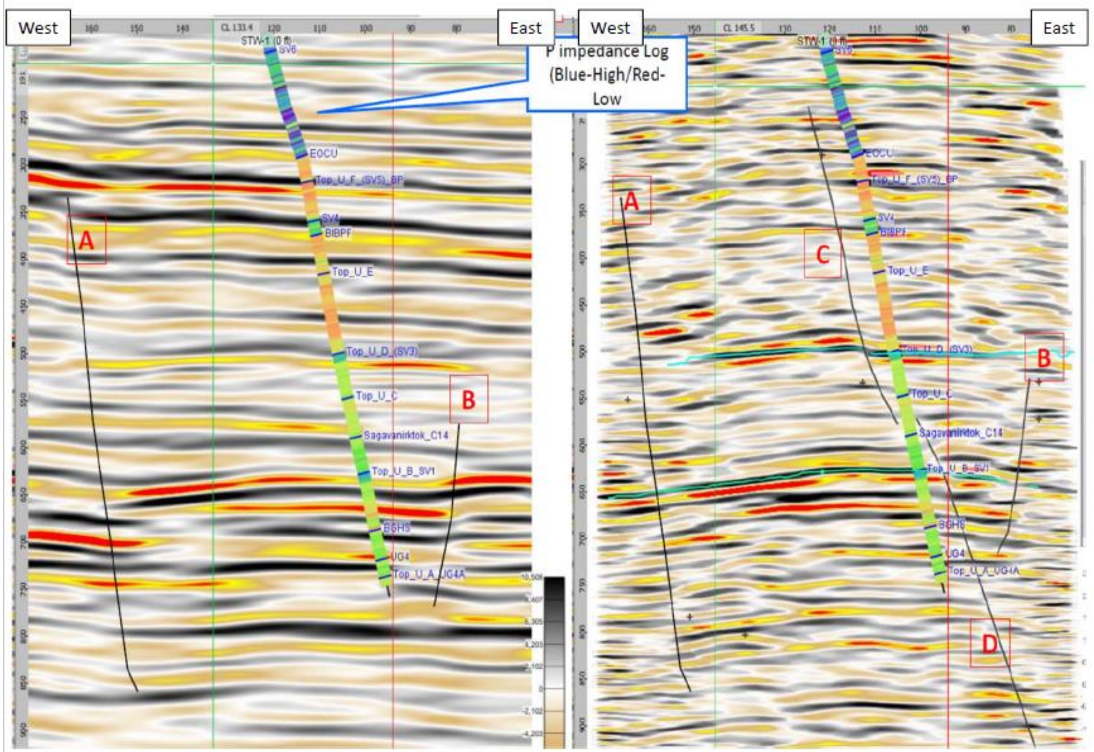




Fujimoto et al. (2021) SEGJ

3D VSP for Fault Delineation

Surface seismic vs. High-res 3D VSP

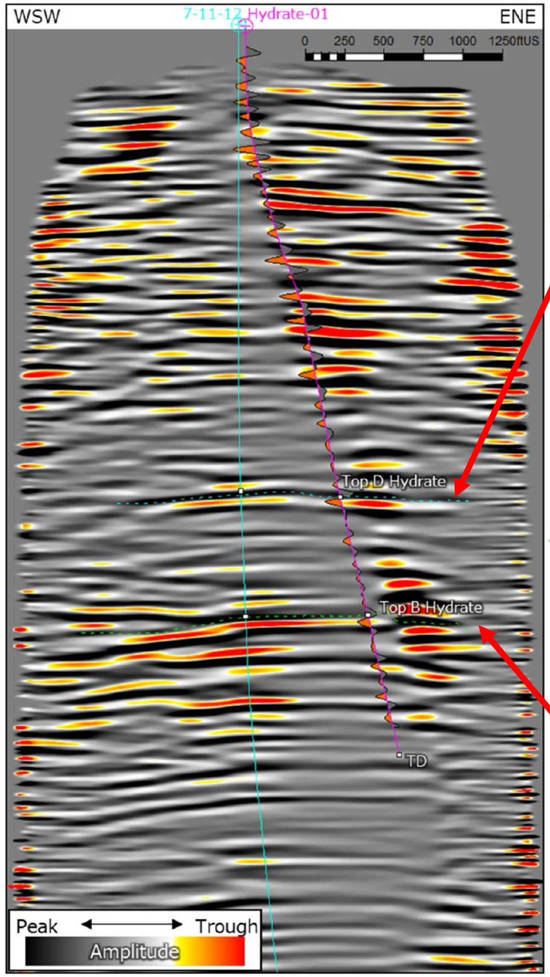


P-P & P-S imaging around the well

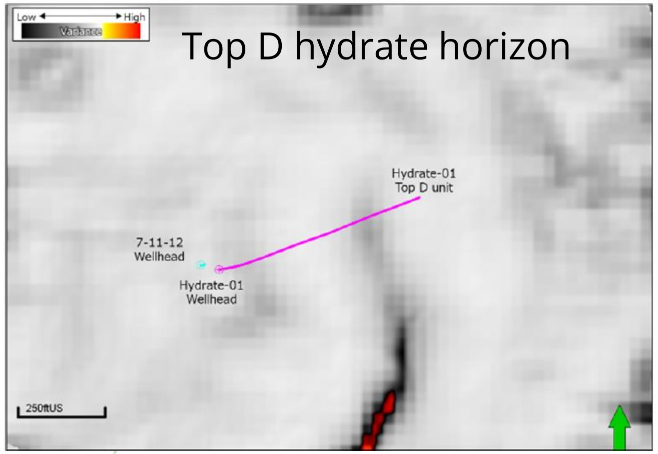
Faults C and D are visible only in 3D VSP

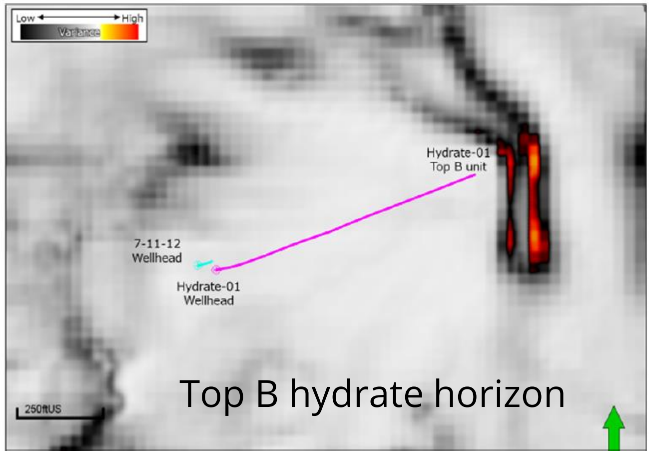
Courtesy of JOGMEC

3D VSP section



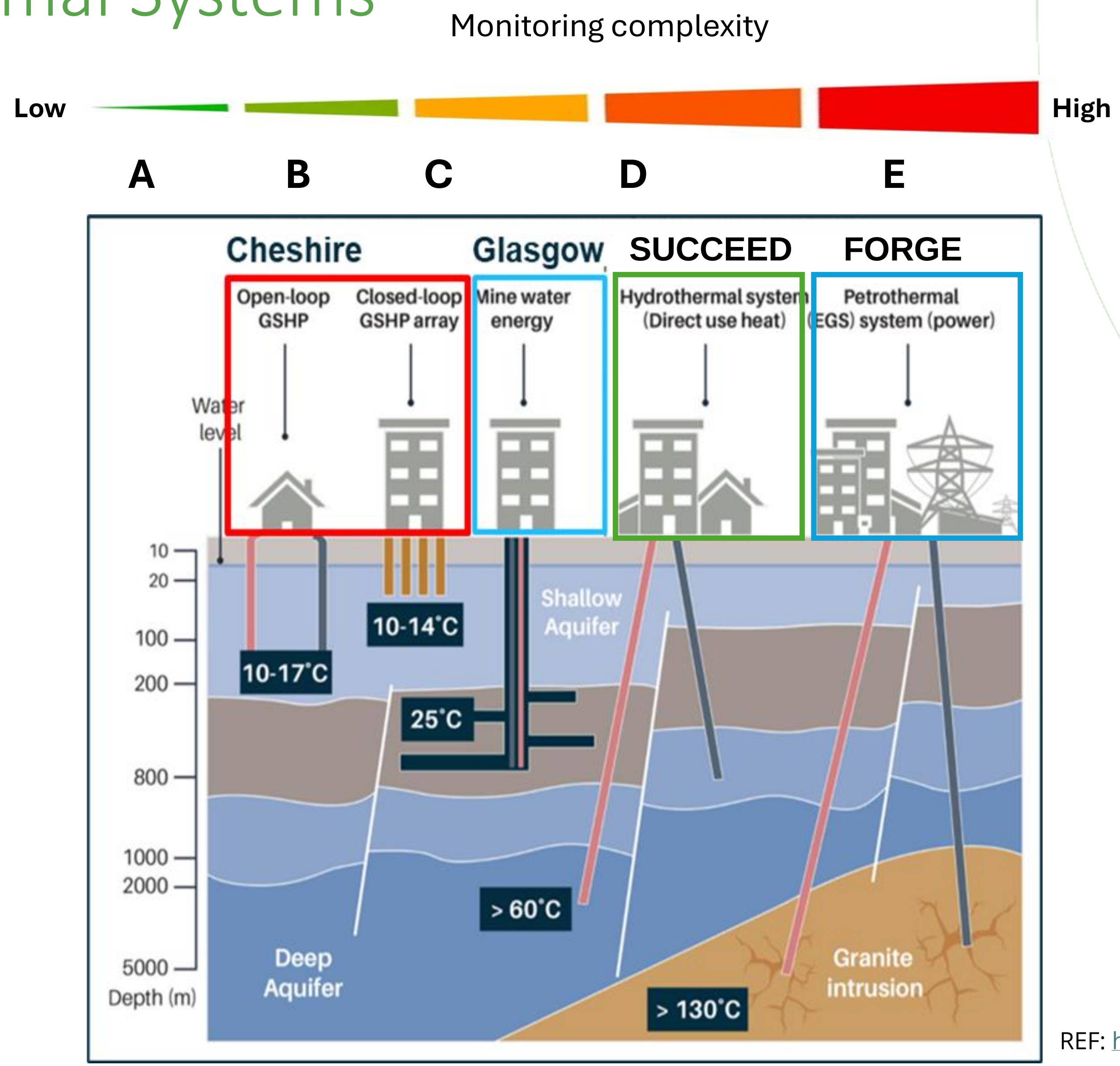
Variance attribute





Fujimoto et al. 2021 SEGJ

Geothermal Systems



Low-temperature (< 60º C)

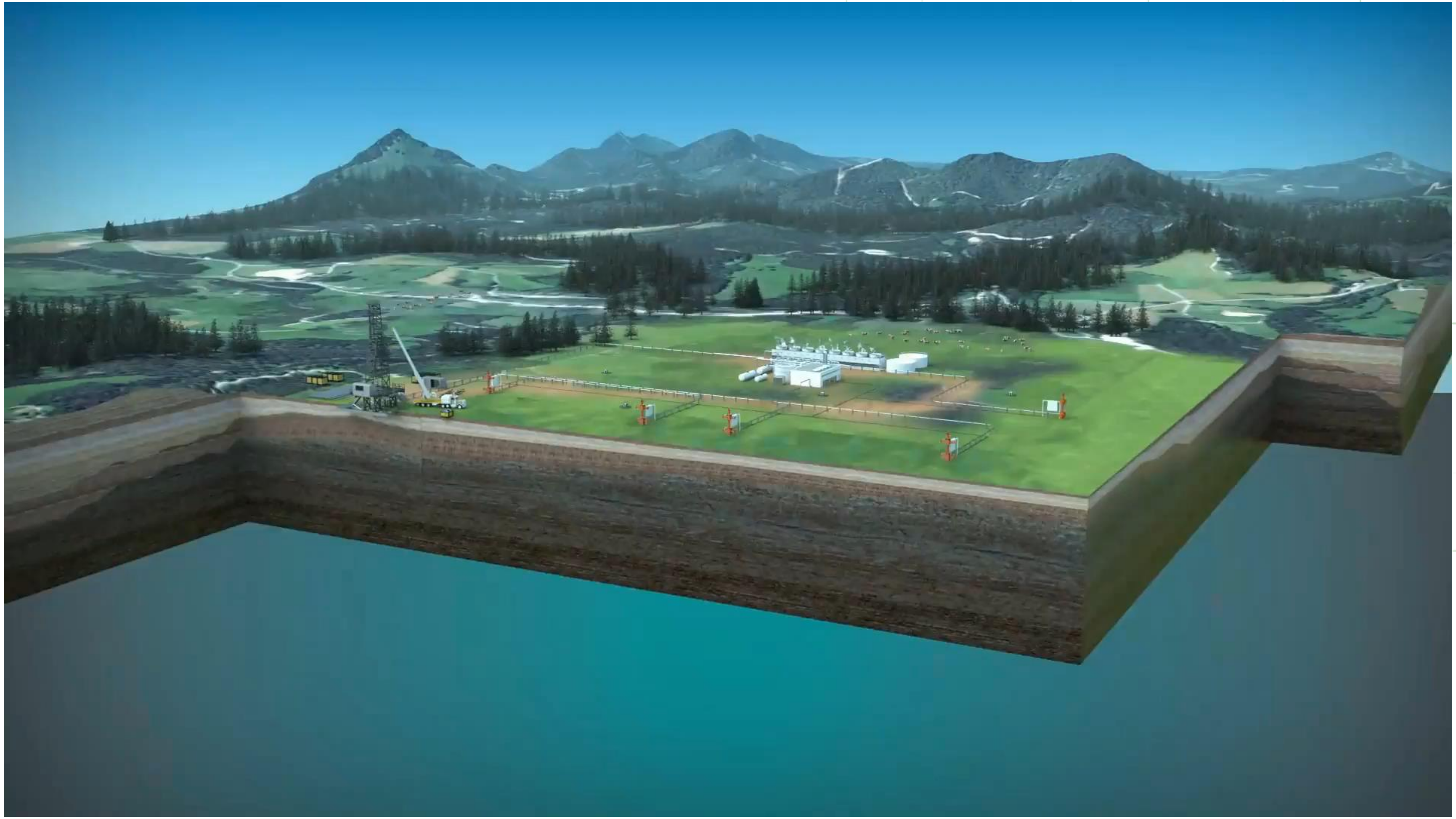
A. Open loop system
B. Closed loop system
C. Mine water energy

High-temperature (> 60º C)

D. Hydrothermal system
E. Enhanced Geothermal System (EGS)

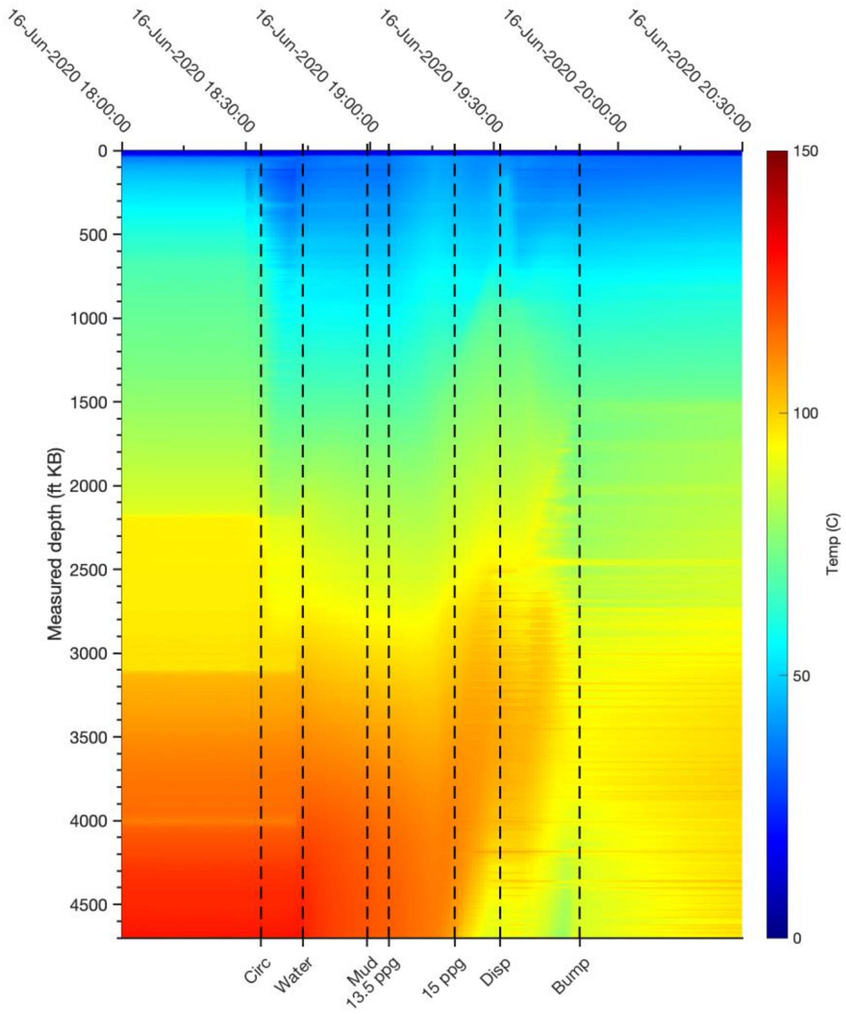
REF: https://ukgeos.ac.uk/

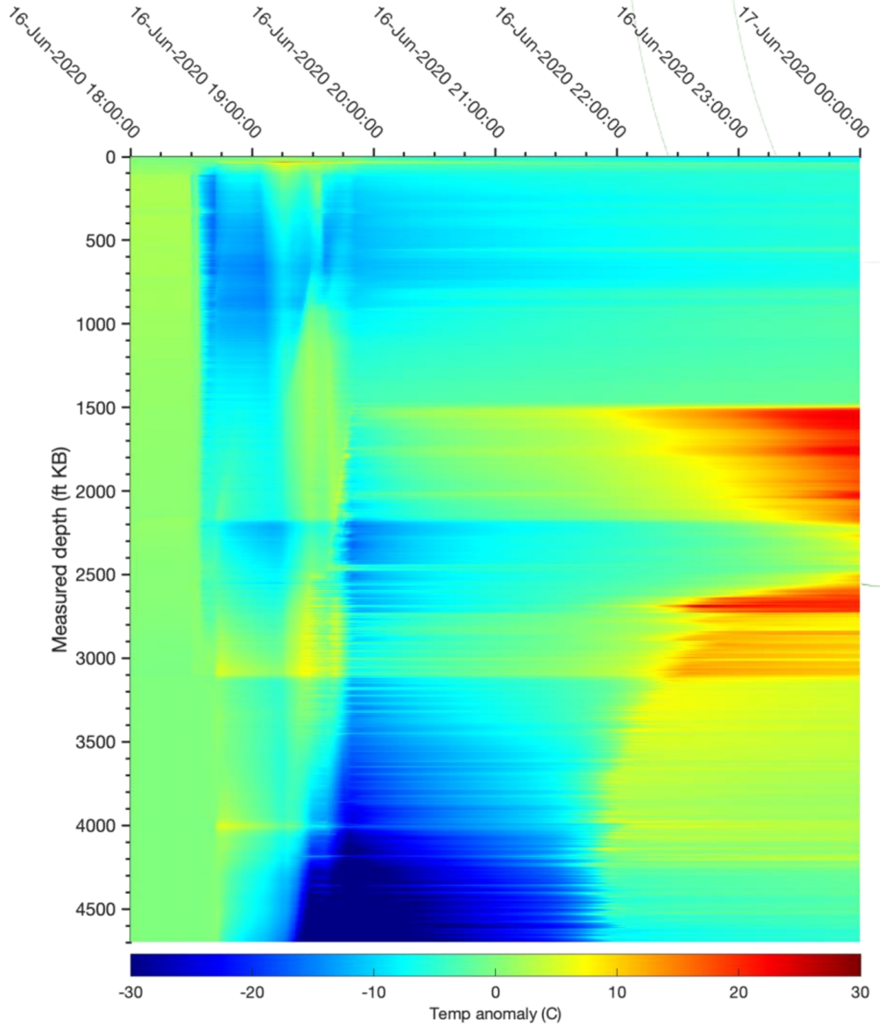
DFOS Geothermal Monitoring

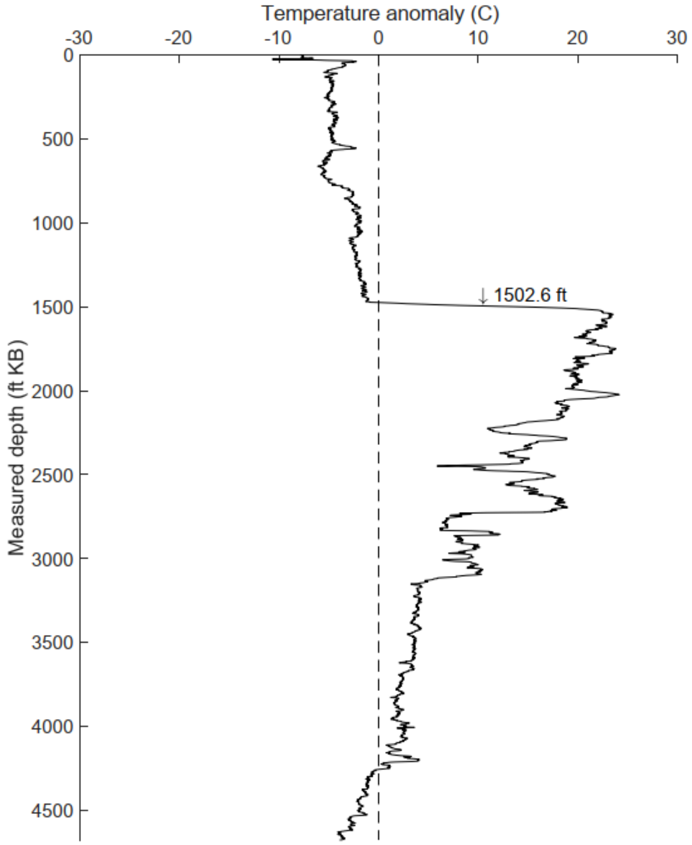


https://silixa.com/sectors/energy/geothermal

Cementation Monitoring – New Mexico (2020)



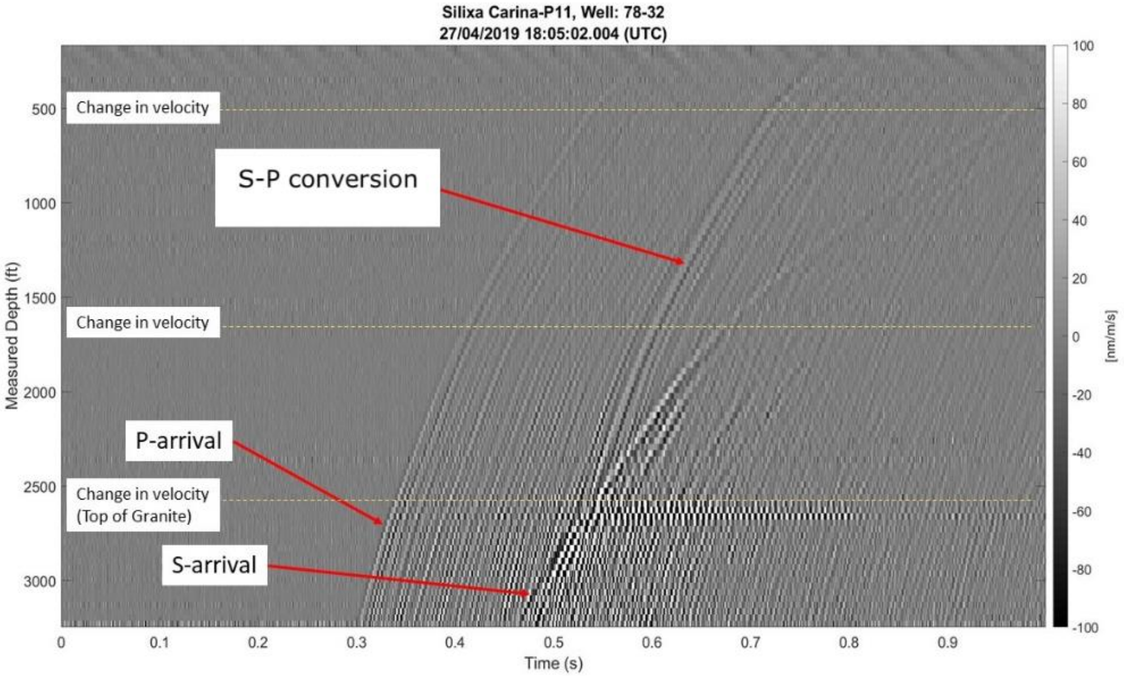




Geothermal Case Study: Utah FORGE

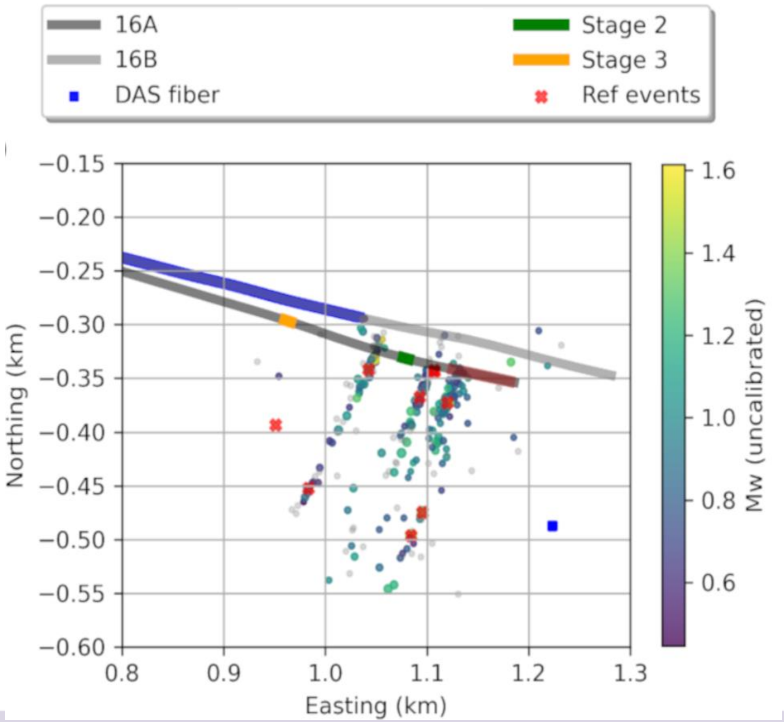
- Department of Energy (DOE) funded
- Provide an underground laboratory for developing and testing innovative tools and stimulation techniques for developing EGS reservoirs.
- Extend existing technologies developed for oil and gas beyond current capabilities to successfully produce electricity from hot crystalline rocks

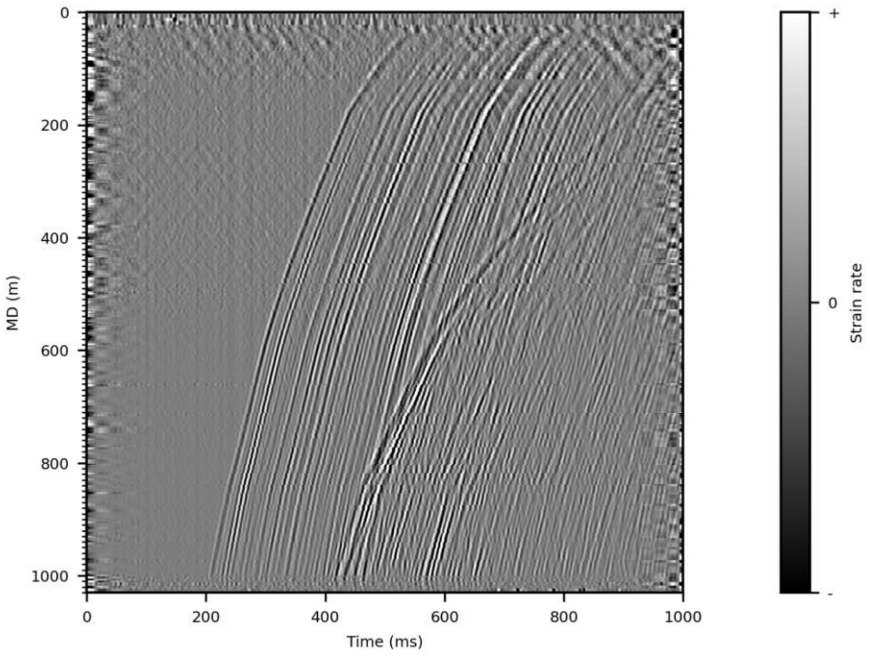
- **Stage 2C:** April 2019
- Single well microseismic monitoring
- Carina system acquisition

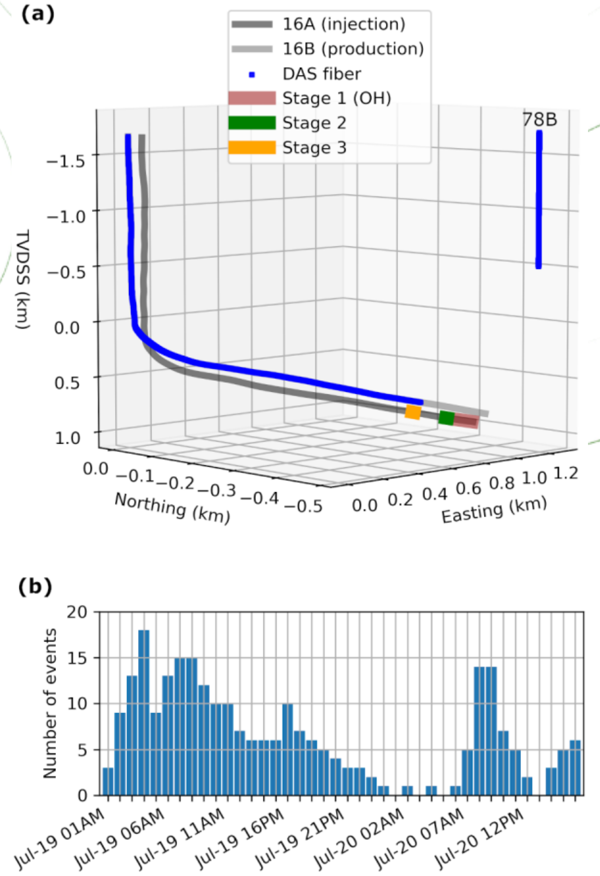


Microseismic Monitoring – 2019 – ongoing

- Circulation tests were performed over a period of approximately two days in July 2023 following completion of the second well
- Run microseismic event detection algorithm on continuously acquired DAS data recoded during stimulation.
- 250 microseismic events detected in the close vicinity of the new well.







Case Study: Synergetic Utilisation of CO2 storage Coupled with geothermal Energy Deployment (SUCCEED)

Aimed at reducing CO_2 emissions by storing CO_2, while enhancing geothermal performance.

- **Maintain reservoir pressure**
- **Increase reservoir permeability**
- **Understand the effects of reinjection of produced CO2**

Kizildere hydrothermal plant in Turkey

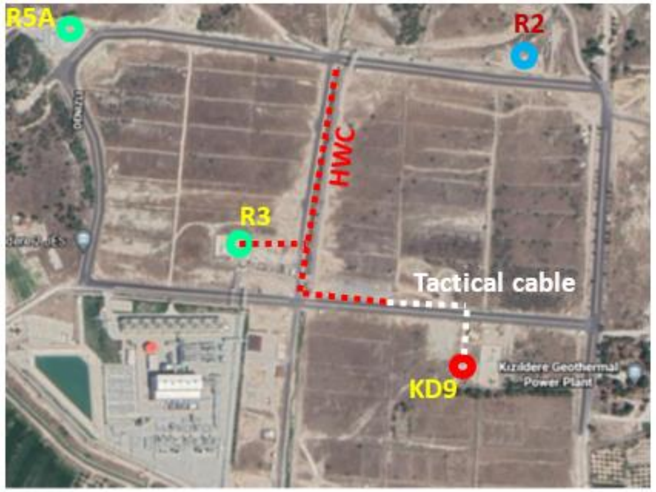
- 260 MWe installed capacity
- 2,000 – 3,500 m reservoir depth
- 220 – 245°C reservoir temperature
- Carbonate reservoir

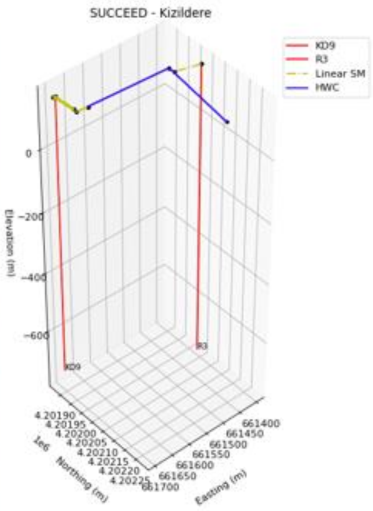
Produced raw gas piped from Kızıldere Unit 2, injected with a compressor/booster system at the injection well @700m depth @ supercritical state

DFOS Monitoring solution – suspended deployment

Challenge: high-temperature monitoring and installation of monitoring equipment in pre-existing wells

- In R3 and KD9 wells DAS engineered fibre downhole suspended fibre optic cable.
- temperature and seismic profiling in two wells (rated at 260°C).
- Surface HWC path through the analysis of geothermal fluid flow paths and land conditions - imaging with improved broadside P-wave sensitivity
- Electric linear synchronous motor (LSM) seismic vibrator (E-vibe) (10 kN, 3.6 to 240 Hz, 10 kW)



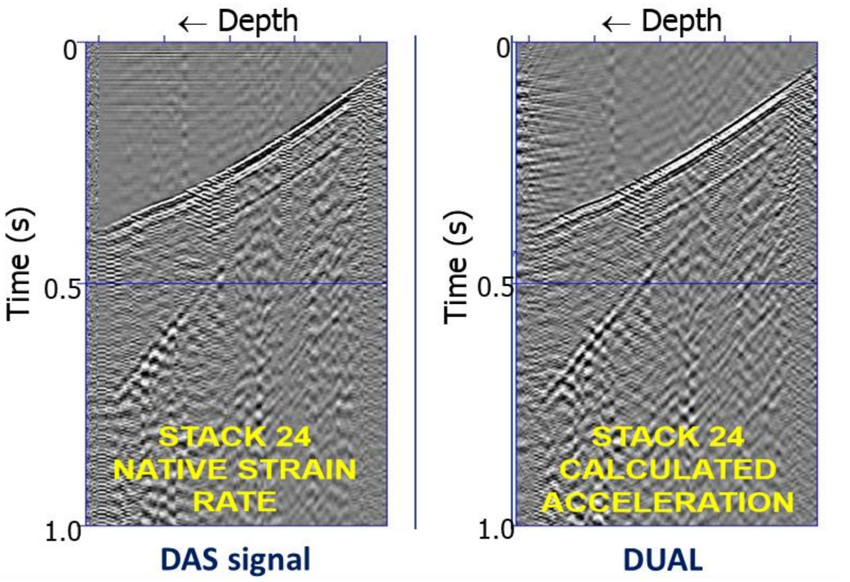


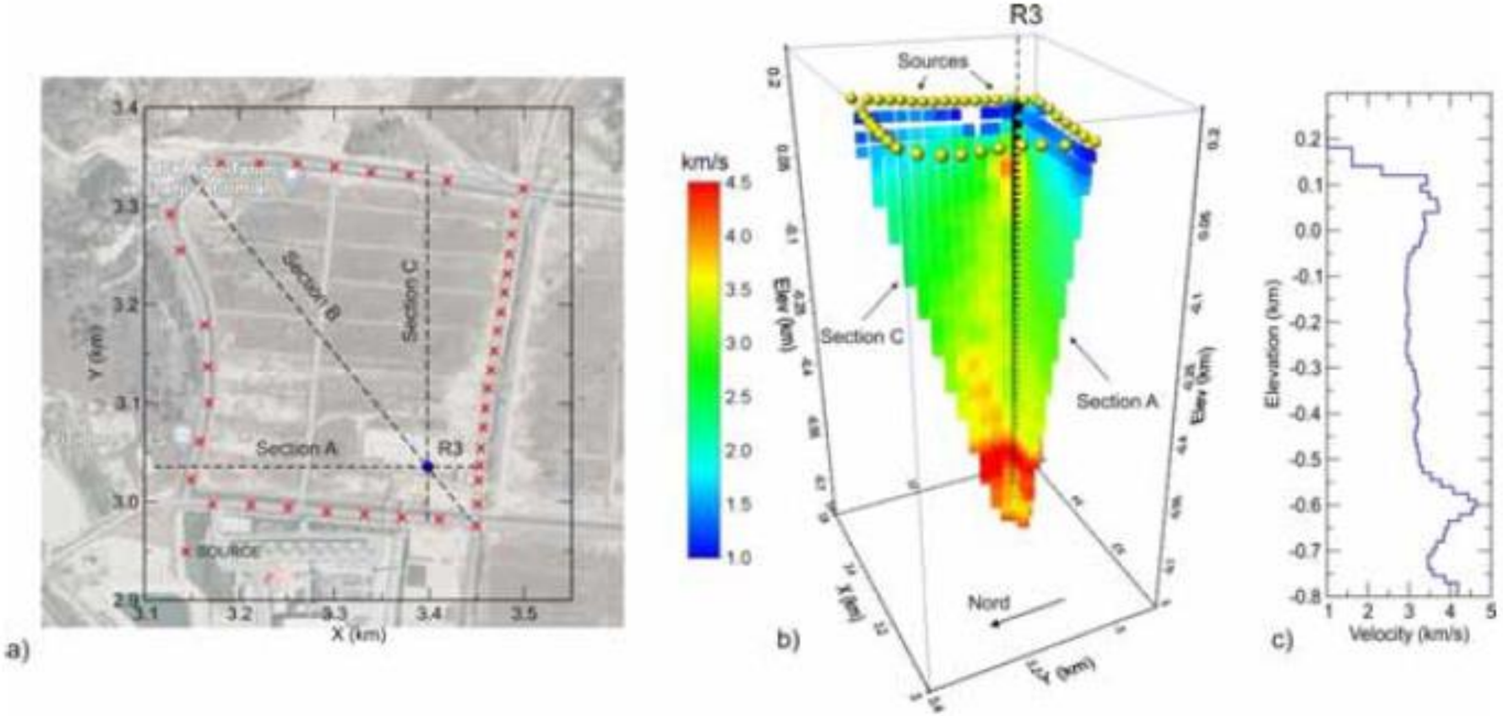
near-offset VSP QC during acquisition

Vertical Seismic Profiling (VSP) and seismic reflection imaging of the reservoir.

Baseline survey before CO2 injection begins. Aim is to provide time-lapse monitoring of the injection process

DAS DUAL wavefields combination provides an advantage in survey quality control, especially when the cable coupling is variable





Case Study: Hellisheiði geothermal field, Iceland

- Combined heat and power plant began operations in 2006
- Currently, site produces ~4,400 tonnes/hour of geothermal fluid
  - 75% reinjected into the reservoir via 17 wells.
  - Annually, ~12,000 tonnes CO_2 captured & stored

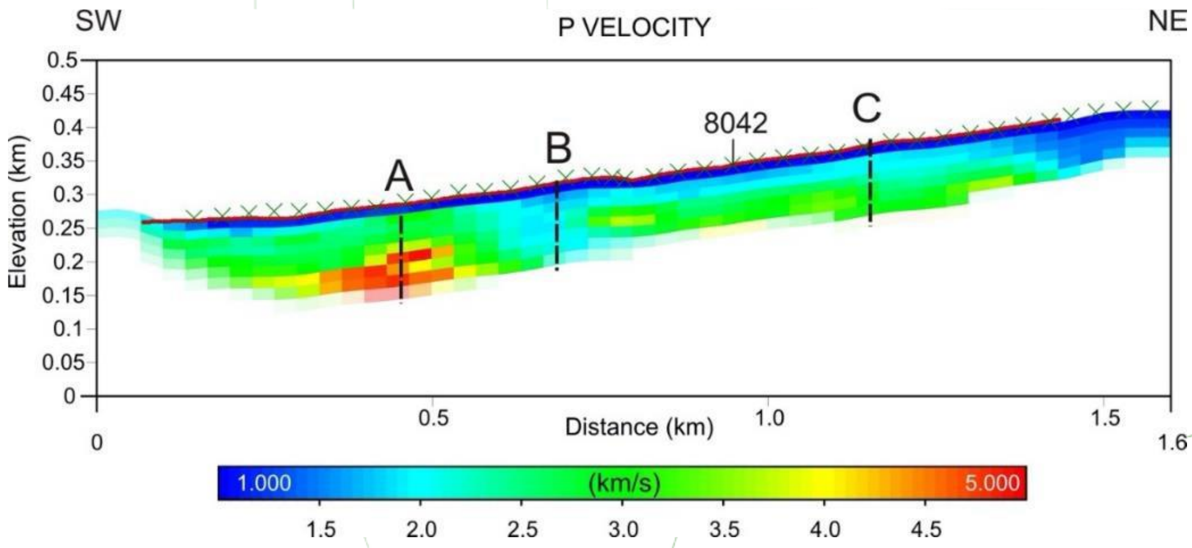
Seismic surveys

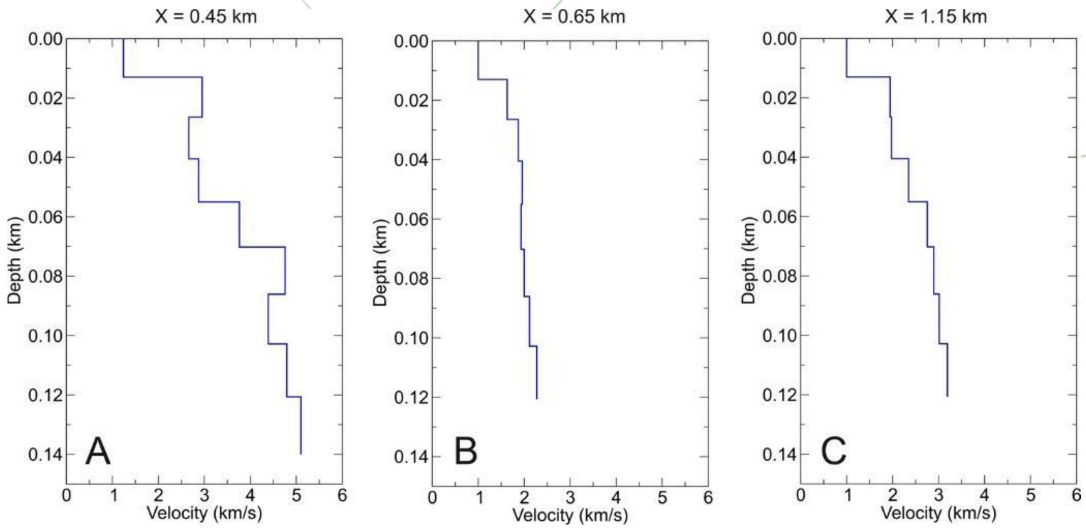
- DAS data: Silixa iDAS v2 10m gauge length
- Surface trenched helically wound cable (HWC)
  - Improve broadside P-wave sensitivity
- Passive seismic recording
  - 2020 (30 days), 2021 (6 days) & 2022 (5 days).
- Active seismic surveys
  - 2021 – HWC DAS & geophones
  - 2022 – HWC DAS only
  - Seismic Mechatronics electric linear synchronous motor (LSM) seismic vibrator (E-vibe)
    - Maximum driving force of 10 kN
    - Flat amplitude response 3.6 to 240 Hz.
    - 10 kW peak power consumption

Seismic imaging & seismicity

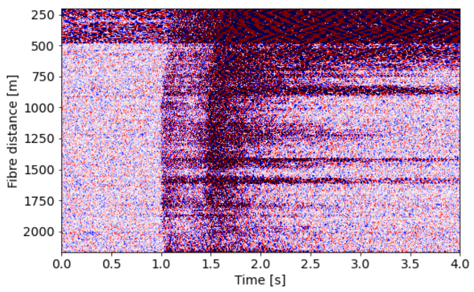
- Tomographic inversion of DAS data
  - First-arrival travel-times,
  - 38 shot points.
- Method
  - Simultaneous Iterative Reconstruction Technique (SIRT) algorithm,
  - Bending ray tracing.
- P-wave velocity models

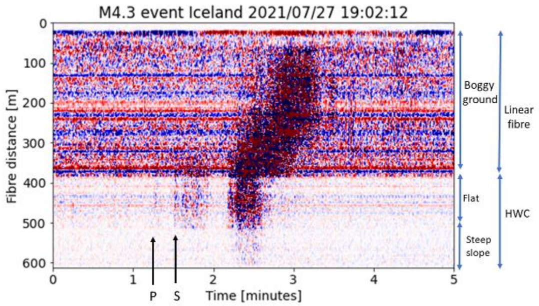
- Seismic event detection: STA/LTA
  - 108 events have been identified
  - 46 events in common with ETH 2020 seismometer data





Local event M>0.0

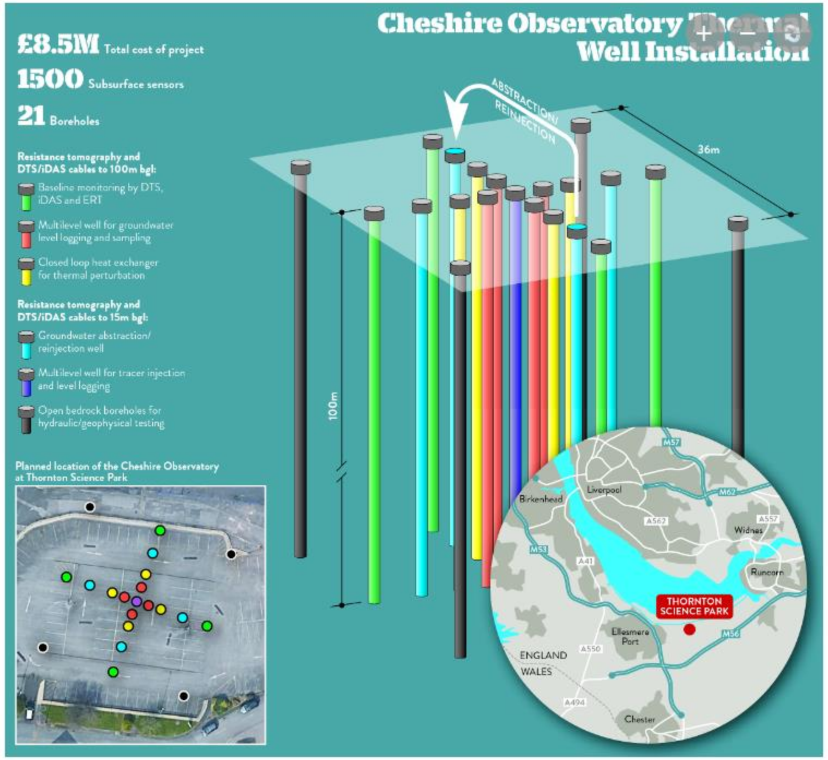




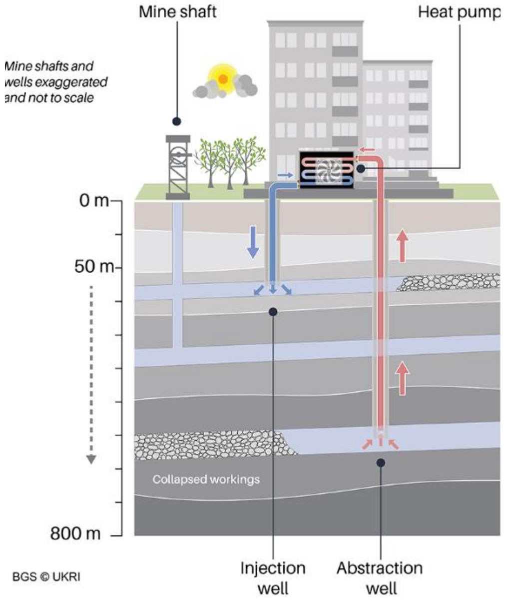
Stork et al (2022) GHGT-16

UK GEOS Observatory Cheshire, UK

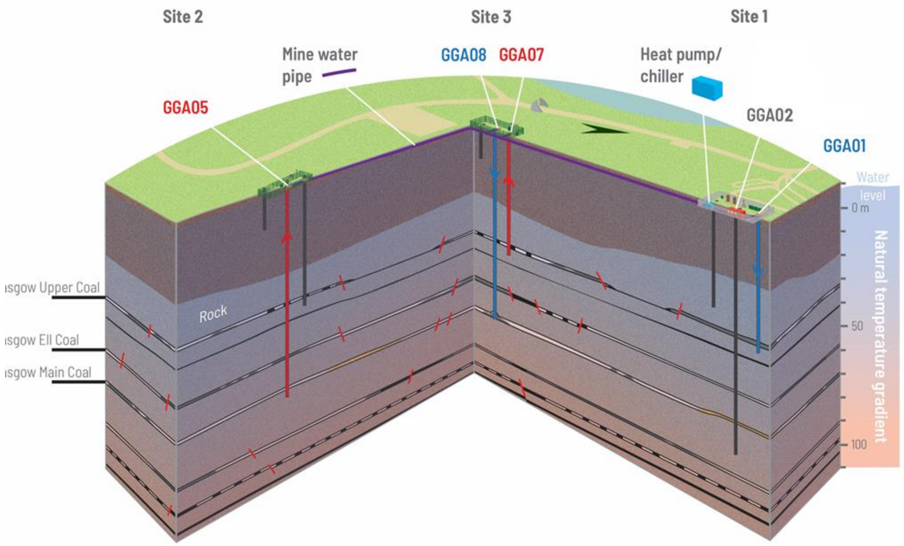
- Enabling research and innovation in aquifer thermal energy
- Subsurface energy storage to meet the challenges associated with decarbonising our society
- Geoenergy-related research opportunities over the 15-year lifetime of the site



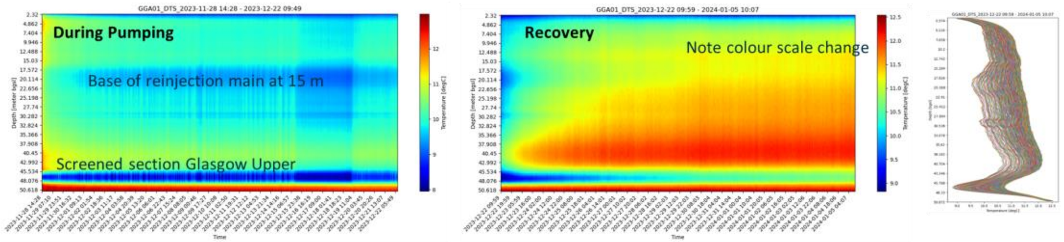
UK GEOS Observatory Glasgow, UK



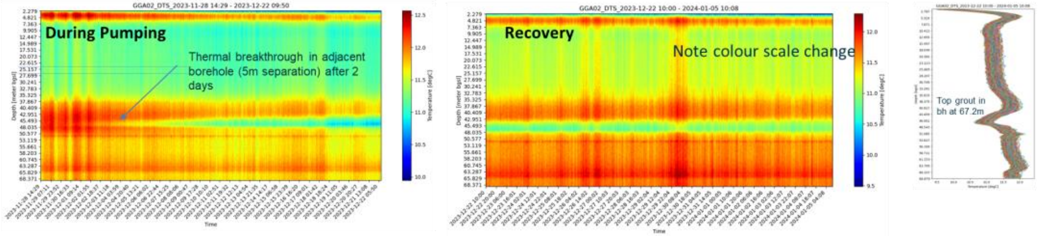
ERT electrodes and fibre optic cable being installed on the outside of the mine water borehole casing and screened section/pre-glued gravel pack



GGA01 – Reinjection borehole



GGA02 – 5m from GGA01



Mine-water heat abstraction from abandoned coal mines

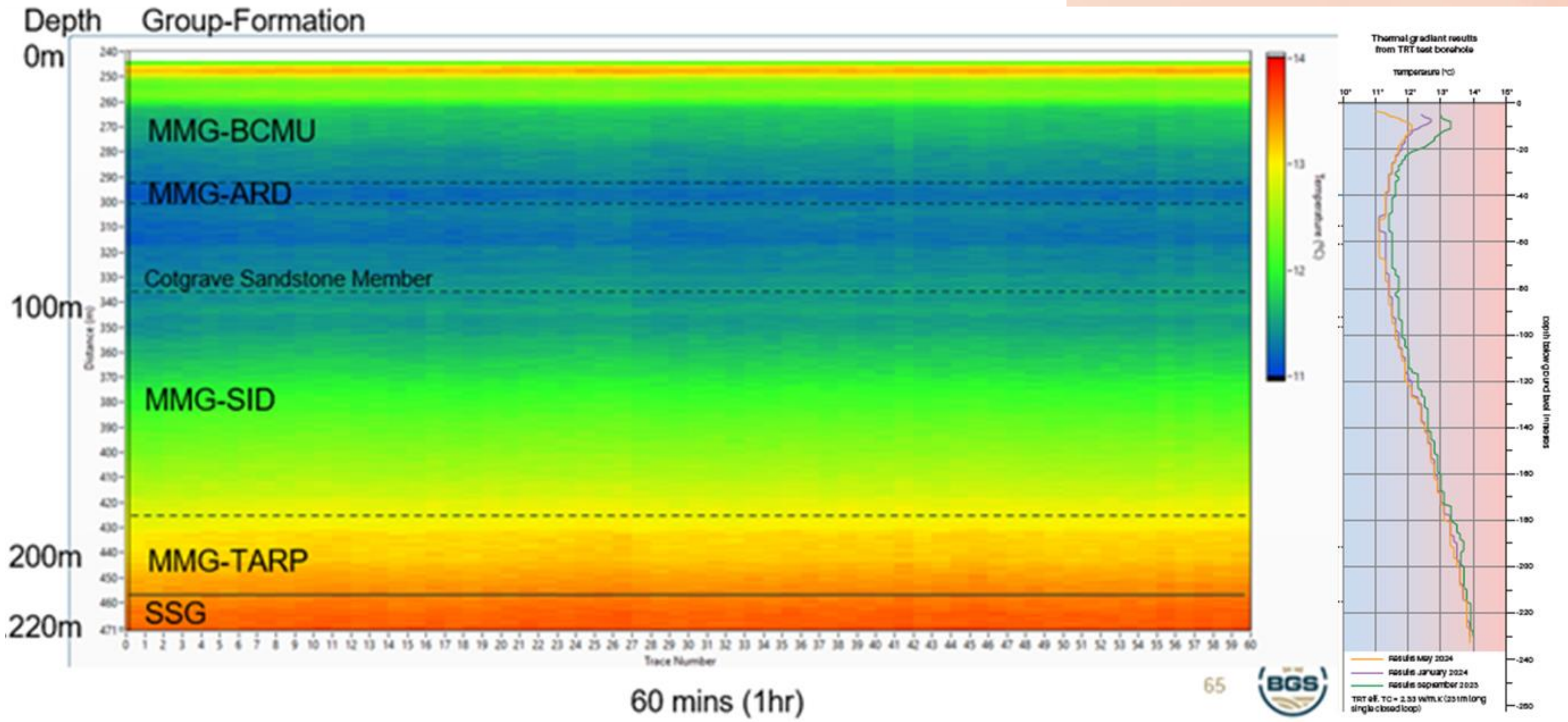
DFOS monitoring enables understanding of processes and interactions

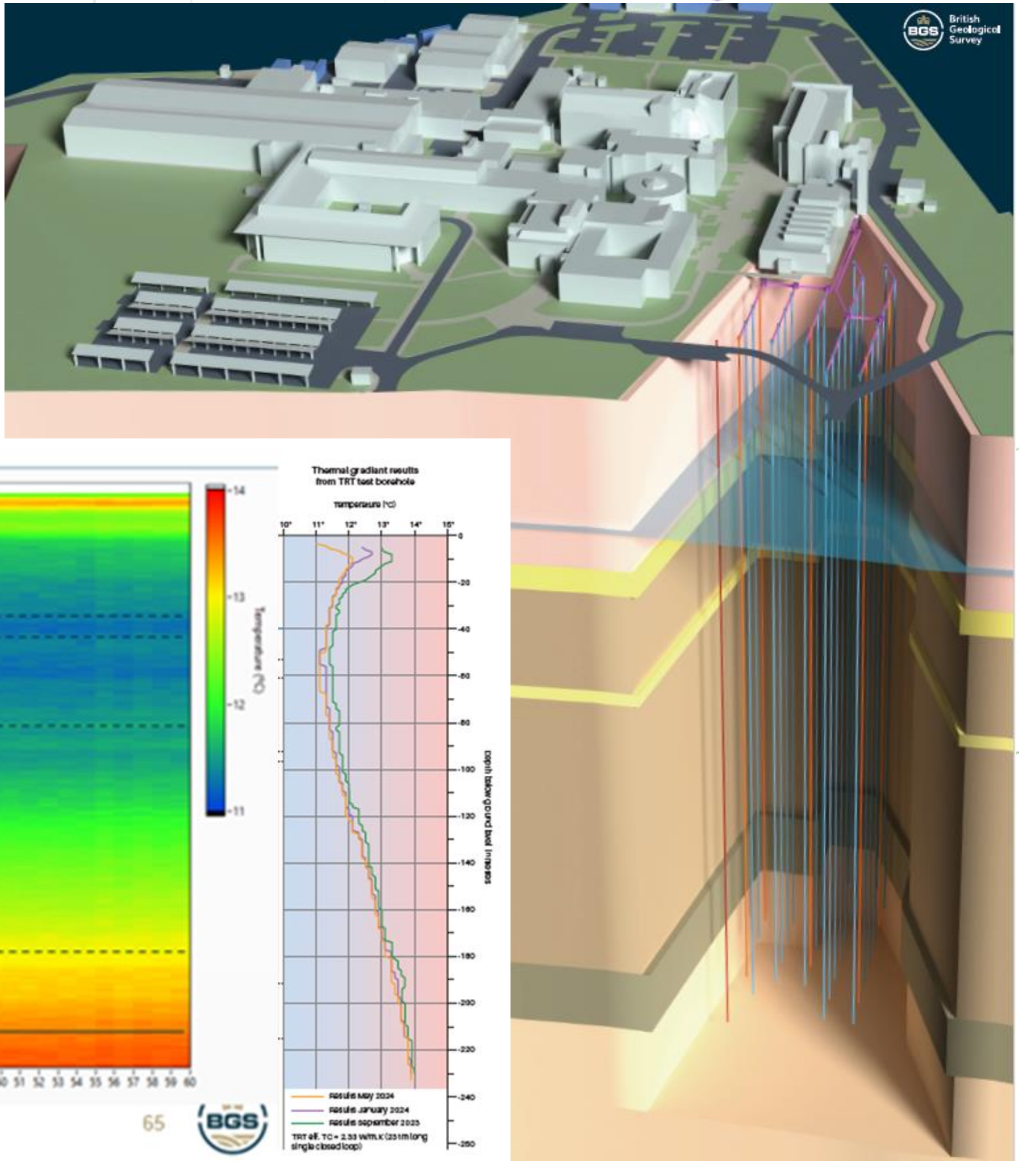
BGS Keyworth Borehole Monitoring

BGS Decarbonisation Programme - decarbonize energy needs by 2030

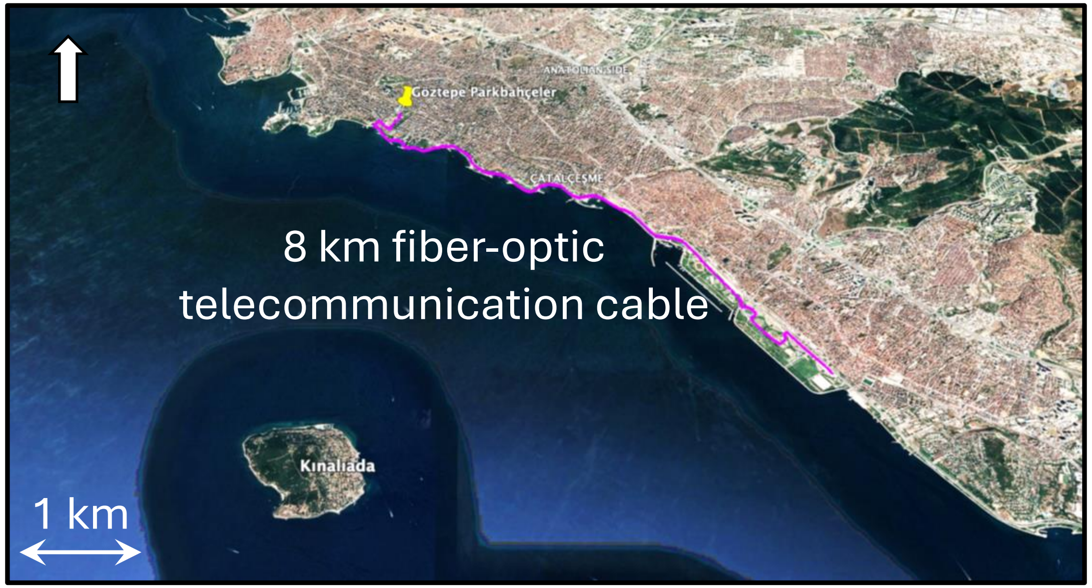
Vertical closed loop ground source heat pump systems capable of supplying all their heating and domestic hot water requirements.

DTS Baseline survey





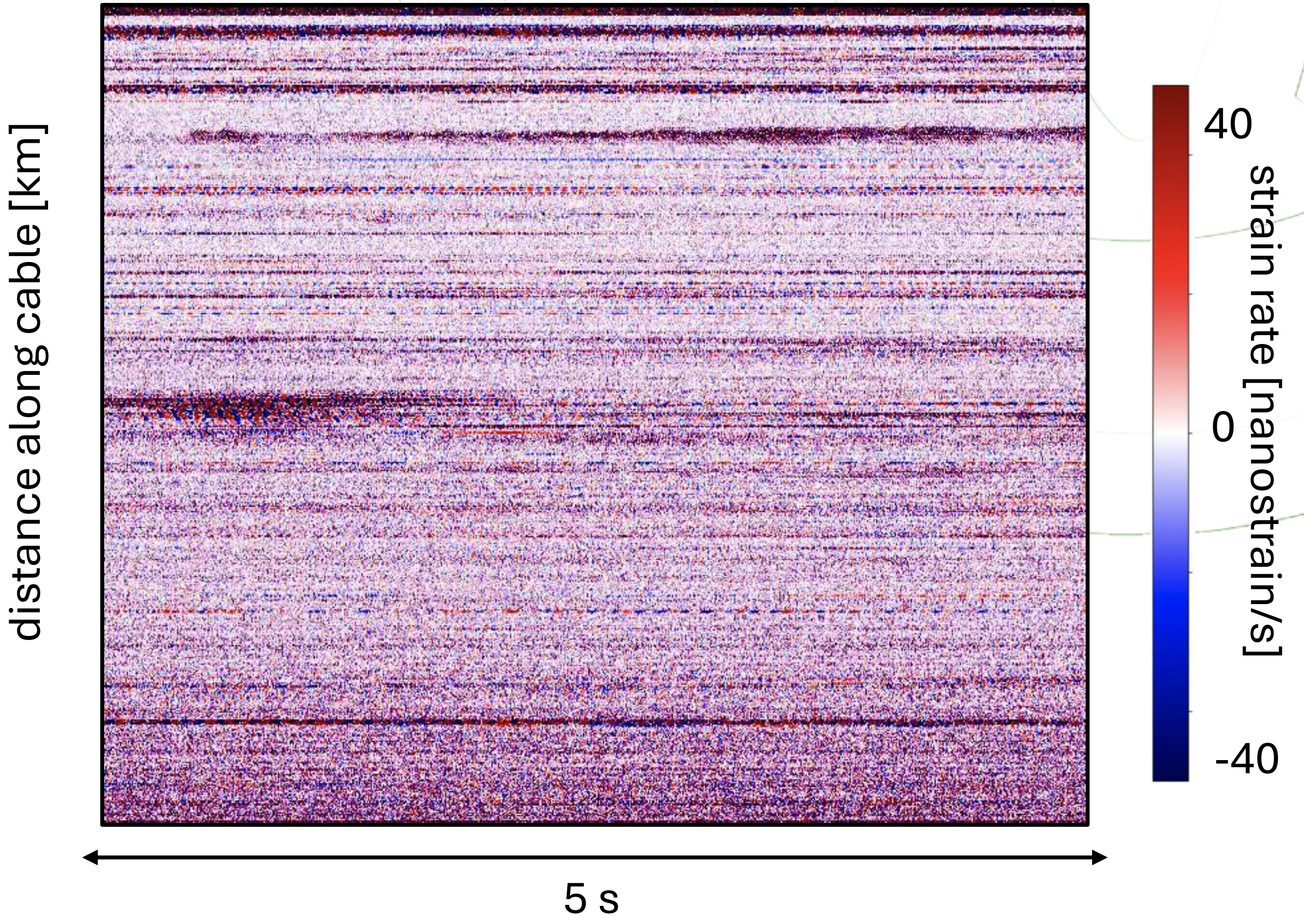
DAS Recording of the M7.8 Gaziantep earthquake Feb 2023



Video courtesy of Andreas Fichtner

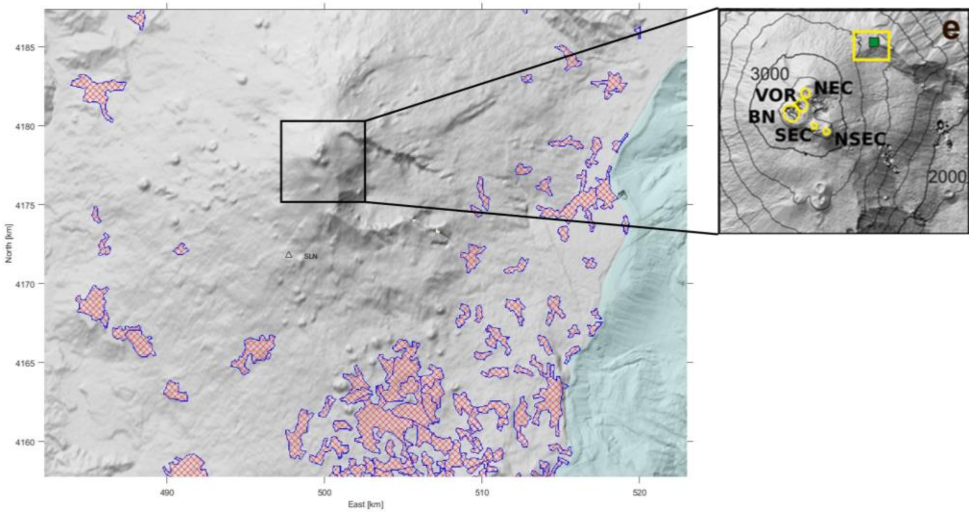
Strain-rate recording - Movie

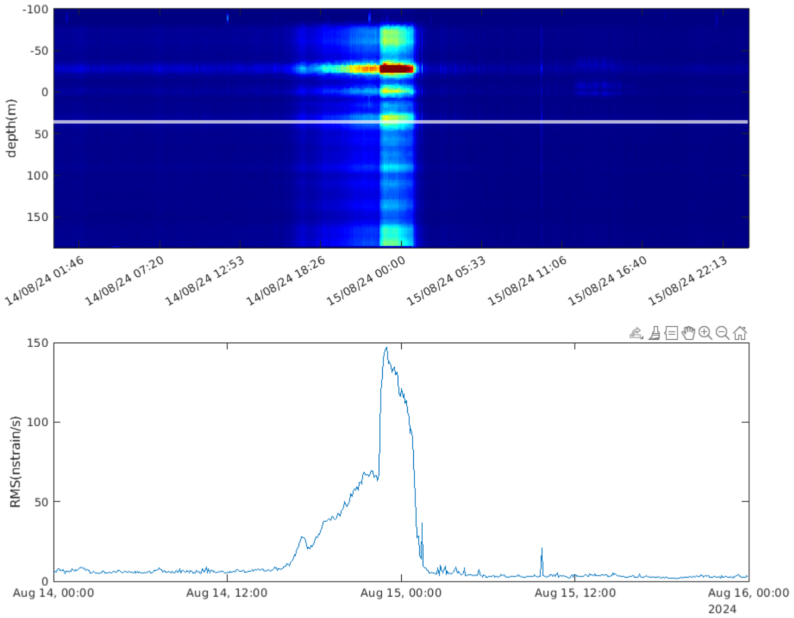
Start time: UTC 01:17:30.00 on 6 February 2023



ETNA Volcano Monitoring, Italy

- Each year more people and infrastructure are at risk from Natural Hazards
- Continuous and detailed observations enables understanding of the physical processes, reduce natural hazard risks & improve resilience
- Important hazards characteristics are frequency, magnitude, extent, onset, consequences
- The overall objective is to protect the safety, security, and economic well-being



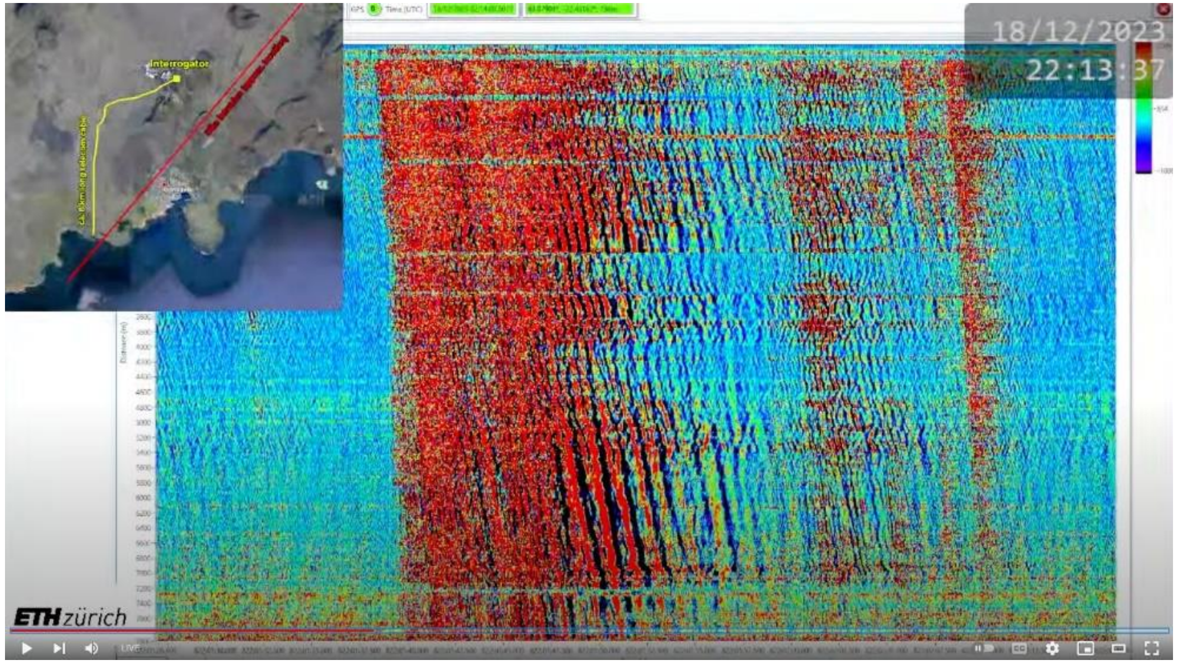


summer 2024 sequence of lava fountains from the from one of the summit crater, the Voragine crater

INGV: Currenti et al.

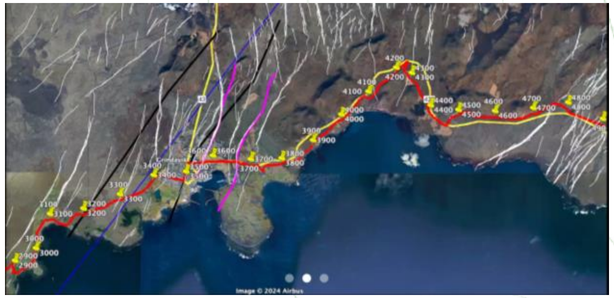
volcanic tremor computed on the DAS data recorded in a deep bore-hole (200 m depth)

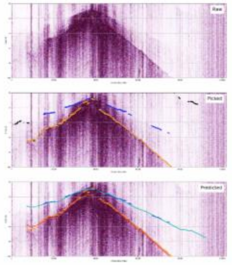
Volcanic Eruption Svartsengi/Grindavik, Iceland

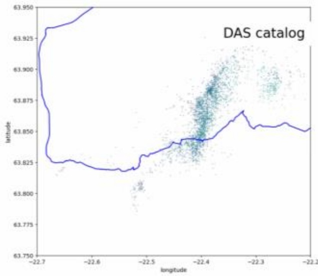


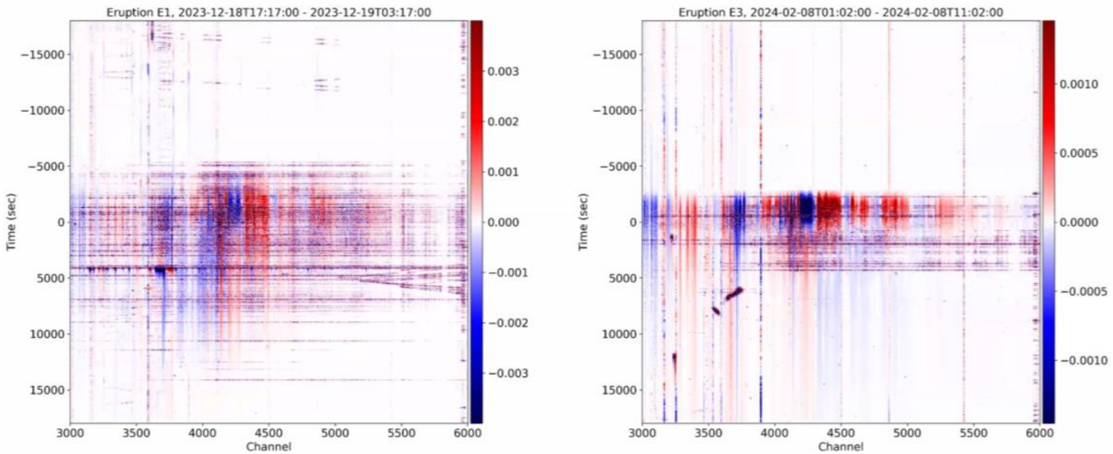
https://www.youtube.com/watch?v=1_3NBuVrmCs

ETH Zurich
8 km fibre optic cable
Live DAS data from Blue Lagoon November 2023 – April 2024





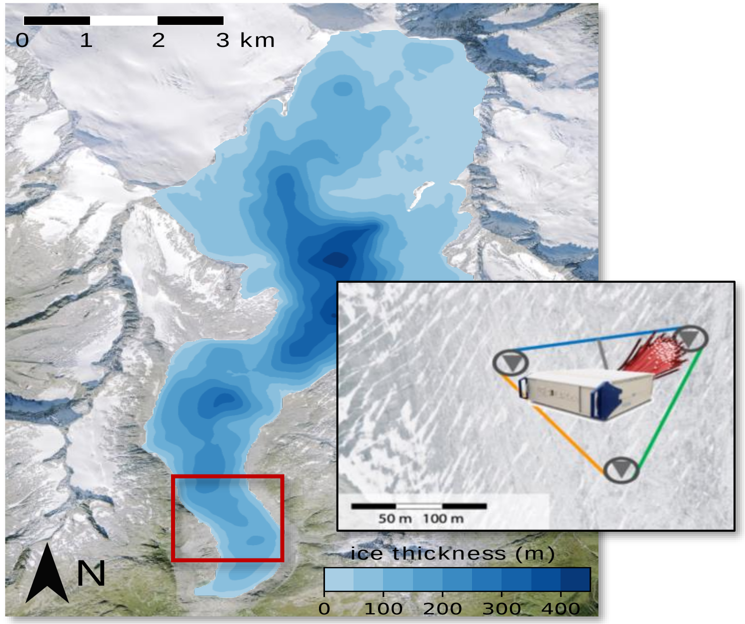




Caltech GMG – 2024
100km Dark Fiber – Strain DAS

Seismicity monitoring & Ground deformation

Glaciers Seismicity



ETH Zurich: Walter et al. 2020

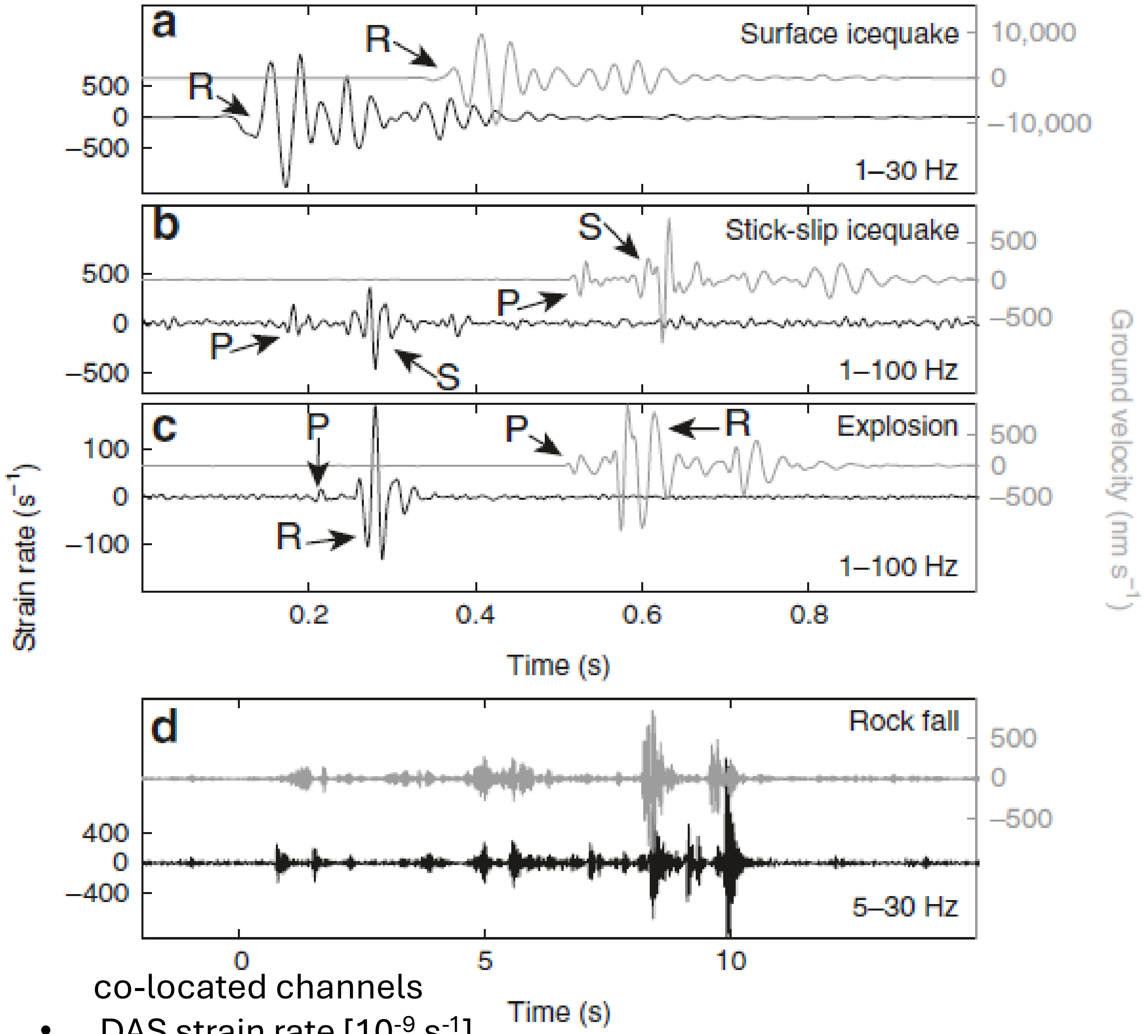
Rhône Glacier

- temperate Alpine glacier
- elevation: 2200 – 3600 m
- area ∽15.5 km^2, length ∽8 km

Location of instruments

- 1 km cable + 3 seismometers [took the same time ~1 hour]
- within ablation zone around 2500 m altitude
- ice thickness ∽200 m, flow velocity ∽35 m/yr

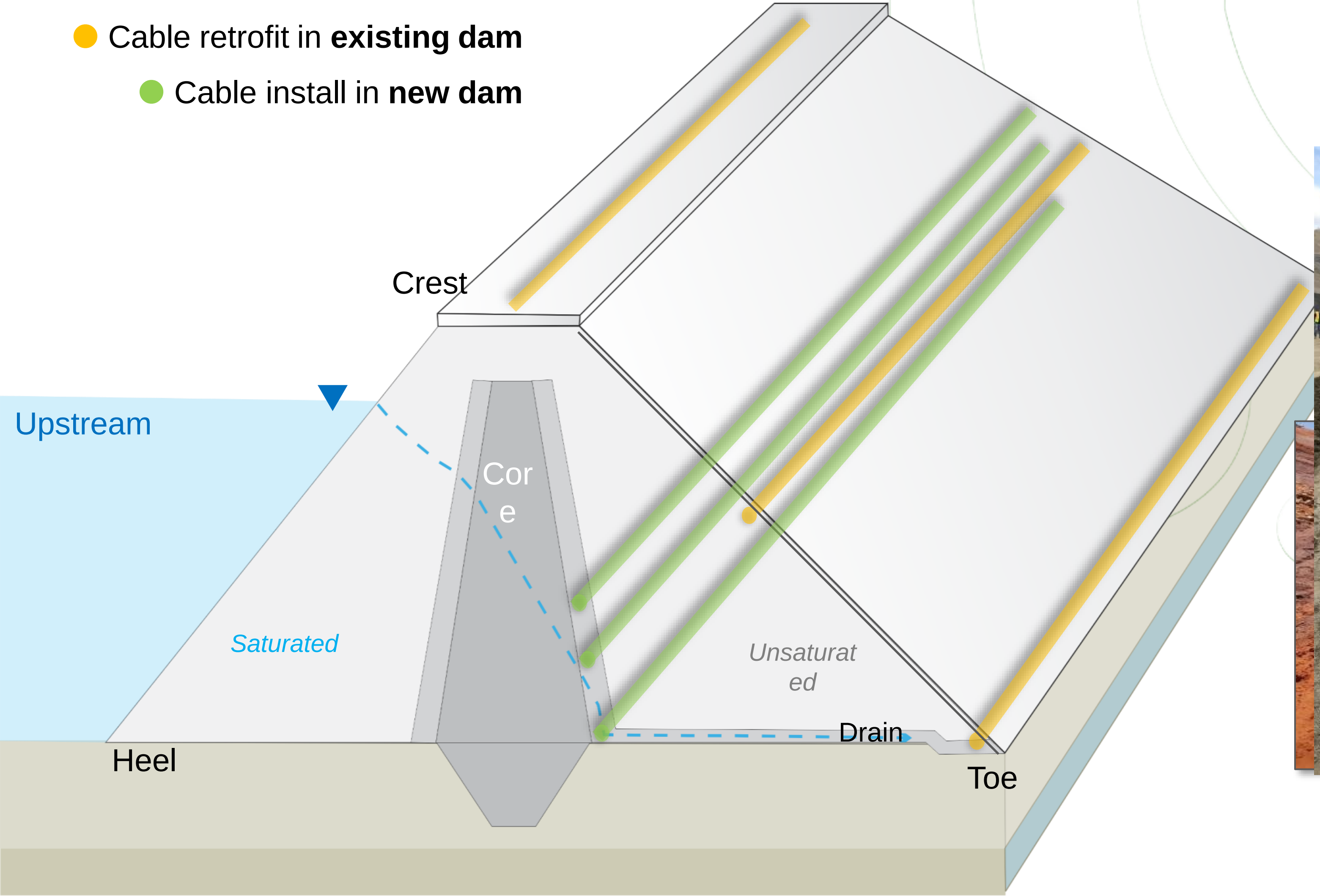
Events detection

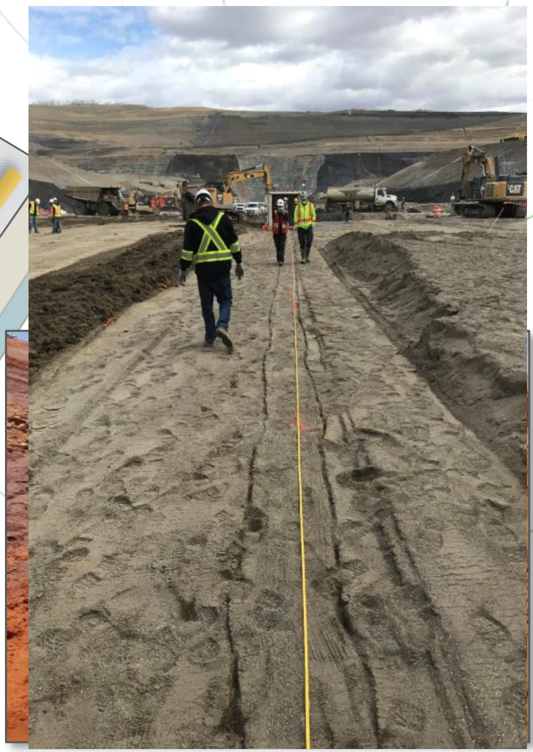


co-located channels

- DAS strain rate [10^{-9} s^{-1}]
- seismometers [nm s^{-1}]

Embankment Dam Monitoring with Distributed Sensing

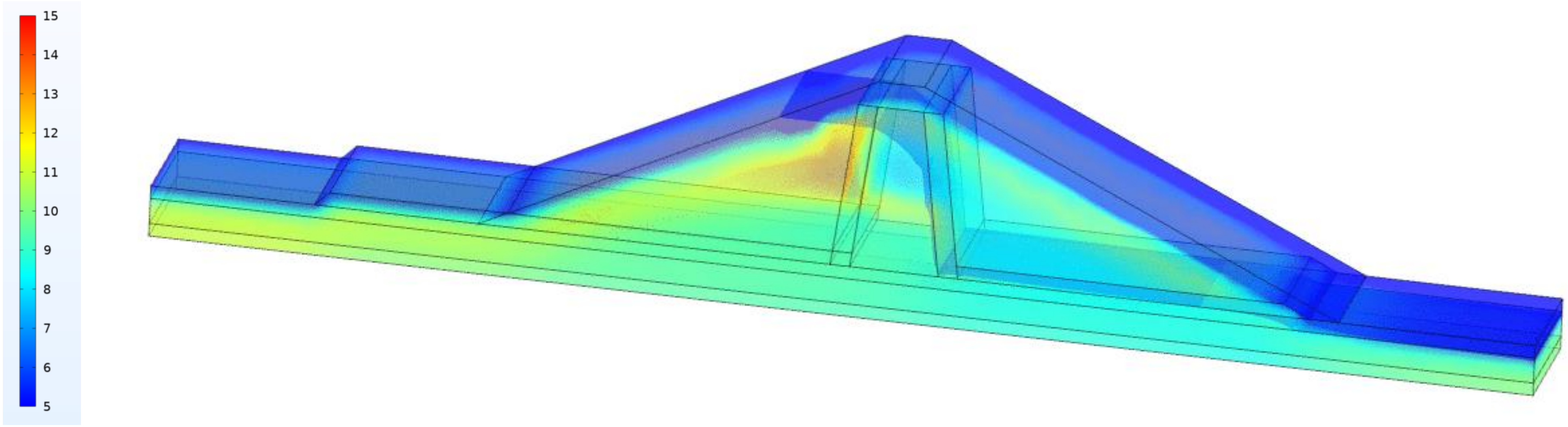




Temperature as heat tracer

Damage 2 m high, 5 m wide

Q=0.156 l/s



Passive Seismic

ITINERIS

Ambient Noise Interferometry (ANI)

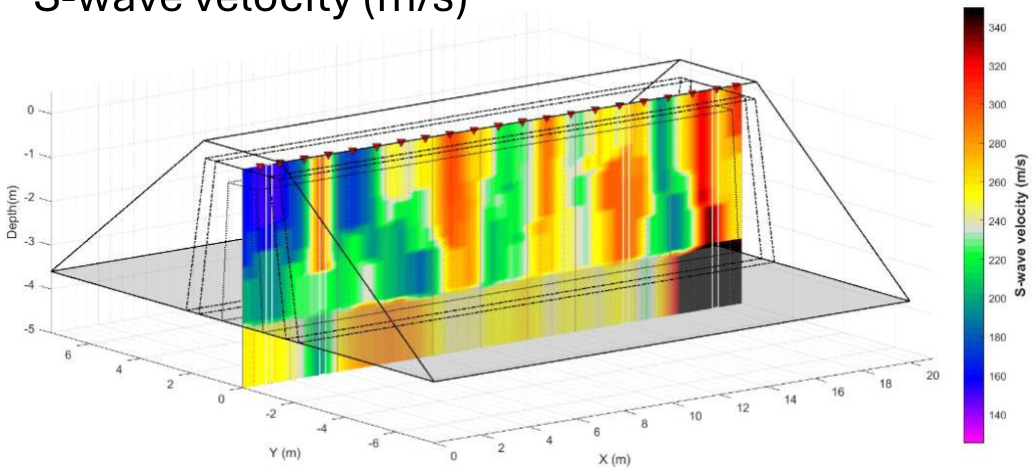
ANI use of naturally occurring background noise to calculate seismic velocities.

By cross-correlating noise records between two sensors, it is possible to reconstruct the response as if one sensor were a seismic source and the other a
receiver. Thus, a seismogram is produced.

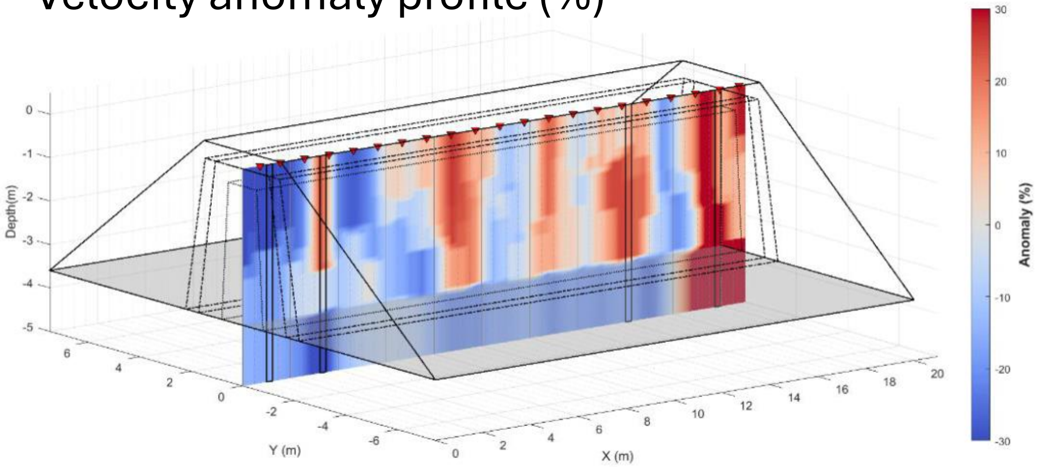
Normalized S-wave velocity anomaly (%)

- Time-lapse monitoring
- Imaging / Tomography of structural/saturation anomalies
- Complements temperature and strain measurements
- Larger tested volume

S-wave velocity (m/s)



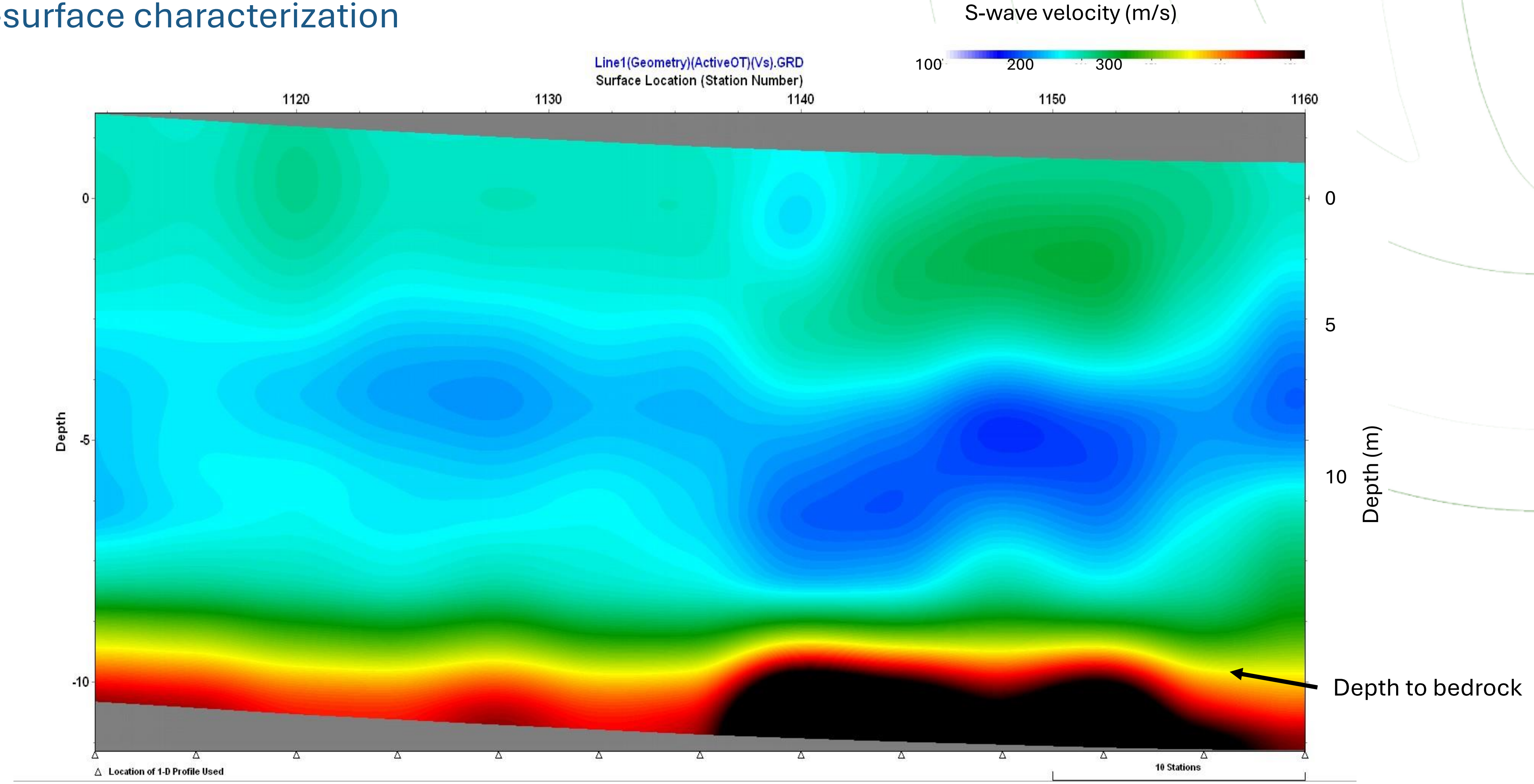
Velocity anomaly profile (%)



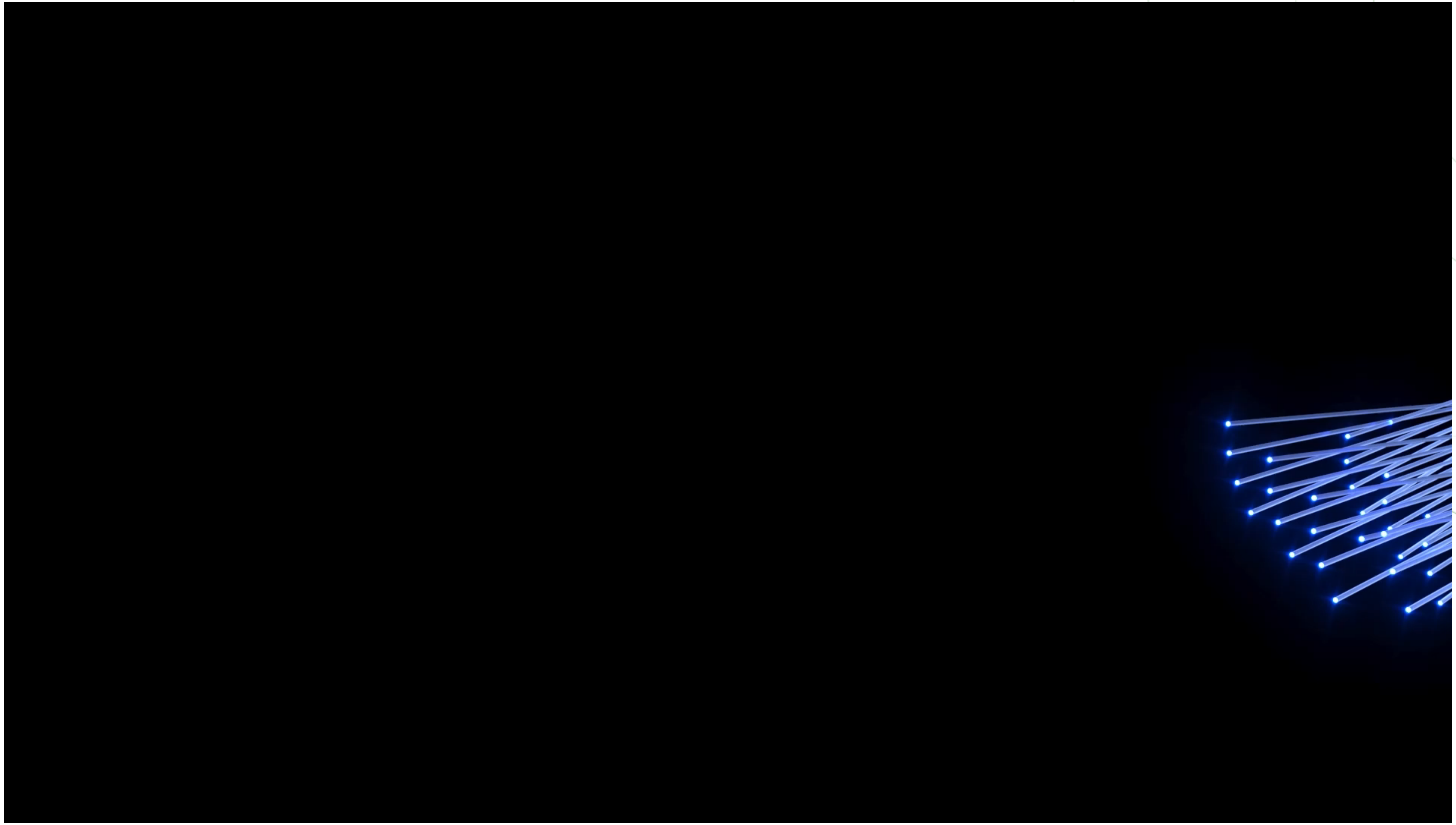
Active near surface seismic

Alternative Approach: Active Survey

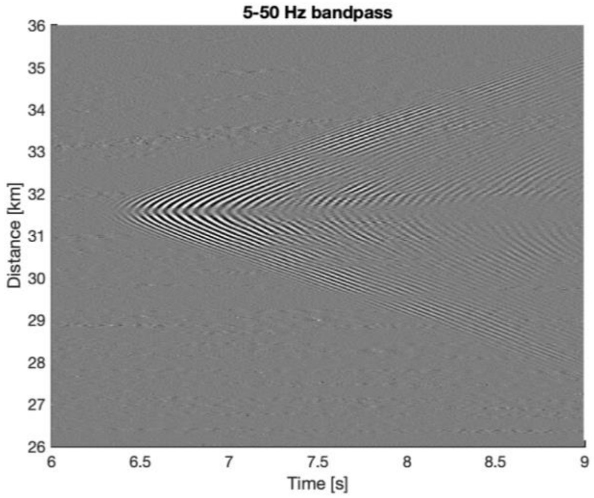
MASW – Near-surface characterization

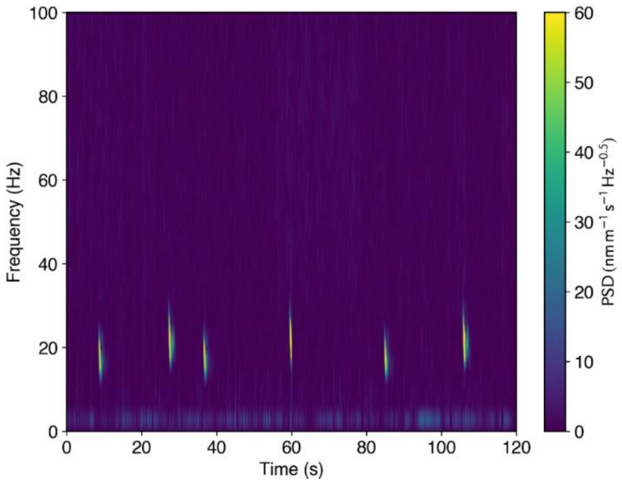


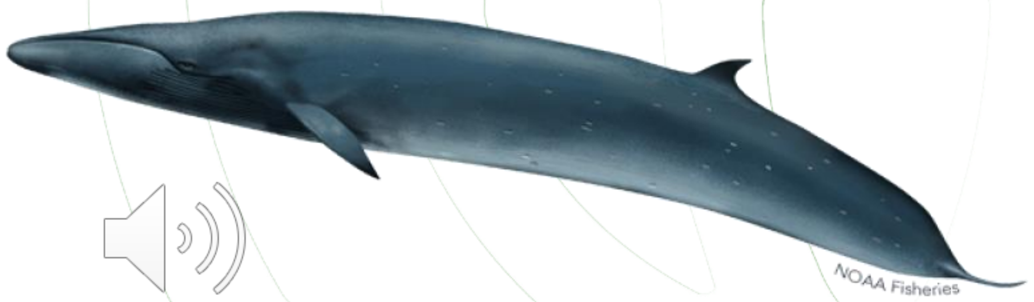
Dam monitoring integrated solution



Recordings of low-frequency whale calls using Dark Fibers



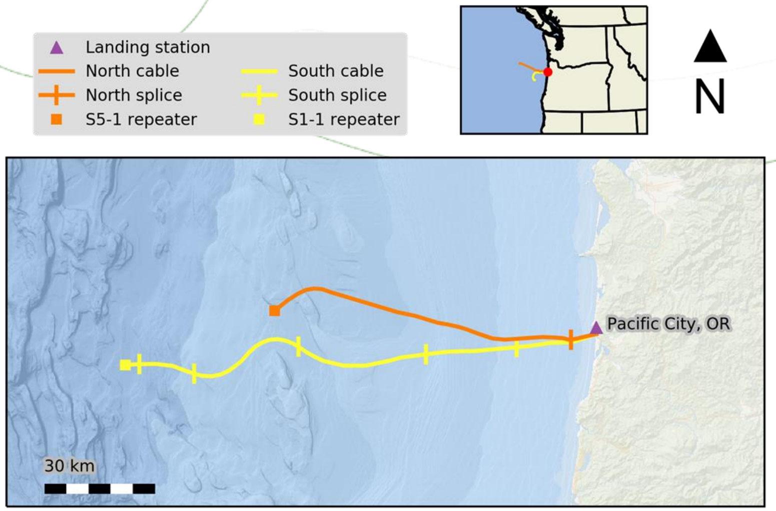


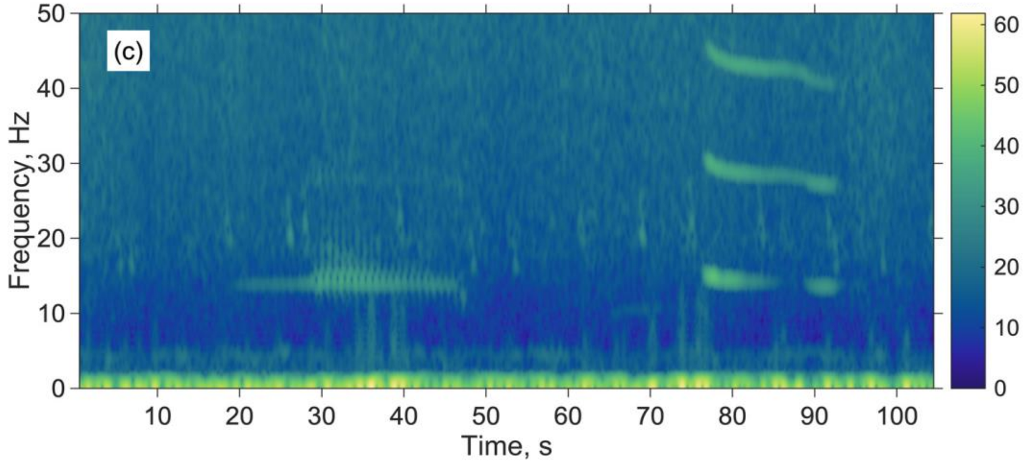


Confirmed Fin Whale calls between 10-30 Hz.
Note the distance scale!

Comma shaped spectrograms centered around 20 Hz. showing six note in a fin Whale doublet song.

OOI Regional Cabled Array





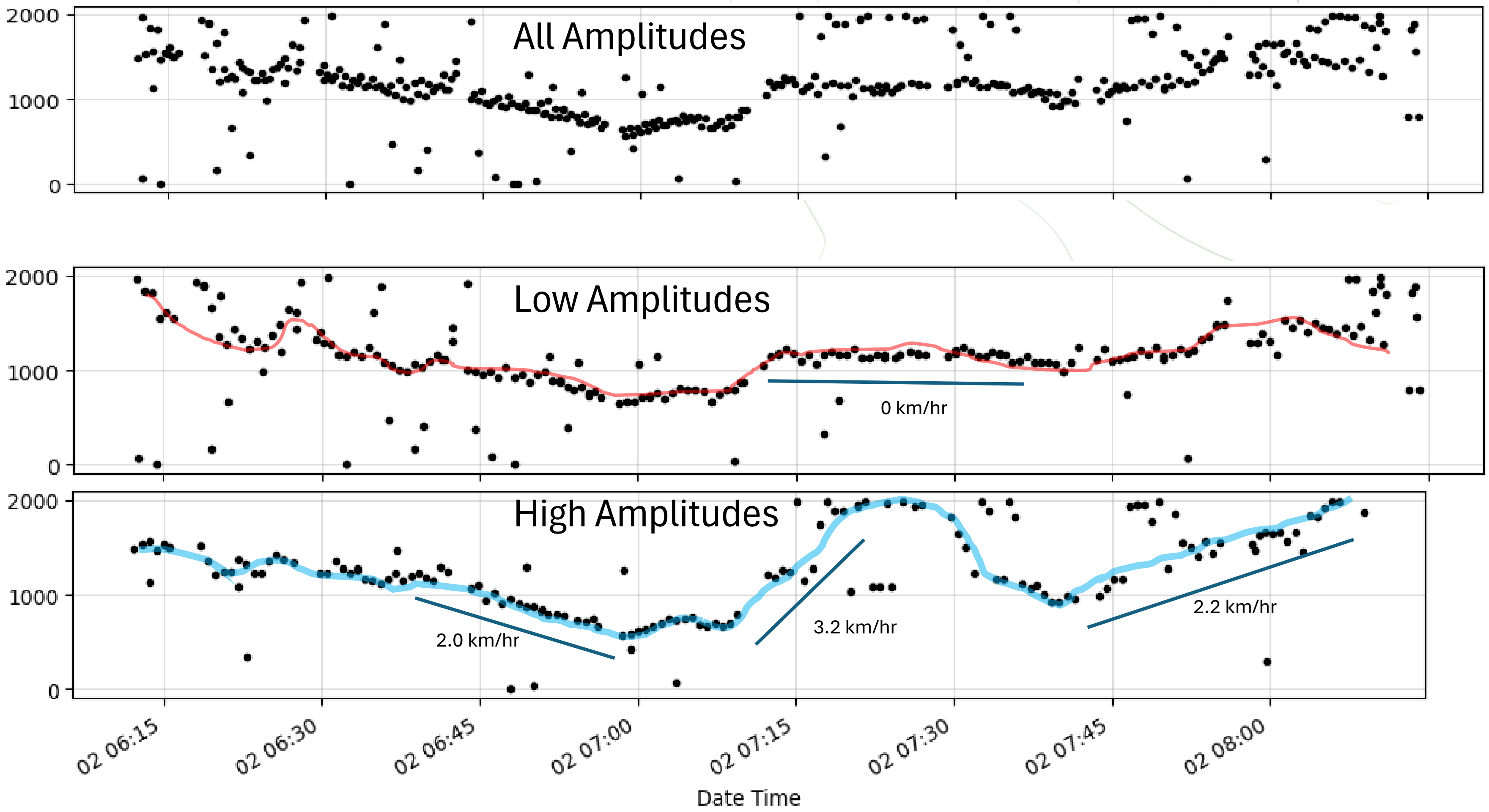
Blue Whale first three harmonics between 10- 50 Hz.

Wilcock et al., 2023

Robust Location Estimation Results

Perhaps two fin whales ?

Does one turn back towards the cable around 7.20



ITINERIS

THANKS!

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
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Ministero dell'Università e della Ricerca

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