Geophysical instruments and data processing

Distributed Fibre Optic Sensing (DFOS) – Overview

- Frantisek Stanek & Mauricio Cogorno

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

12 JUNE

Time		Training Module - Topic	Speaker
09:30 – 11:30	2h00m	Fibre optics basics - DAS principles	Frantisek Stanek
11:30 – 11:45		***Coffee Break***	
11:45 – 13:00	1h15m	Designing a seismic DAS survey – good practices	Frantisek Stanek
13:00 – 14:00		***Lunch Break***	
14:00 – 15:30	1h30m	Data curation	Frantisek Stanek
15:30 – 15:45		***Coffee Break***	
15:45 – 17:00	1h15m	Demostration/ handling optical fibers	Mauricio Cogorno

Outline

- Silixa team
- Silixa introduction
- Technology overview
- Applications & Example Case Studies

Mauricio Cogorno

- Field Engineer

- Mauricio joined the Silixa E&S Business unit in 2023 as a Field Engineer. He has 2 years of hands-on experience with fiber optic sensing systems and field installations, working on and managing projects across the mining, geothermal, and CCUS sectors.
- He holds fiber optic cabling and various safety certifications.
- Originally from Peru, Mauricio is passionate playing the guitar, salsa dancing and spending time camping with family and friends.

Frantisek Stanek

- Sr. Geophysicist, Project Manager, Technical Lead – Environmental and Earth Sciences

- Joined Silixa in 2023 and has been involved in activities ranging from field installations and surveys, project management, product development, and business development of geoscience applications.
- Currently managing CCS projects, developing Solution products, and leading data processing.
- Obtained Ph.D. in geophysics.
- Worked at the Czech Academy of Sciences, cooperated with many international research institutes, and consulted for service companies in the energy sector.
- In 2020-2022, worked as a postdoctoral fellow in the Department of Geophysics at Colorado School of Mines, Golden, Colorado, USA, where he was a member of the Reservoir Characterization Project and the Center for Wave Phenomena consortia.
- Experience with integrated reservoir characterization, microseismic and induced seismicity monitoring using both surface and downhole arrays, fiber-optic sensing applications, and cloud computing.
- Co-author of 20+ peer-reviewed papers, 30+ conference abstracts, and holds 2 patents.
- Active member of the Society of Exploration Geophysics (SEG), Society of Petroleum Engineering (SPE) and the European Association of Geoscientists and Engineers (EAGE).
- Reviewer for numerous journals, AE in Geophysics.

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

Since 2023

Operational Footprint

SILIXA
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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

Midstream

Algorithms for leak detection

Reliable instruments

Longest range (100km)

Total cost of ownership as less instruments needed for long range applications

Security (Perimeter & Fire)

Fully certified products for fire detection (VDS, FM, UL)

Track record and MTBF >40 years

Fully integrated software

Range and track record certificates

Utilities (Cable Monitoring)

Longest range for both instruments

Proprietary algorithms developed (RTTR, DoB)

Total cost of ownership as less instruments needed for long range applications; cost avoidance to deploy a full solution

Upstream

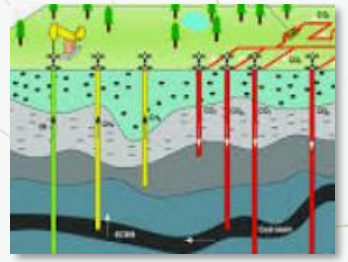
Constellation™ Fiber (better signal, low noise, and industry leading data quality)

Customized solutions for in-time decisions

Monitoring solution with proactive recommendations for improved oil recovery

Improved efficiency with cost avoidance, small footprint & reduced operational interrup tion

Scientific & Environmental



Multiphysics based characterization and monitoring

EDGE software platform enabled application solutions

Customized monitoring systems

Advanced Geophysics

Measurements with the greatest repeatability, accuracy, and precision enable the most advanced applications

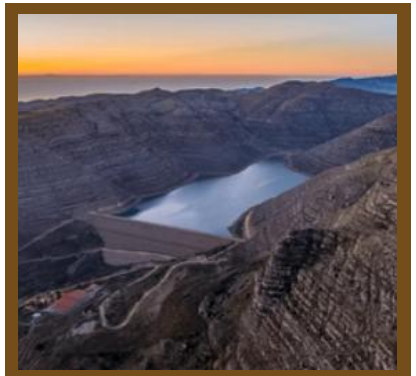
Providing Solutions and Services whenever it is meaningful

Application Sectors

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

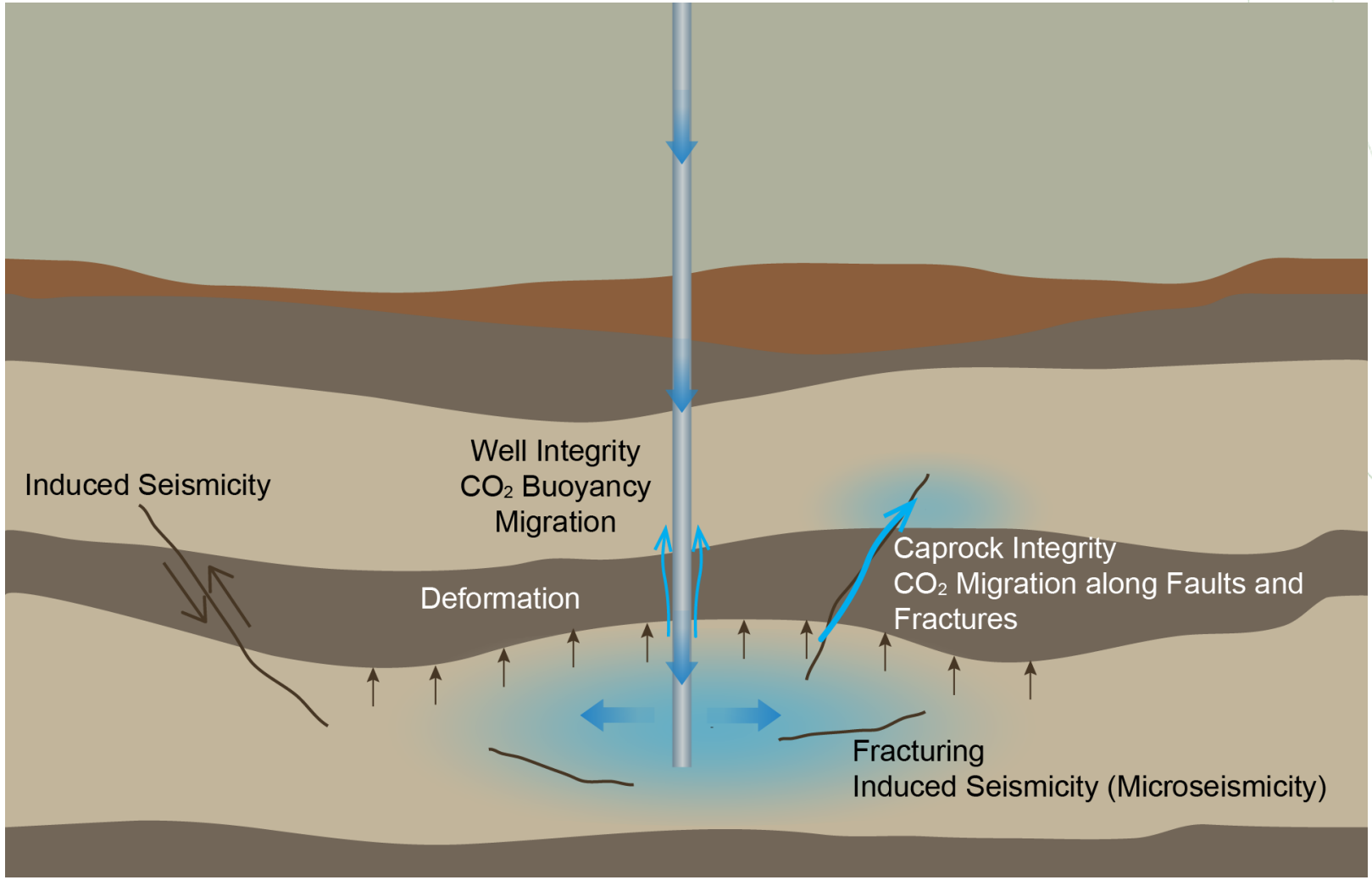
- Custom monitoring systems
- Dense, long sensor arrays
- High sensitivity and precision
- Harsh environments
- Subsea

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**

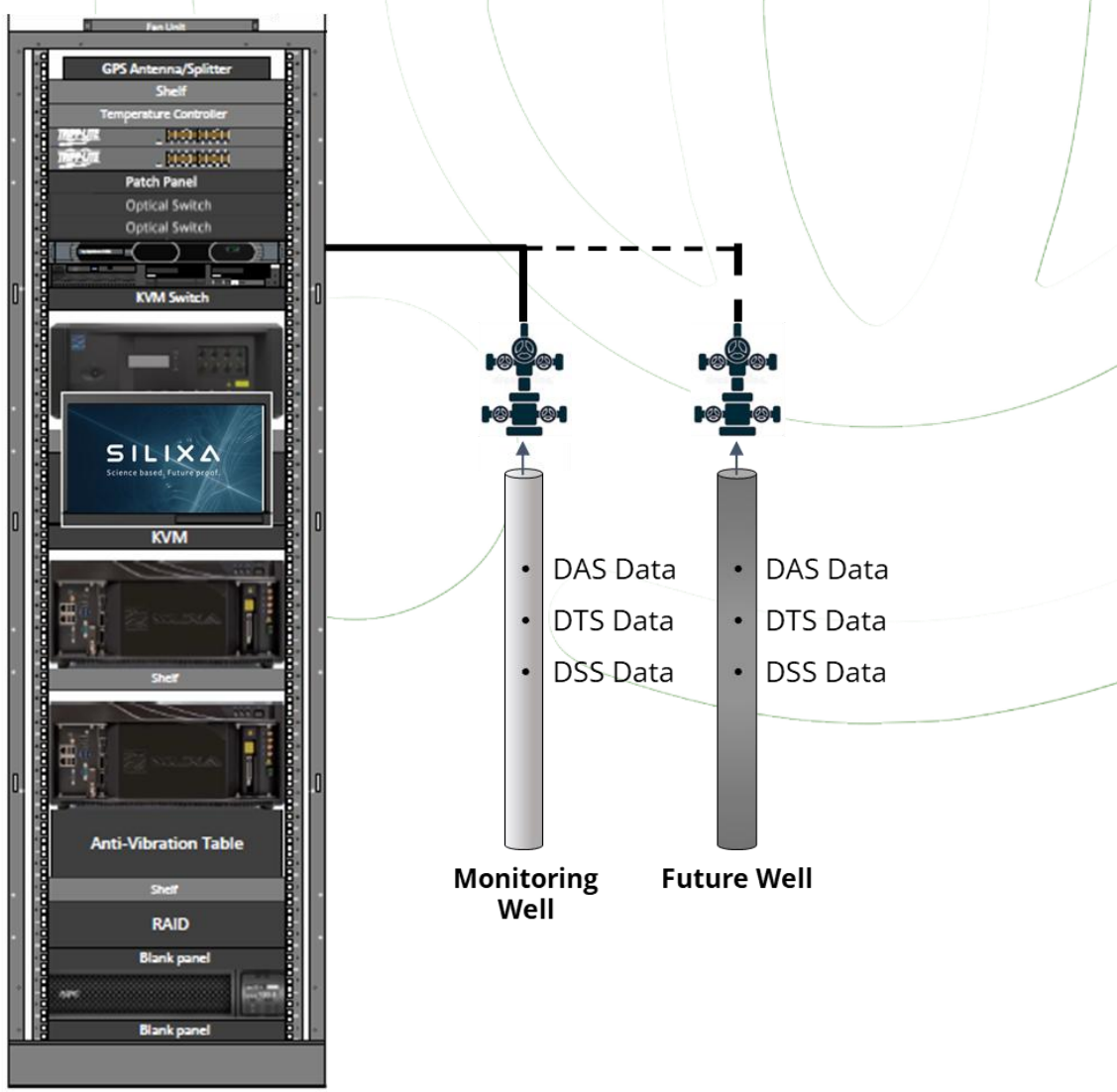
Containment: MMV data to trigger timely controls

Conformance: MMV data to predict long term behavior

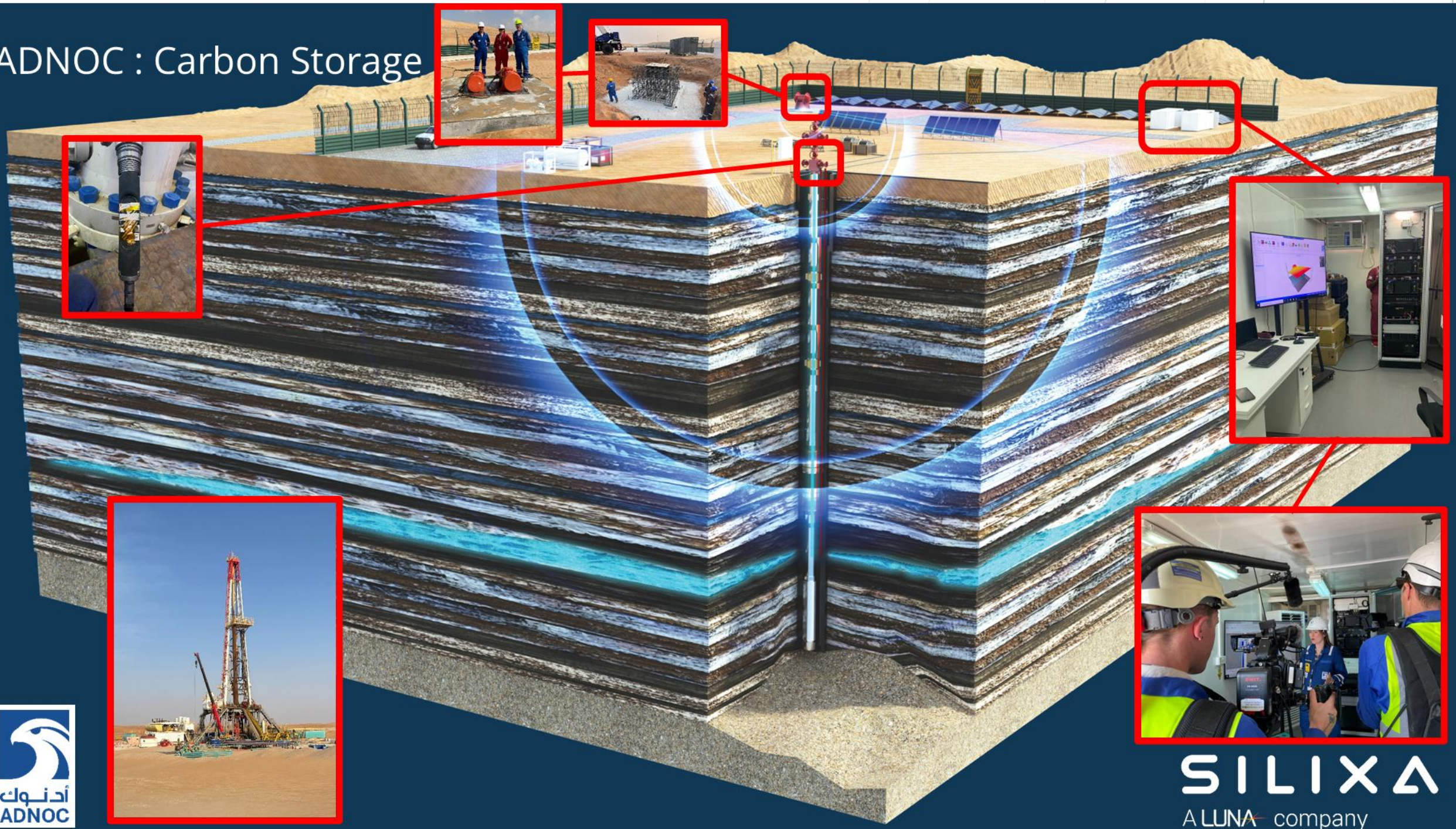
Confidence: MMV data to maintain license (also storage closure)

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



ADNOC : Carbon Storage



أدنوك
ADNOC

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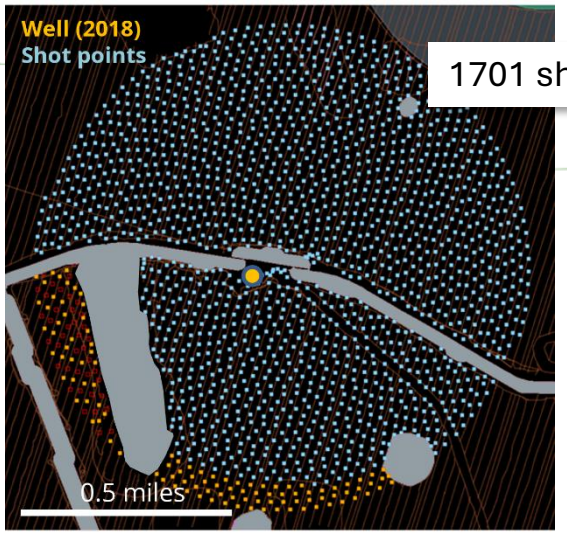
Gas Hydrate Research Project

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

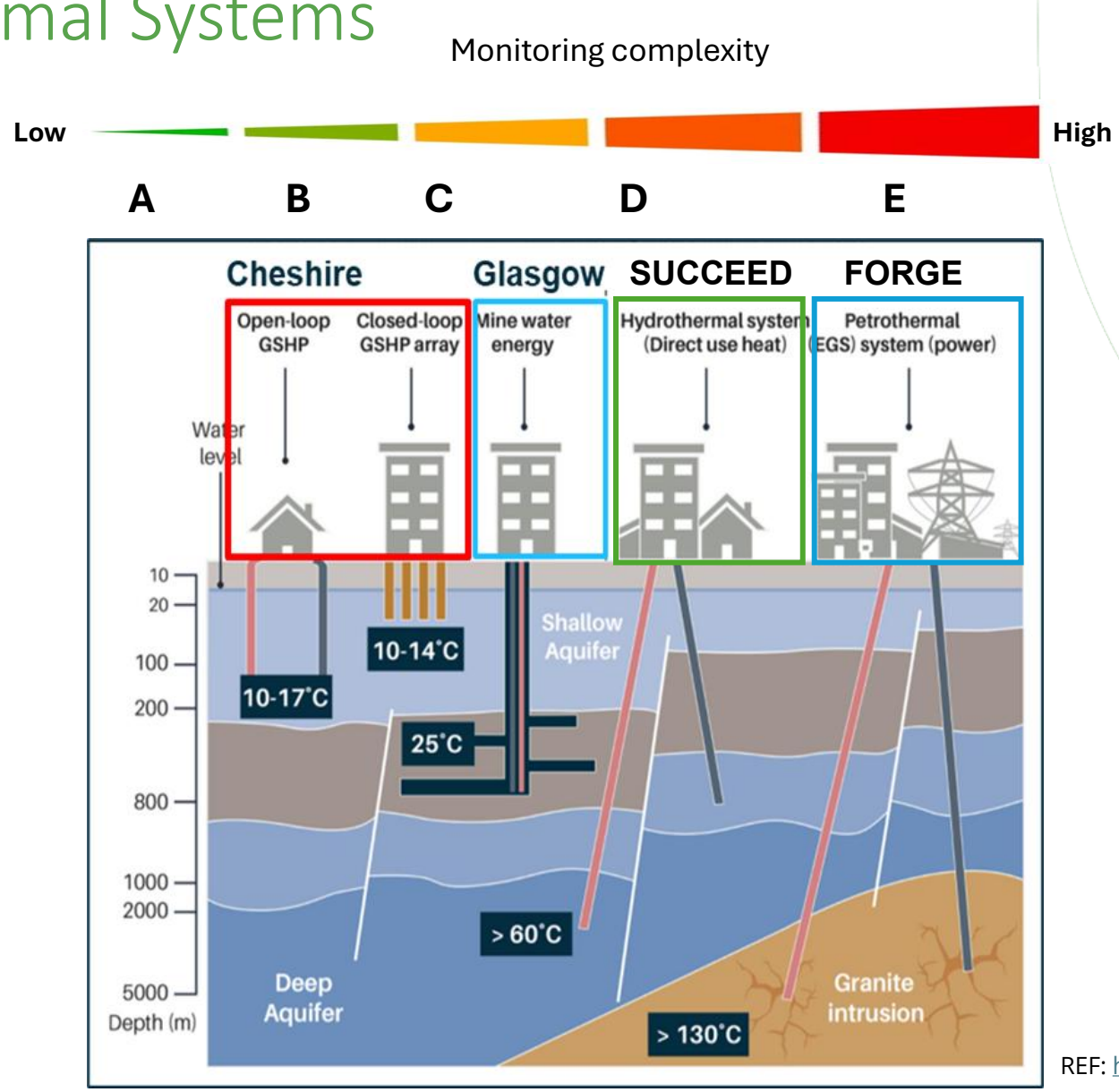
Project outline:

- 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



Fujimoto et al. (2021) SEGJ

Geothermal Systems



Low-temperature (< 60º C)

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

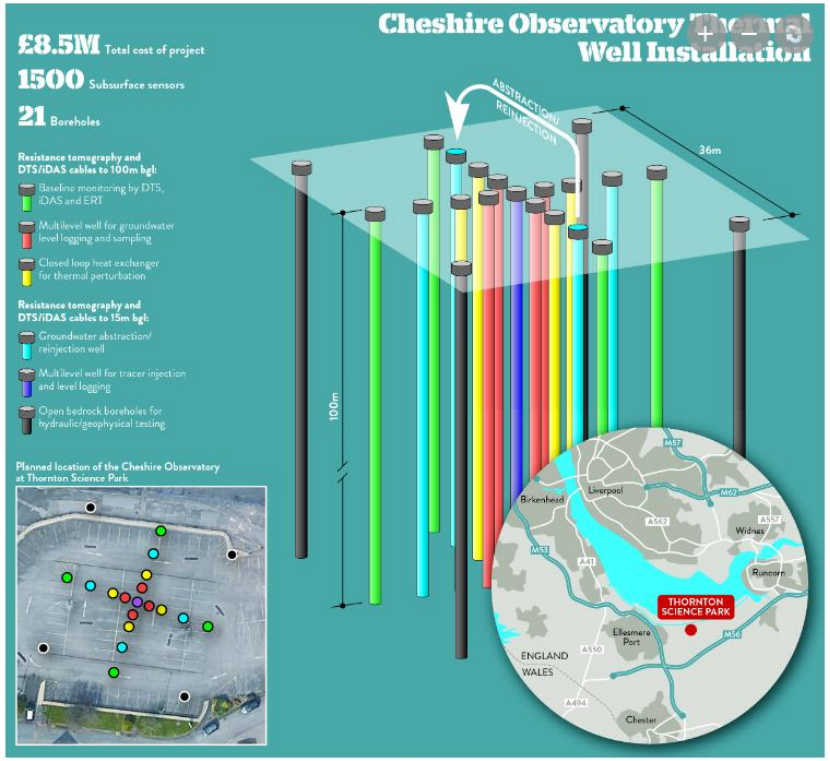
High-temperature (> 60º C)

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

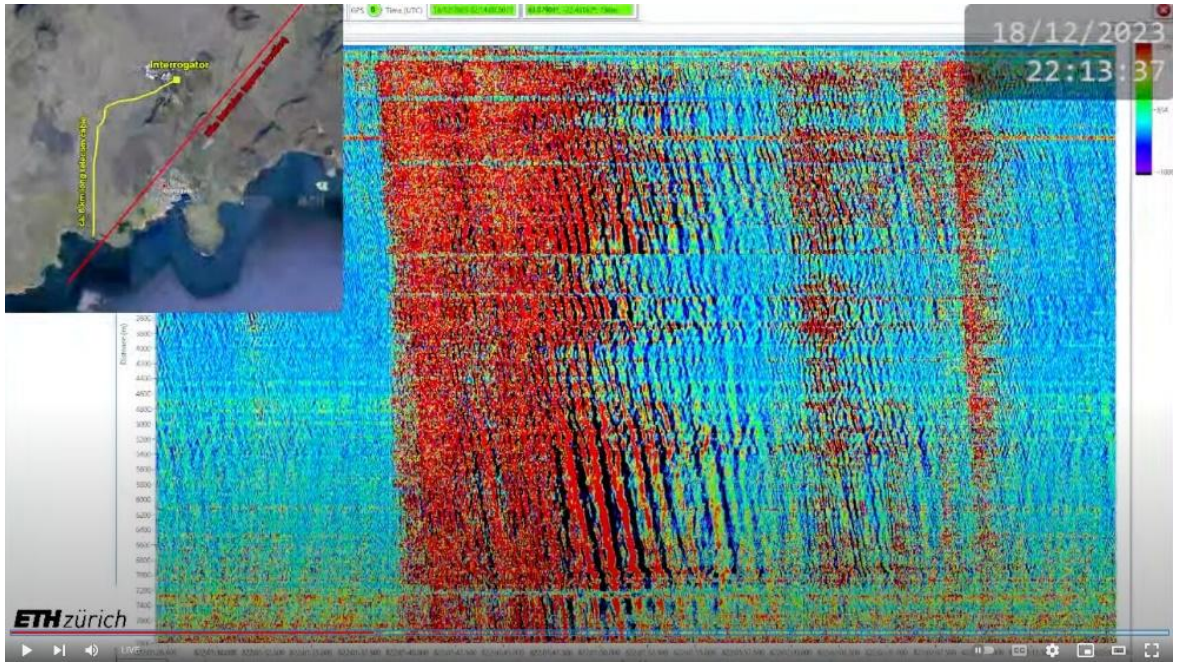
REF: https://ukgeos.ac.uk/

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

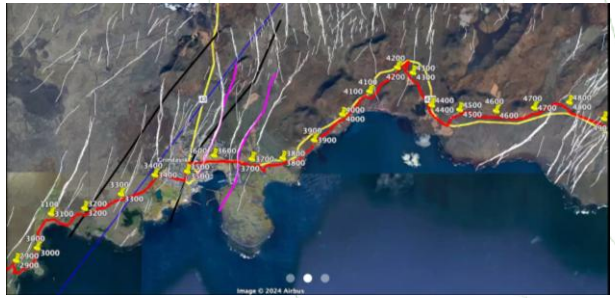


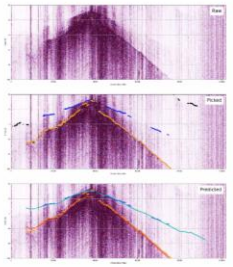
Volcanic Eruption Svartsengi/Grindavik, Iceland

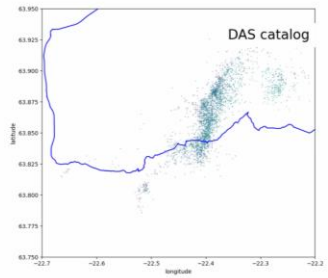


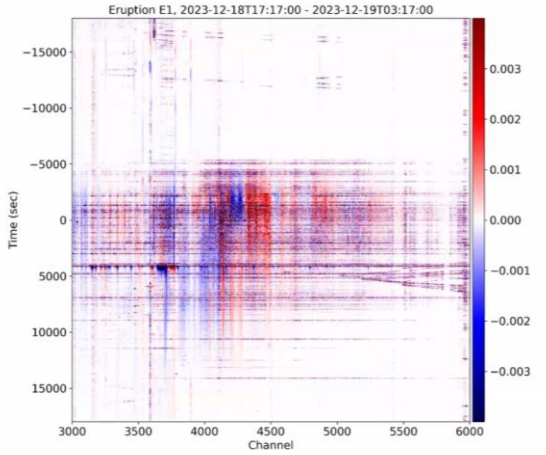
https://www.youtube.com/watch?v=1_3NBuVrmCs

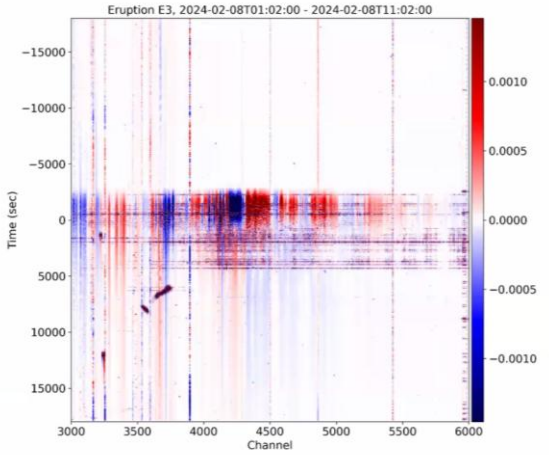
ETH Zurich
8 km fibre optic cable
Live DAS data from Blue Lagoon November 2023 – April 2024









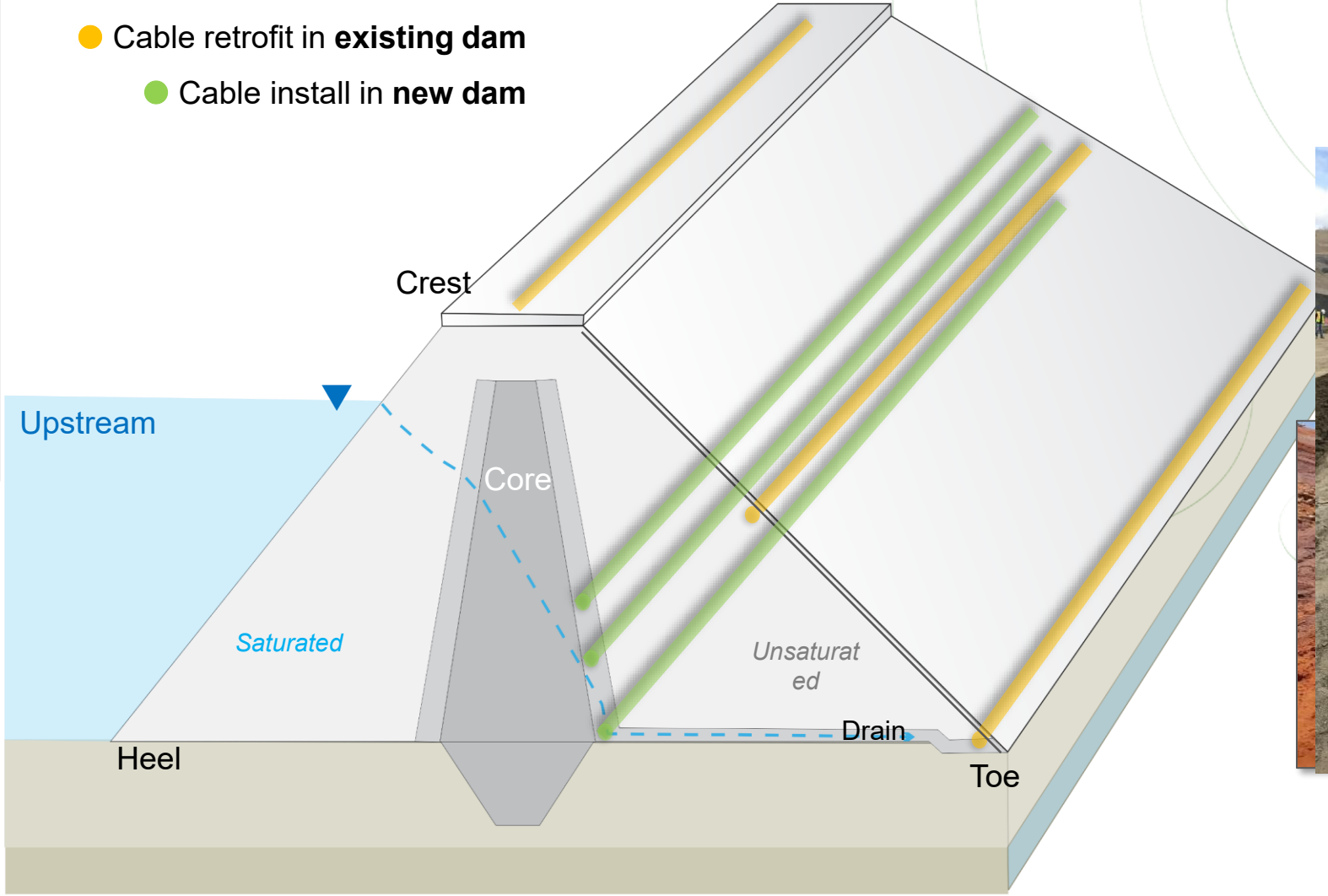


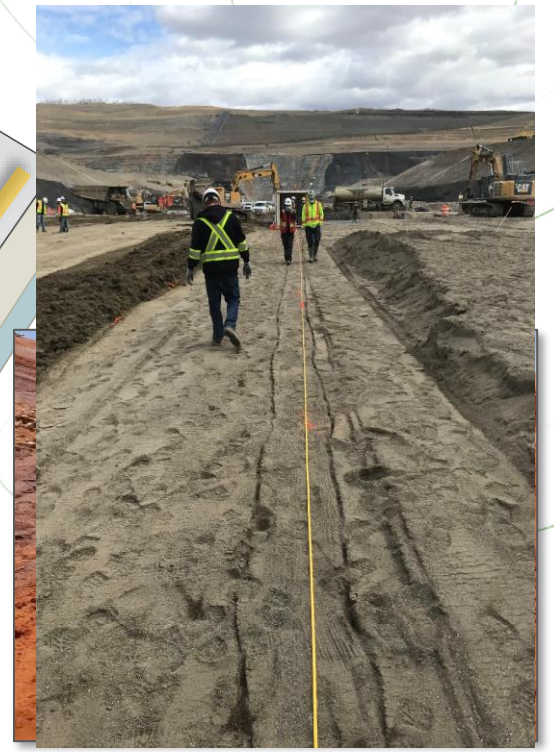
Caltech GMG – 2024
100km Dark Fiber – Strain DAS

Seismicity monitoring & Ground deformation

Dam Monitoring with Distributed Sensing

- Cable retrofit in **existing dam**
- Cable install in **new dam**

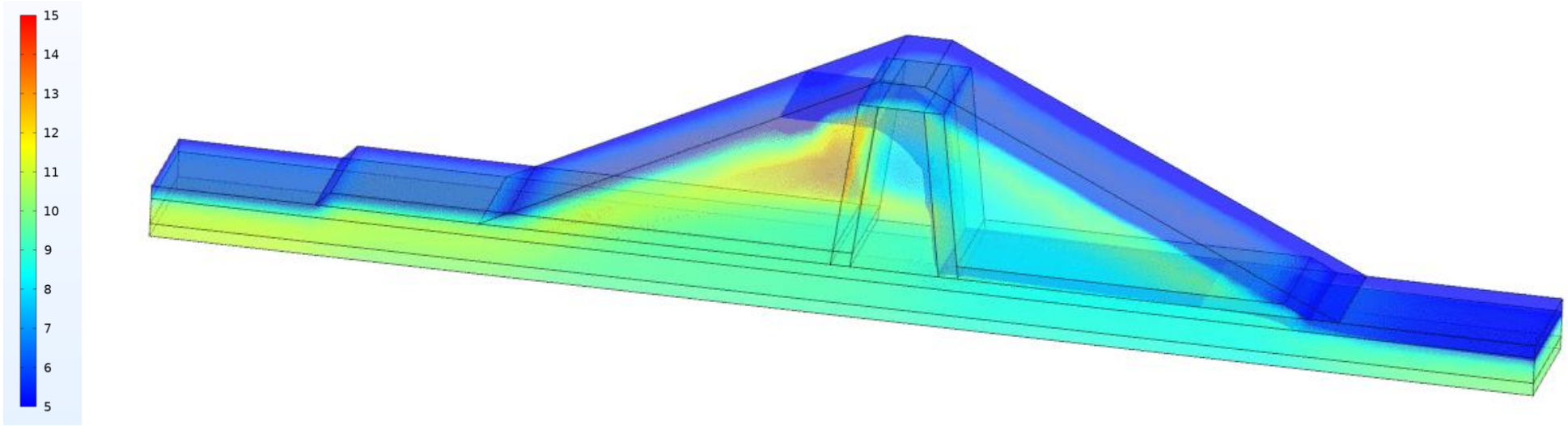




Temperature as heat tracer

Damage 2 m high, 5 m wide

Q=0.156 l/s



Passive Seismic

Ambient Noise Interferometry (ANI)

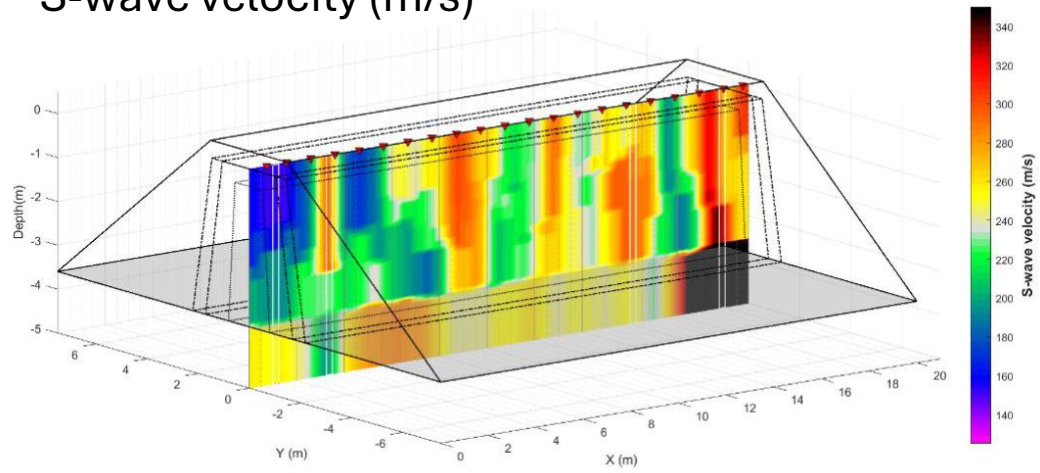
ANI use of naturally occurring background noise to calculate seismic velocities.

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.

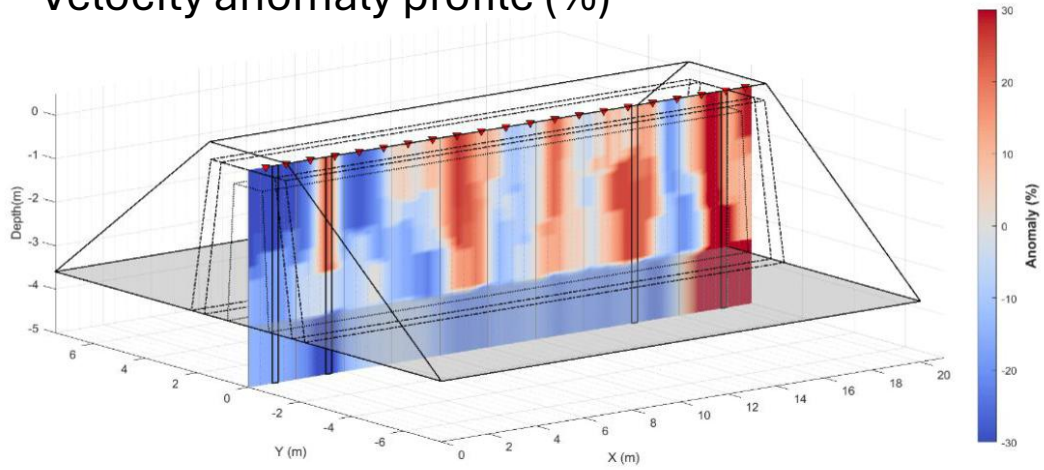
Normalized S-wave velocity anomaly (%)

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

S-wave velocity (m/s)

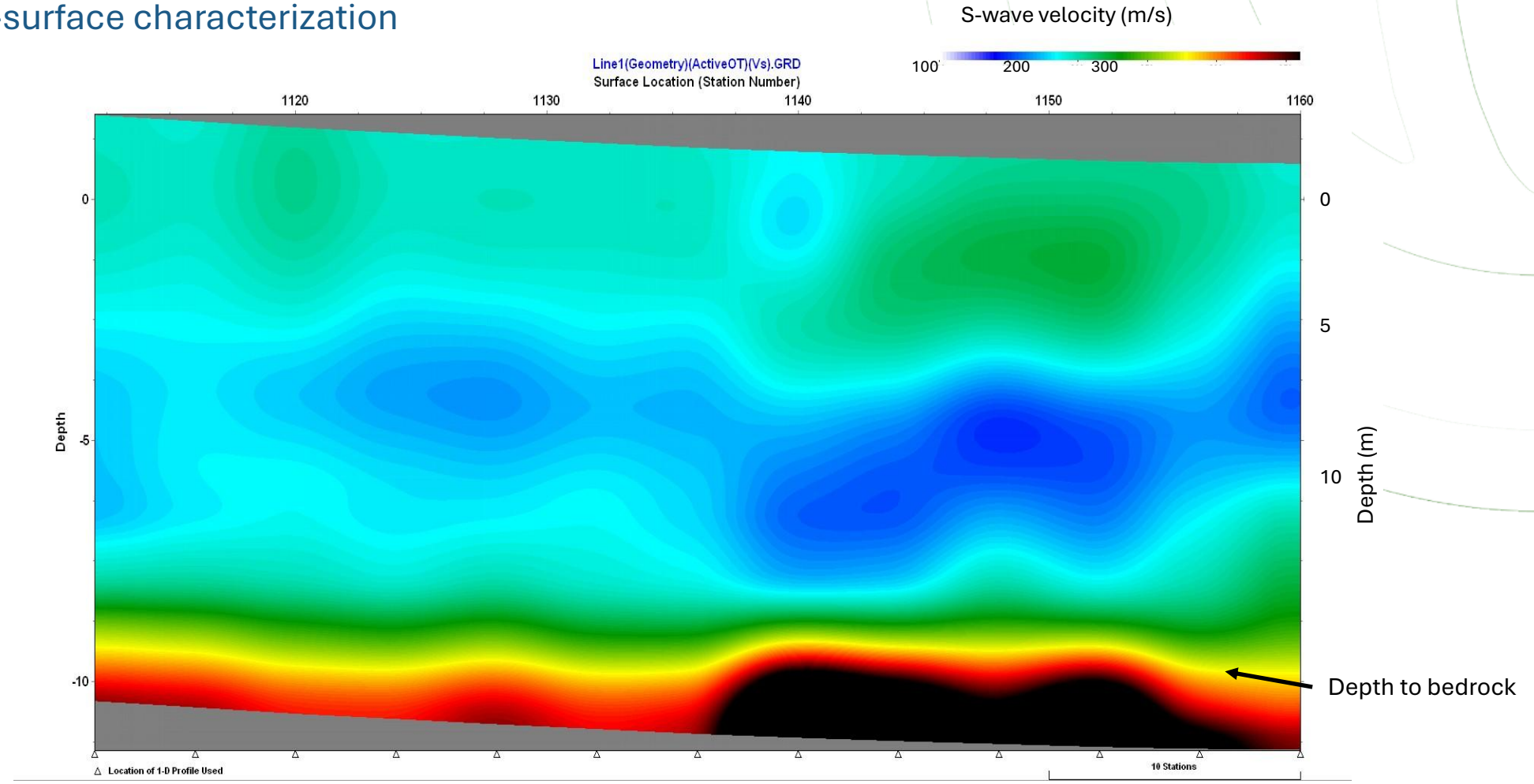


Velocity anomaly profile (%)



Active near surface seismic

Alternative Approach: Active Survey
MASW – Near-surface characterization



THANKS!

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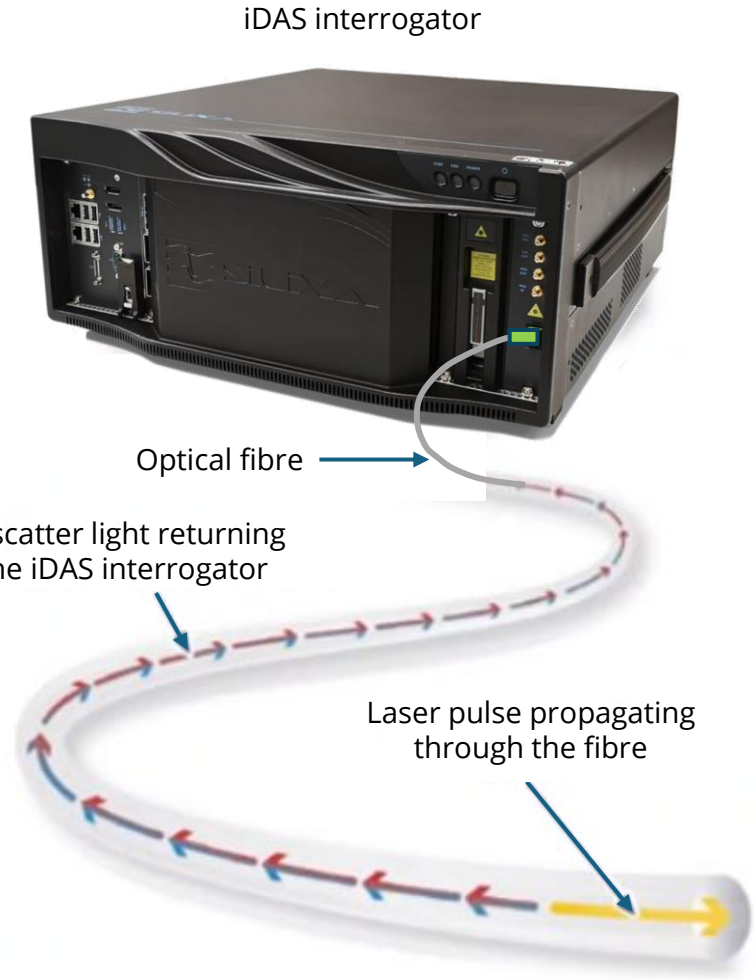
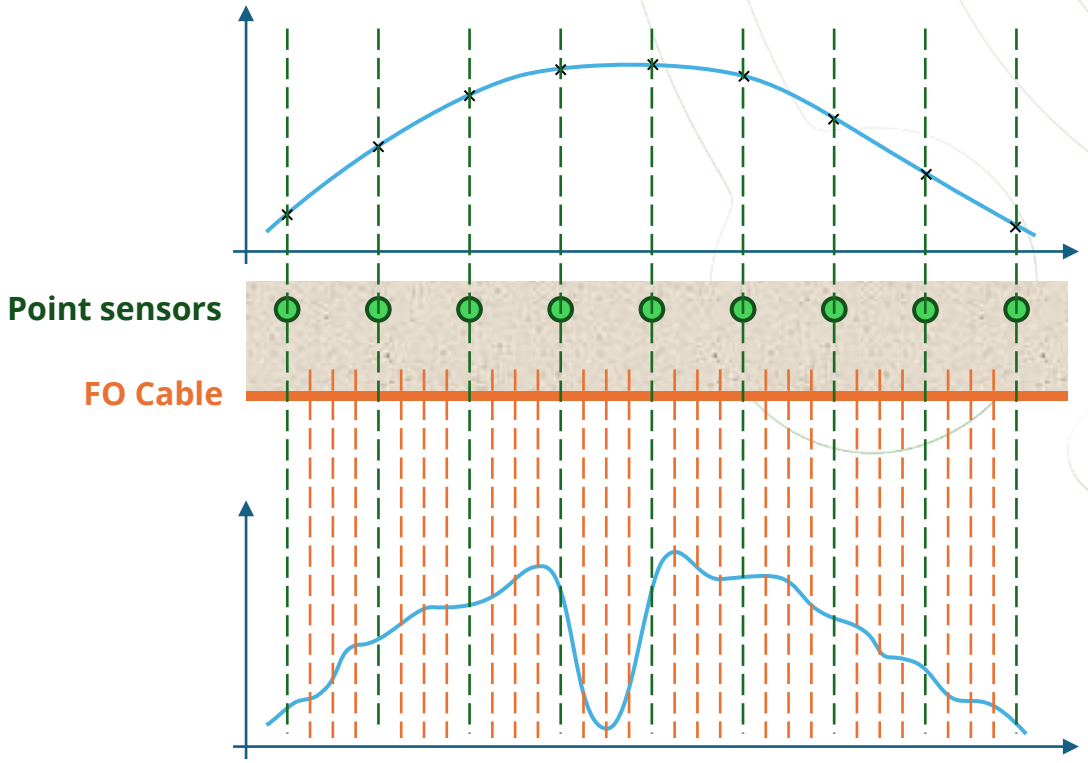
The advantage of true distributed measurements





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.

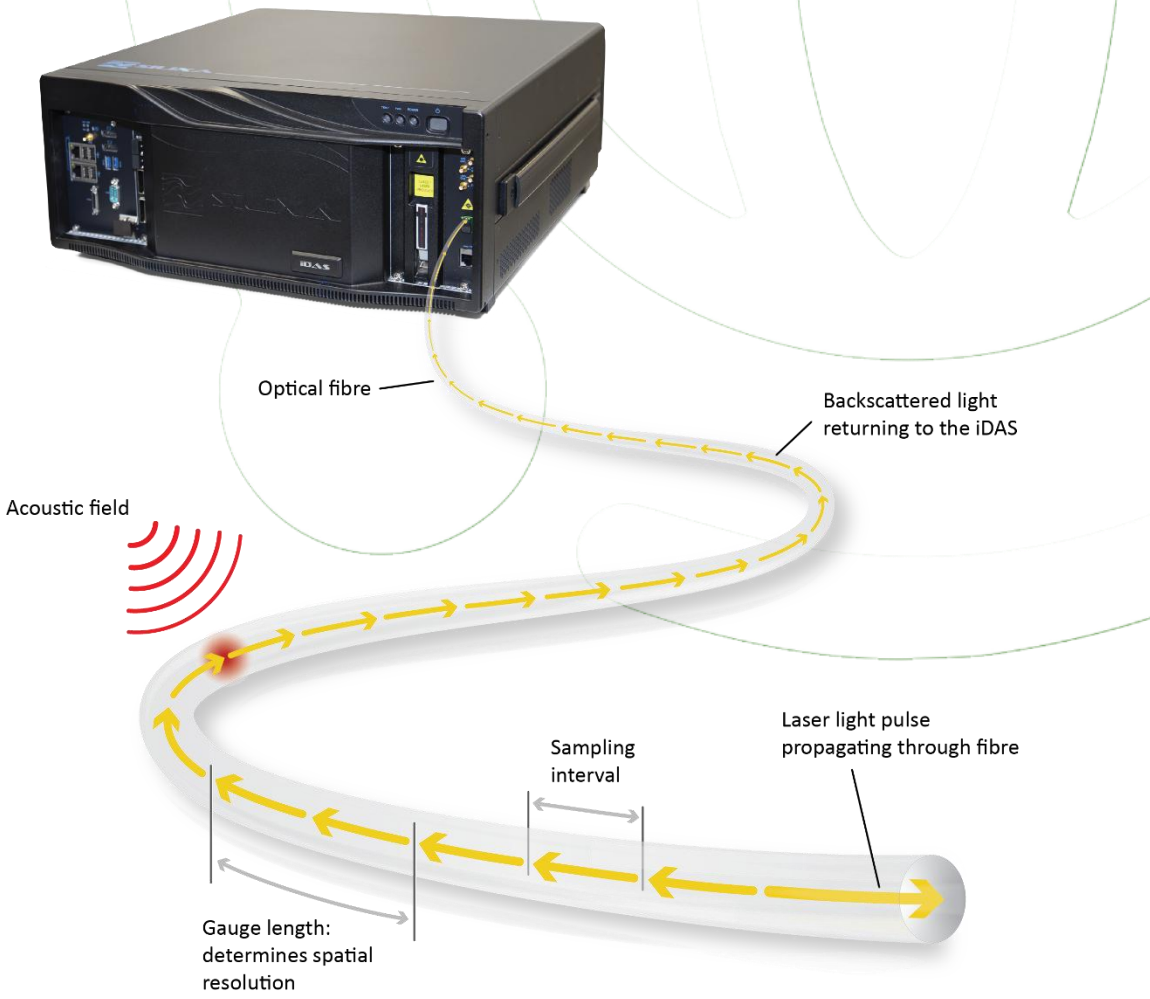
Fibre optics require no electronics at point of measurement.

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

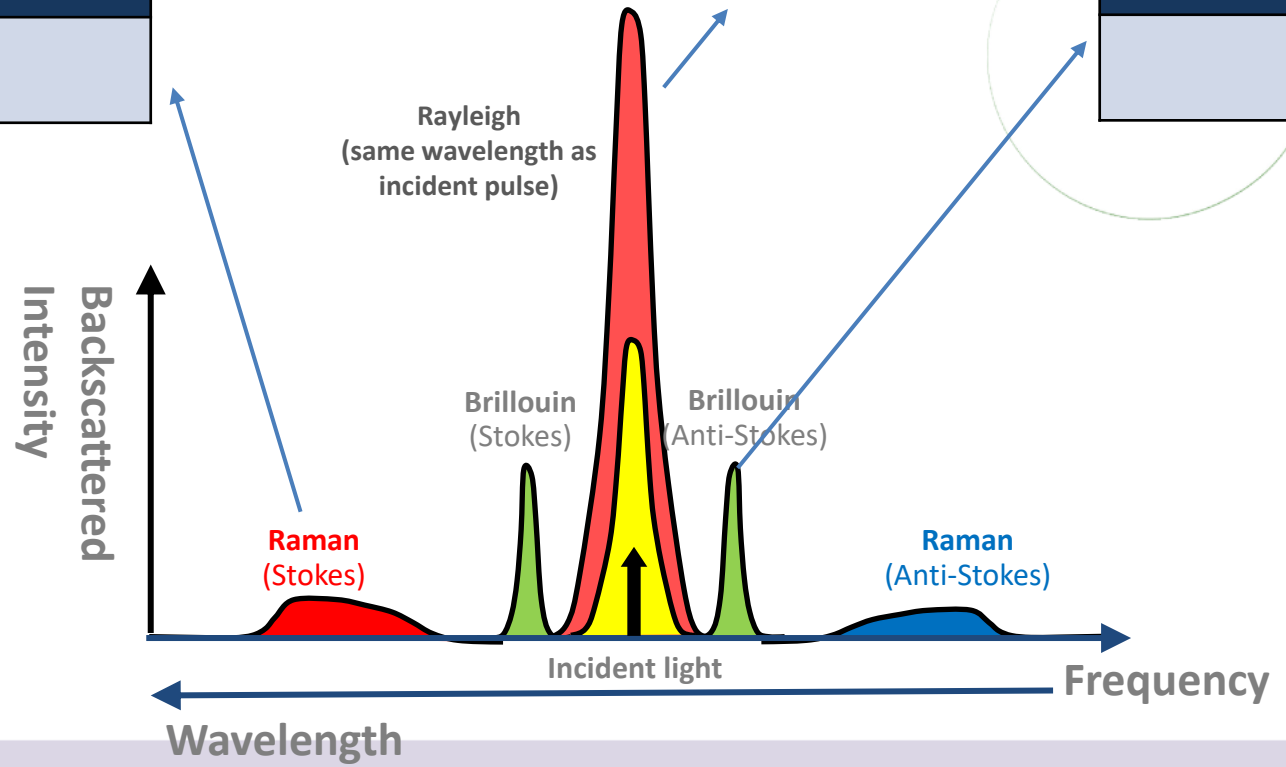


Silixa Distributed Sensing

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

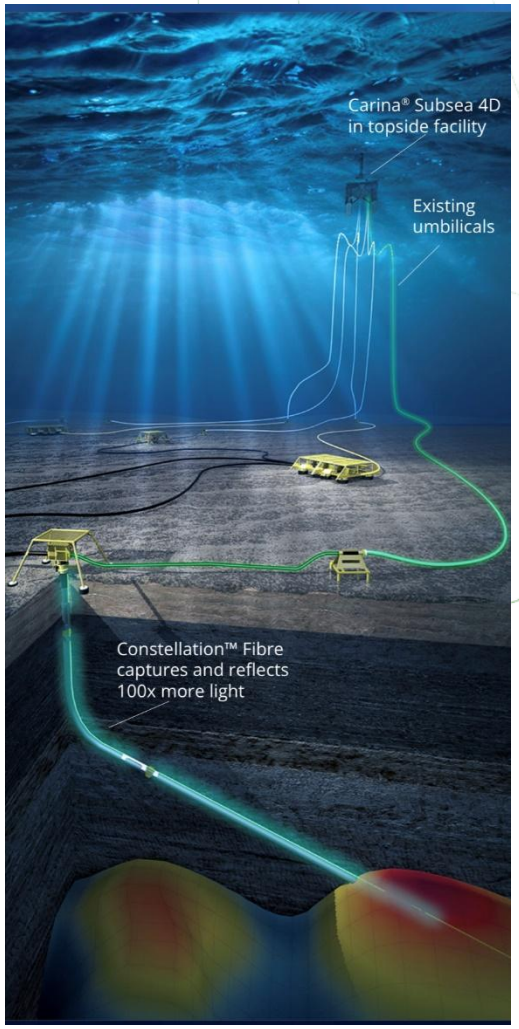
IDAS MG	CARINA
Acoustics (DAS) >120dB Dynamic range	

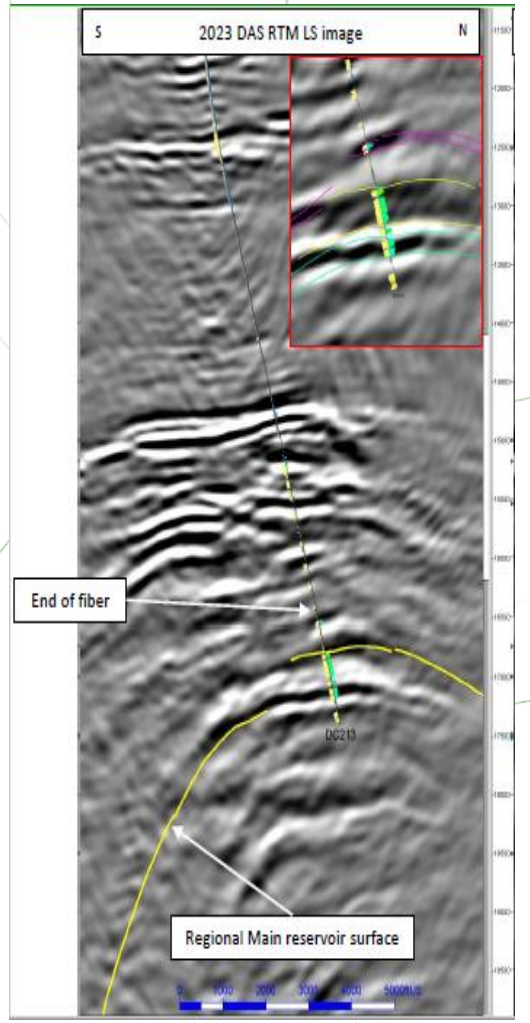
iDSS
Strain (DSS) 1 με Resolution



Competitive Advantage given by Carina® Sensing System

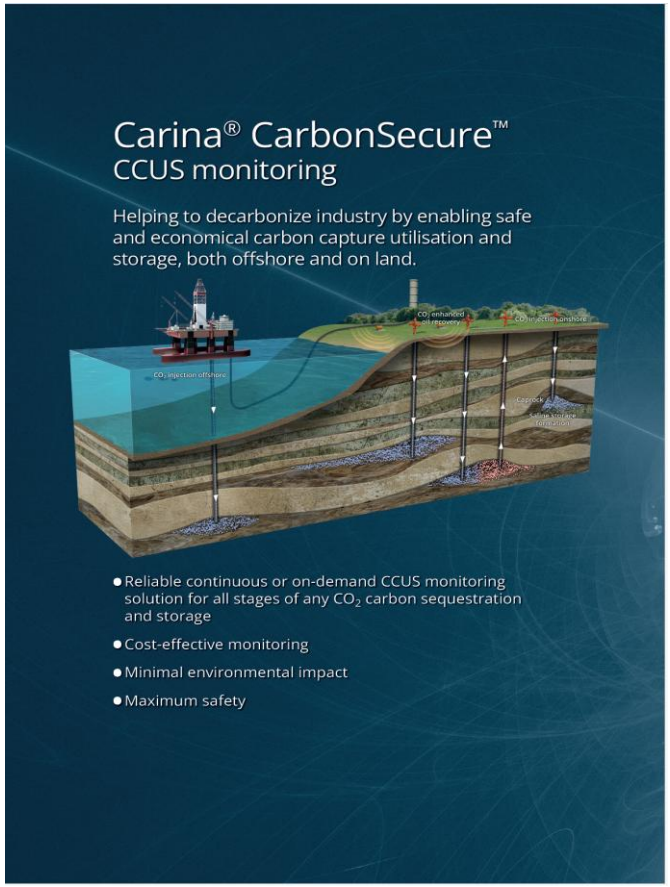
- **20dB additional optical budget**
  - High tolerance to splice and wet-connect losses
- **20dB reduction in required seismic source energy**
  - Monitoring in urban or environmentally sensitive areas; reduced source cost
- **Equivalent to 100x fewer seismic shots**
  - Reduces cost, time and environmental 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

Real-time, online, modular, Edge Monitoring Platform



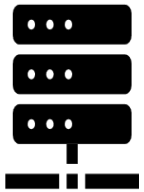
Remote operation

- 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:

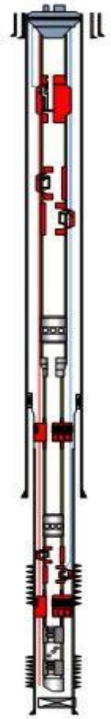
- Low energy consumption
- Low carbon emission
- Small footprint

Improved Safety:

- Reduced mobilizations
- Reduced personnel onsite

Perenco : Offshore North Sea Carbon Storage

Perenco CCS • Leman CO_2 Injection Test



Wellhead compatible for low temperature service

Safety valve compatible for CO_2 and low temperature service

Packers for injection zone selection

Electric gauges for data acquisition

Optical gauges for data acquisition

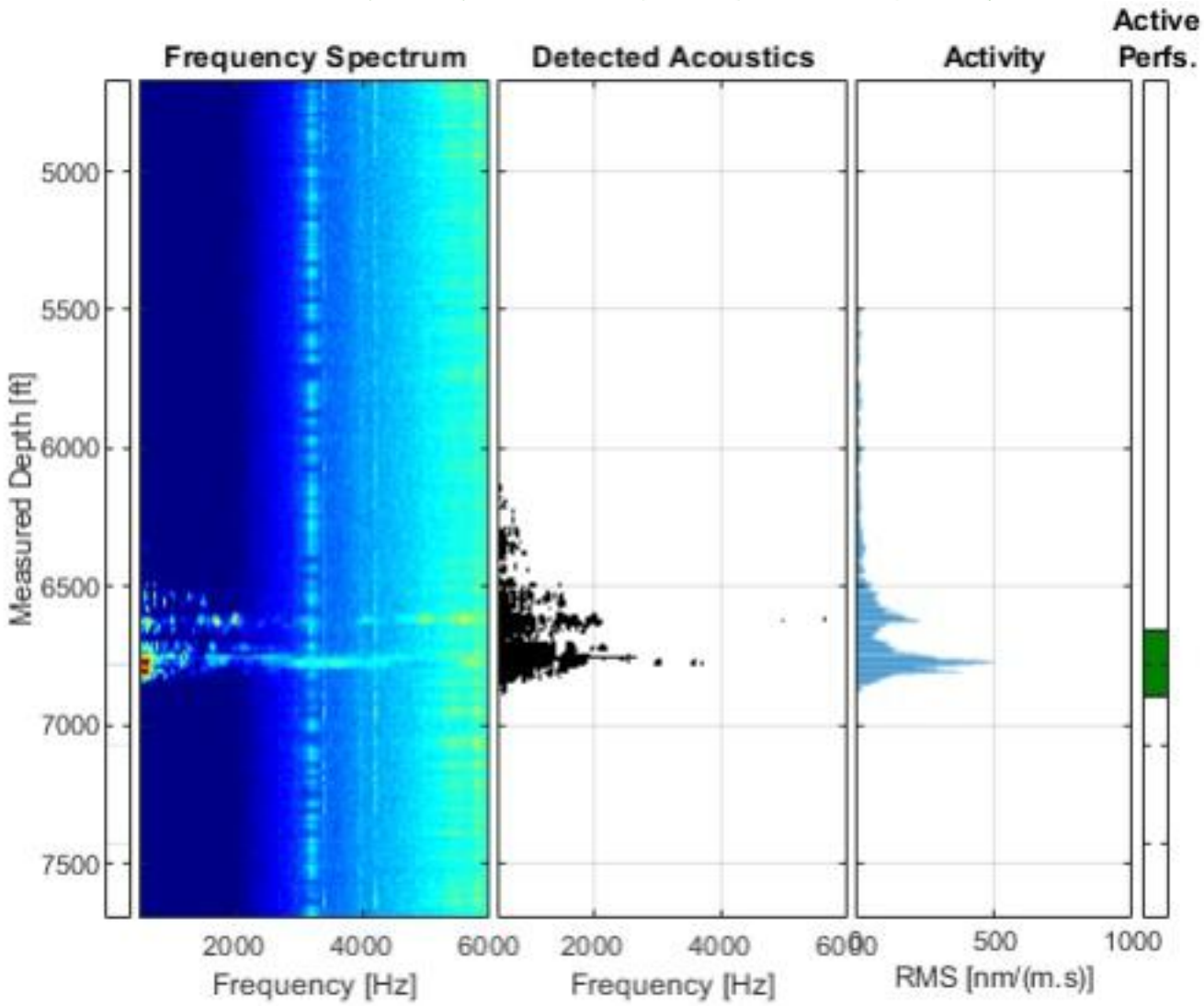
Optical fibre for temperature data acquisition and near-bore seismic

Poseidon Project • CO_2 injection test well
Completion equipments & main technology providers

[Perenco CCS - Deploying cutting edge technologies - YouTube]

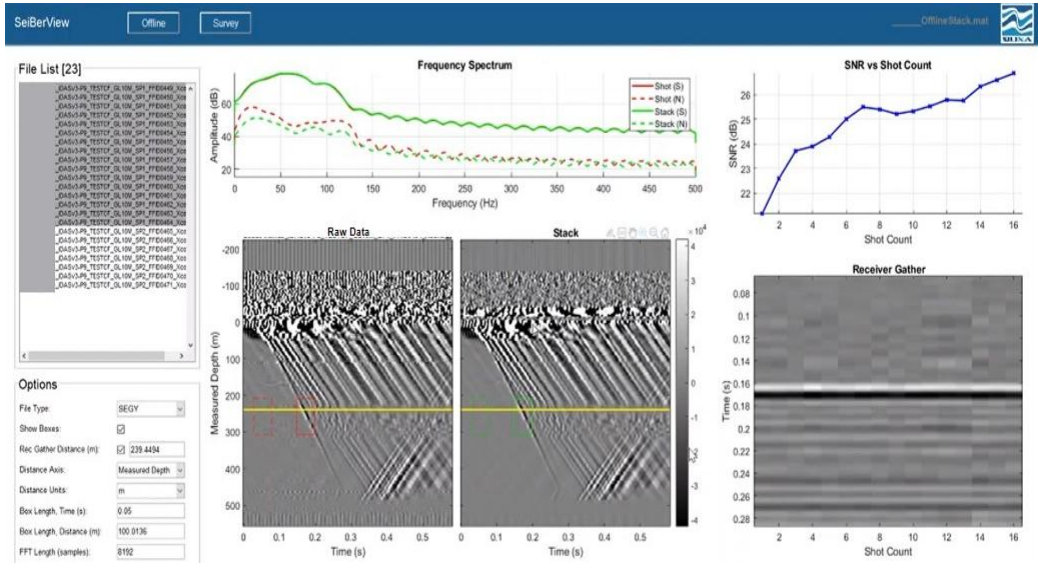
Perforation and Injectivity Test

- 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

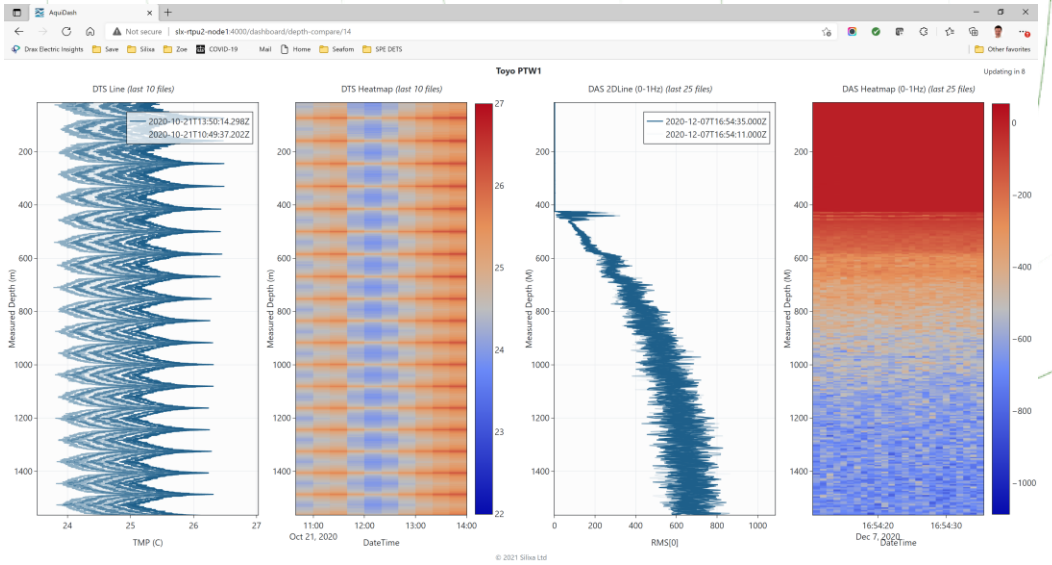


Real-time, modular Edge Platform

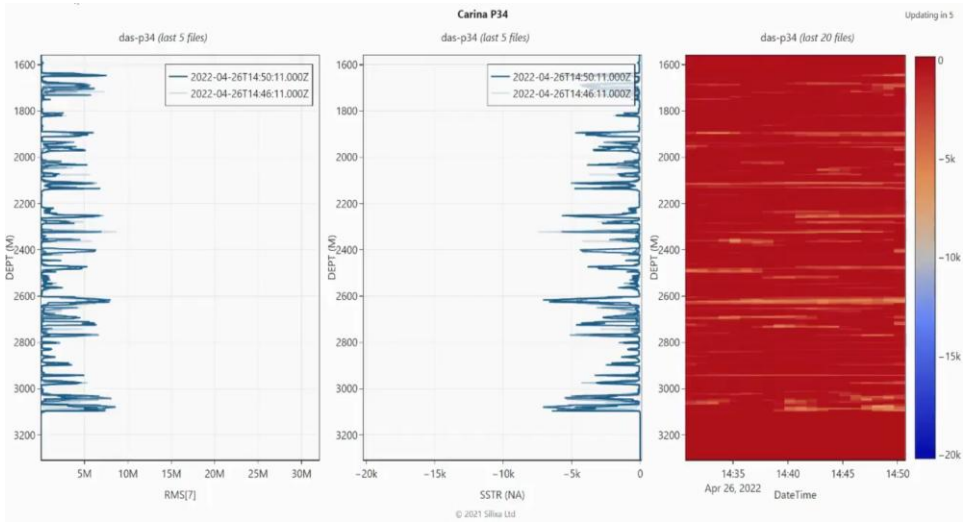
VSP (DAS)



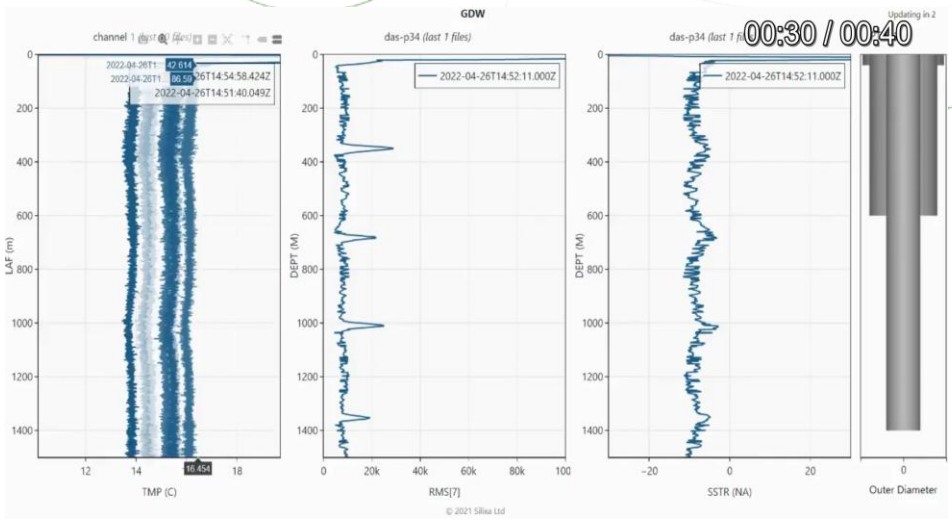
Thermal Profiling (DTS)



Continuous Acoustic (DAS)

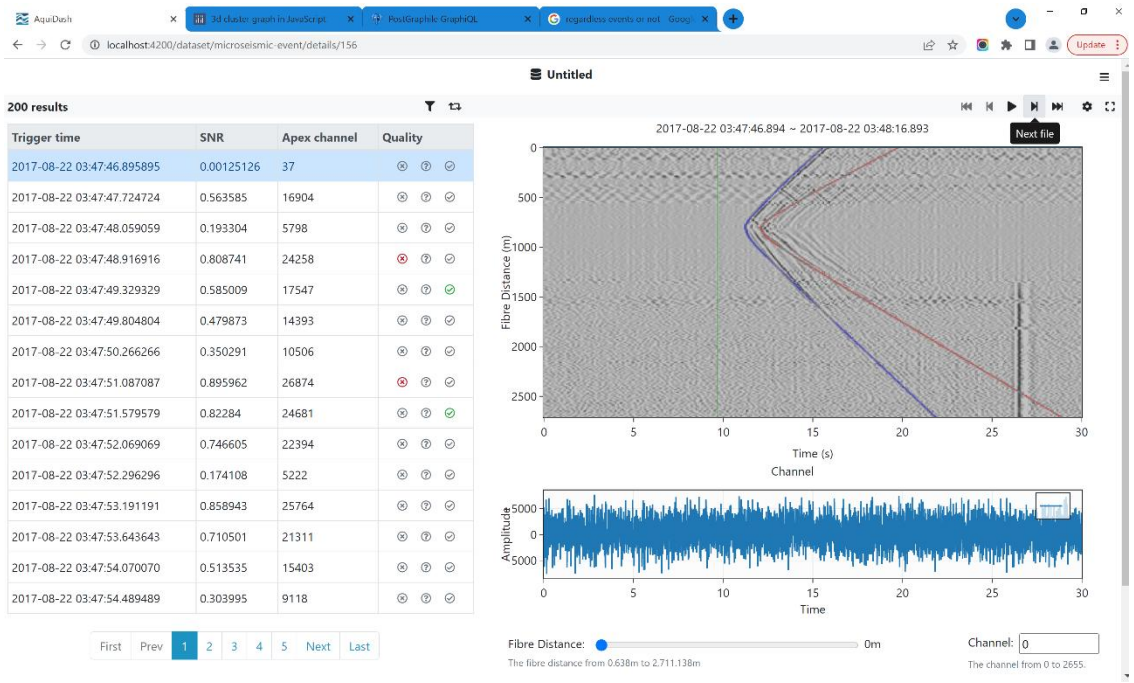


Casing Integrity (DAS, DTS)



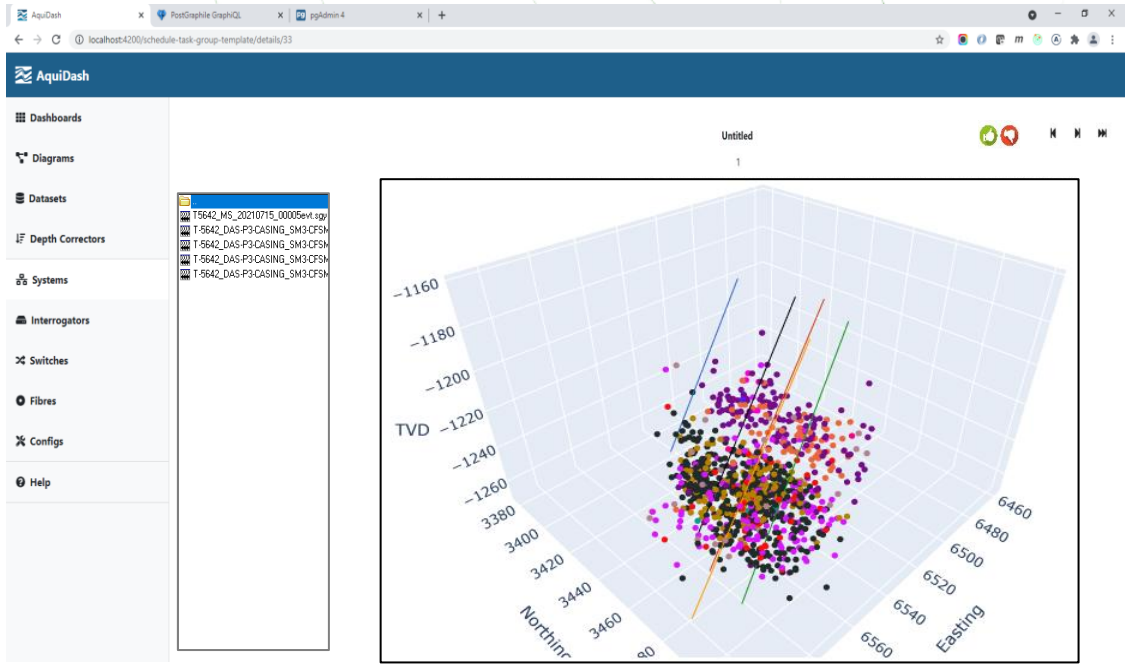
Microseismic Monitoring

Detection Module



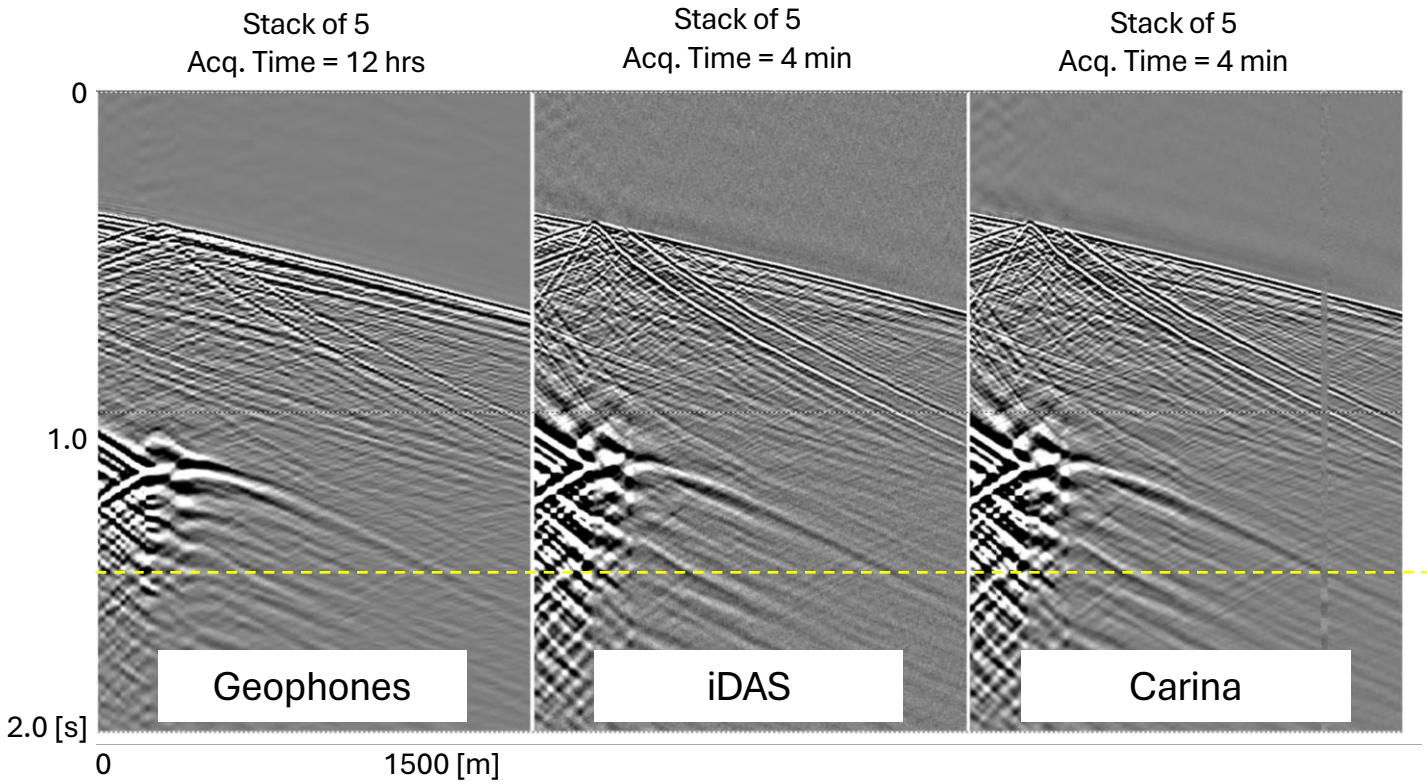
- Event detection catalogue.
- QC/QA on SNR and arrival times.

Location Module



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

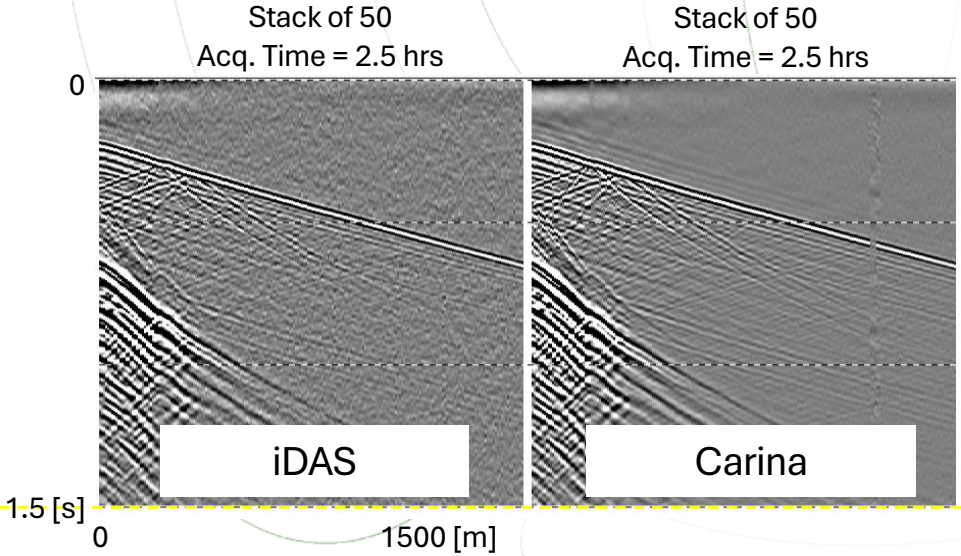
Geophone vs DAS



VSP with Vibe truck

High-cost, high environmental impact, non-continuous

Correa et al. 2019 US-DOE/NETL



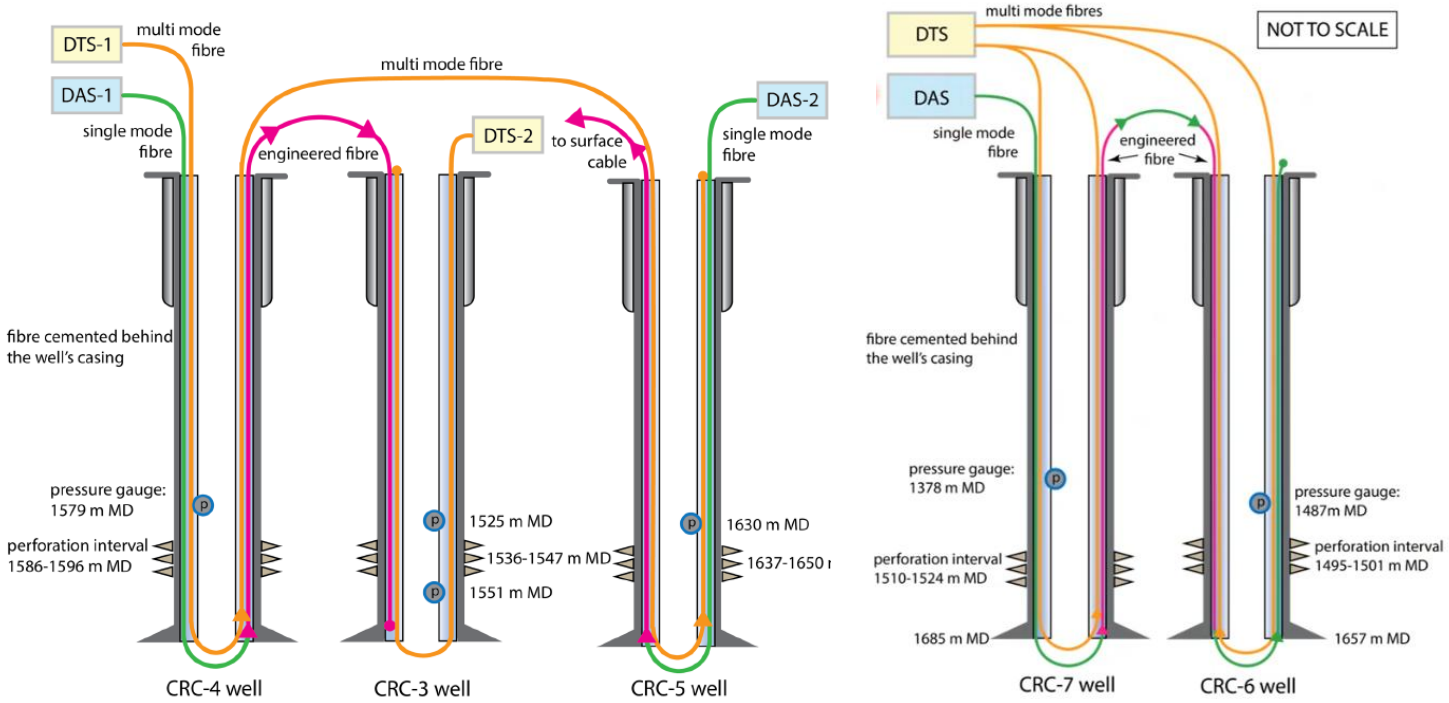
VSP with SOV 80 Hz

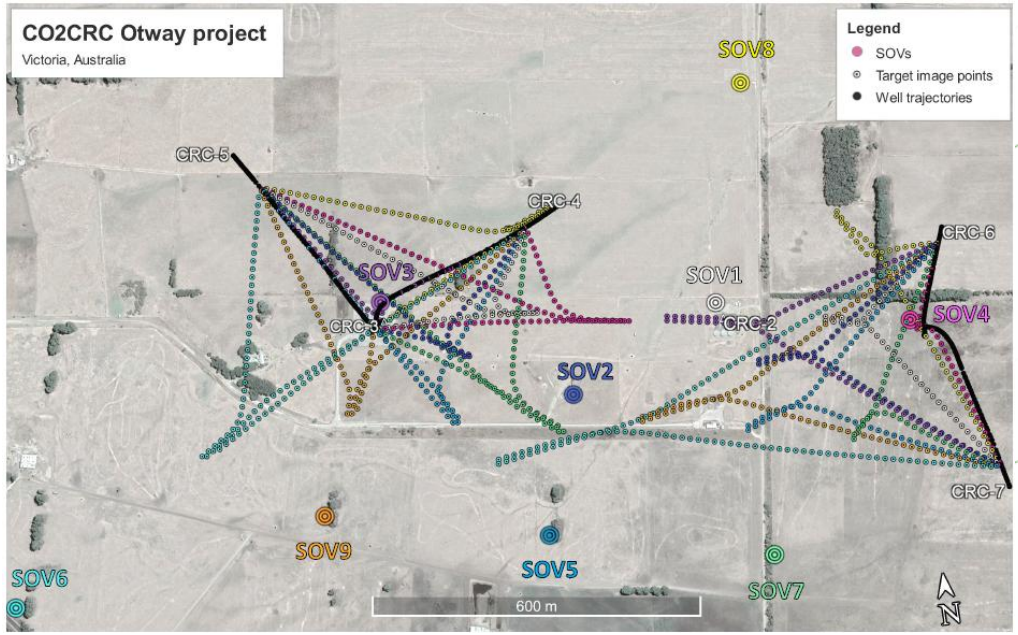
Low-cost, low environmental impact, continuous

Data courtesy of Curtin University

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

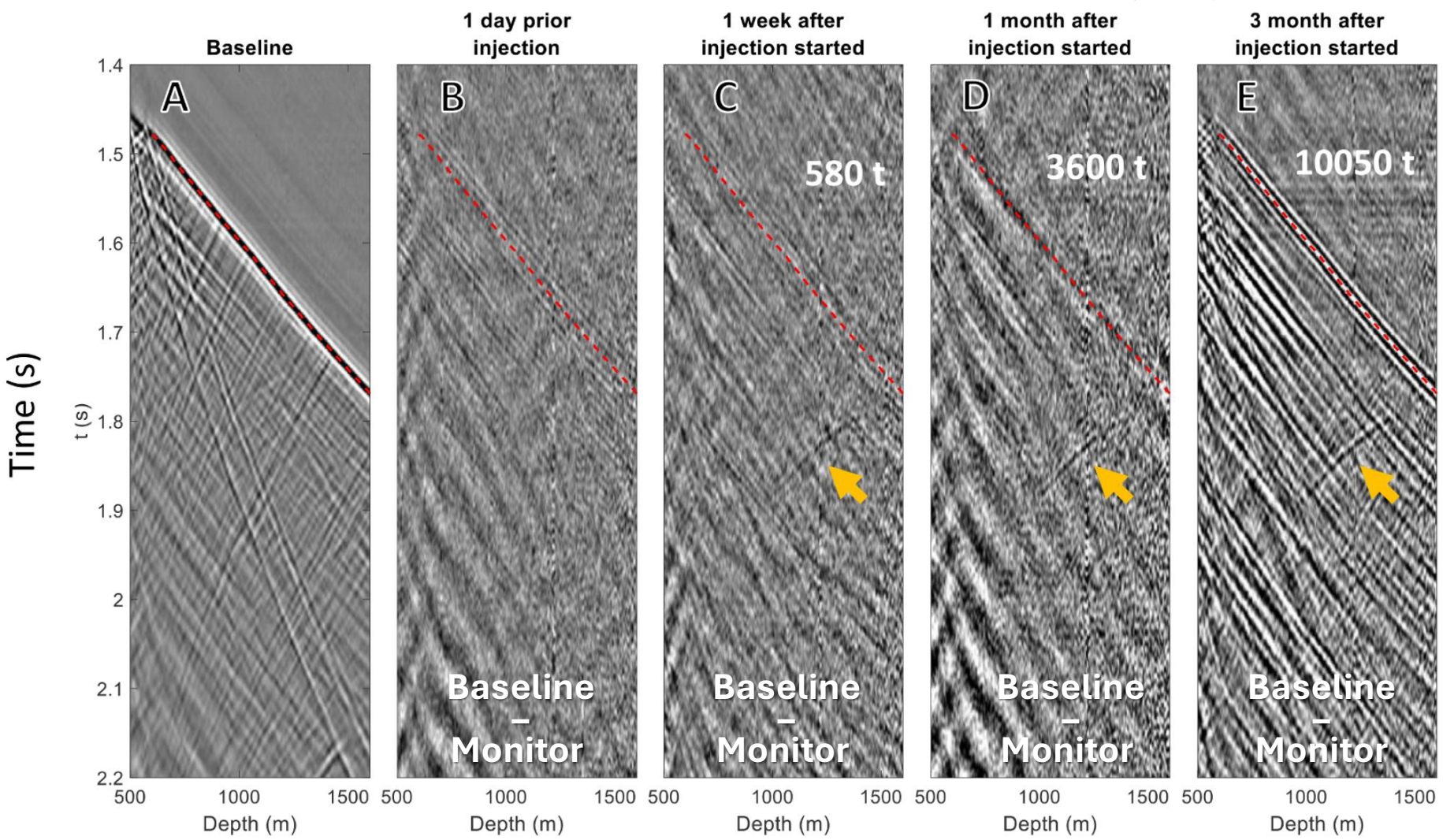
Cable Layout





Sidenko et al. 2022 Intl Journal of Greenhouse Gas Control

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

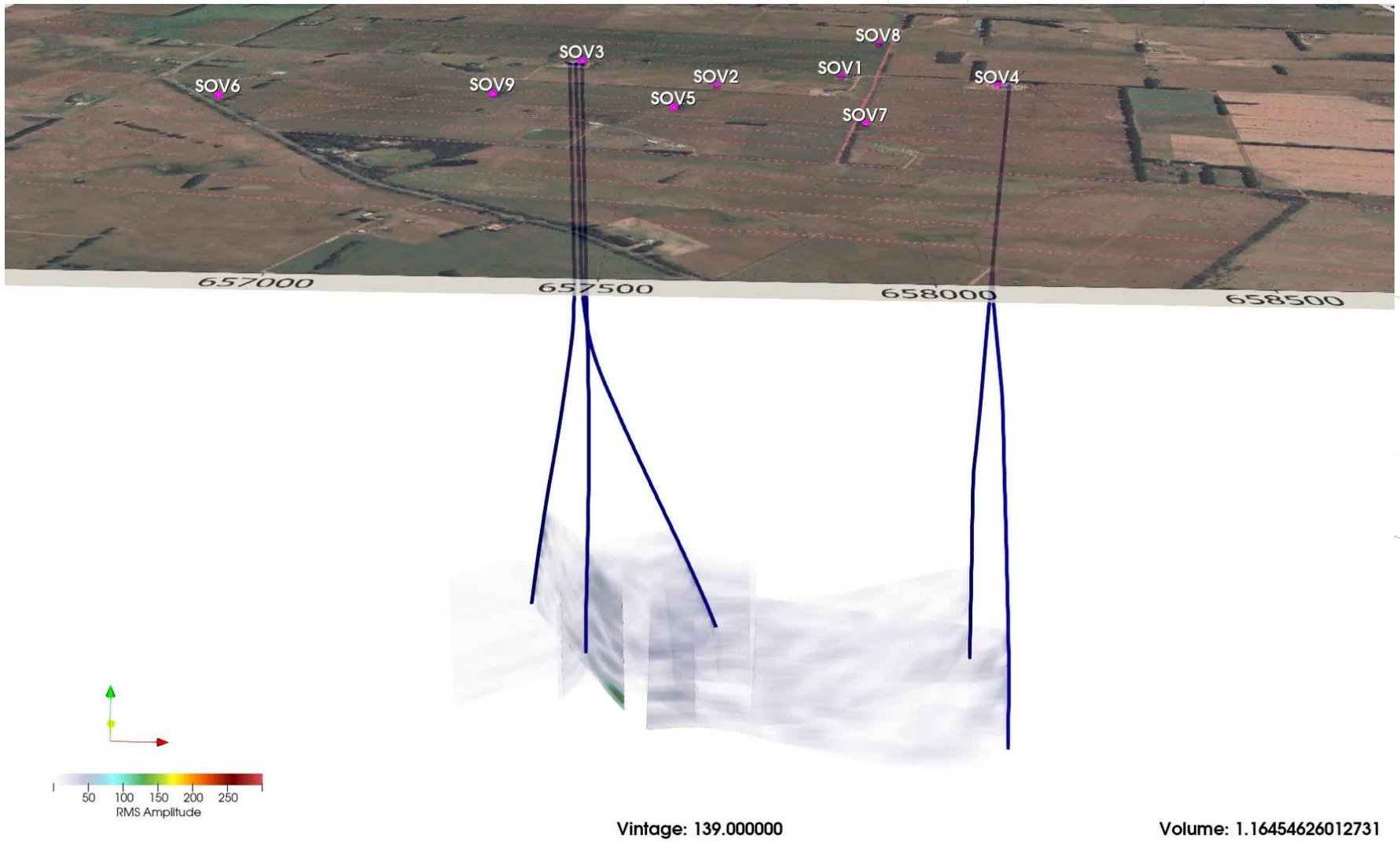


Incremental injected CO_2 in [tons]

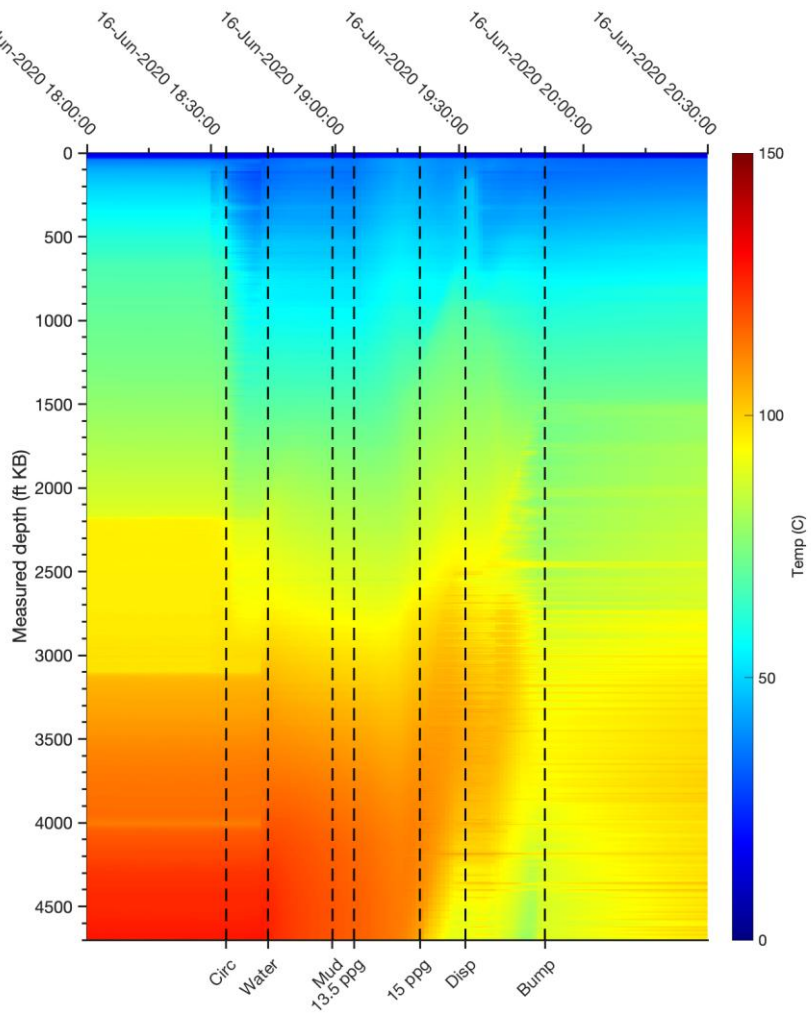
Growing seismic signature of the CO_2 plume

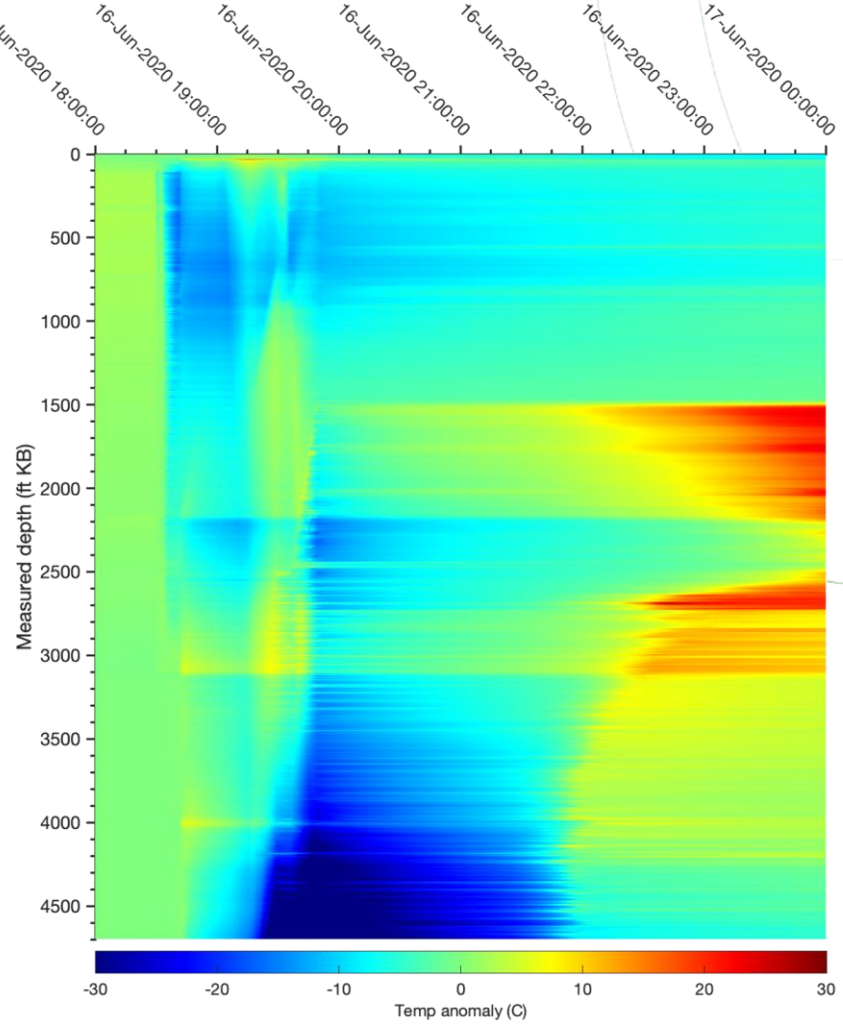
Pevzner et al. 2021 Intl Journal of Greenhouse Gas Control

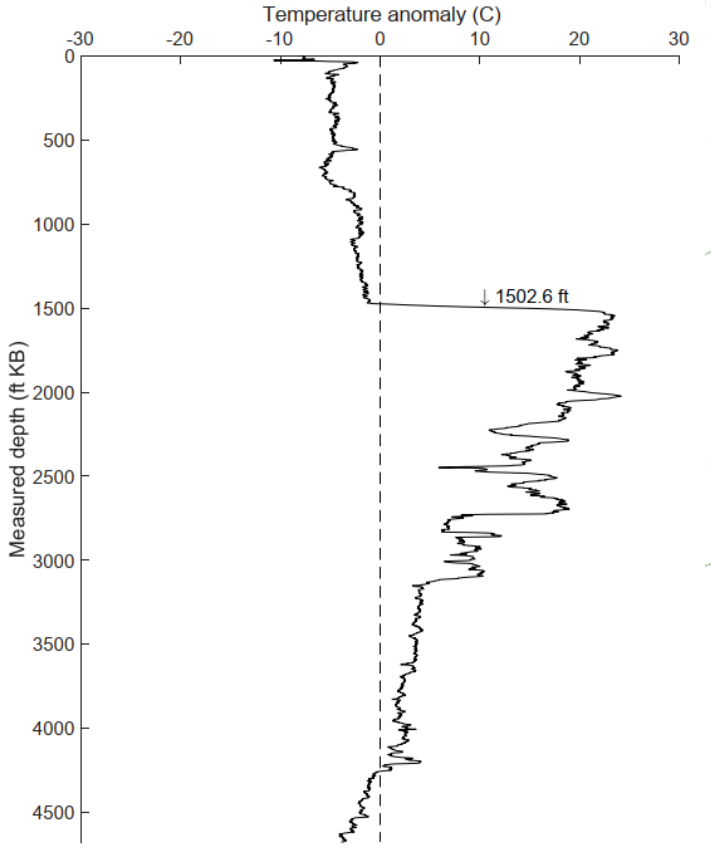
Continuous plume monitoring using permanent sources



Cementation Monitoring – New Mexico (2020)



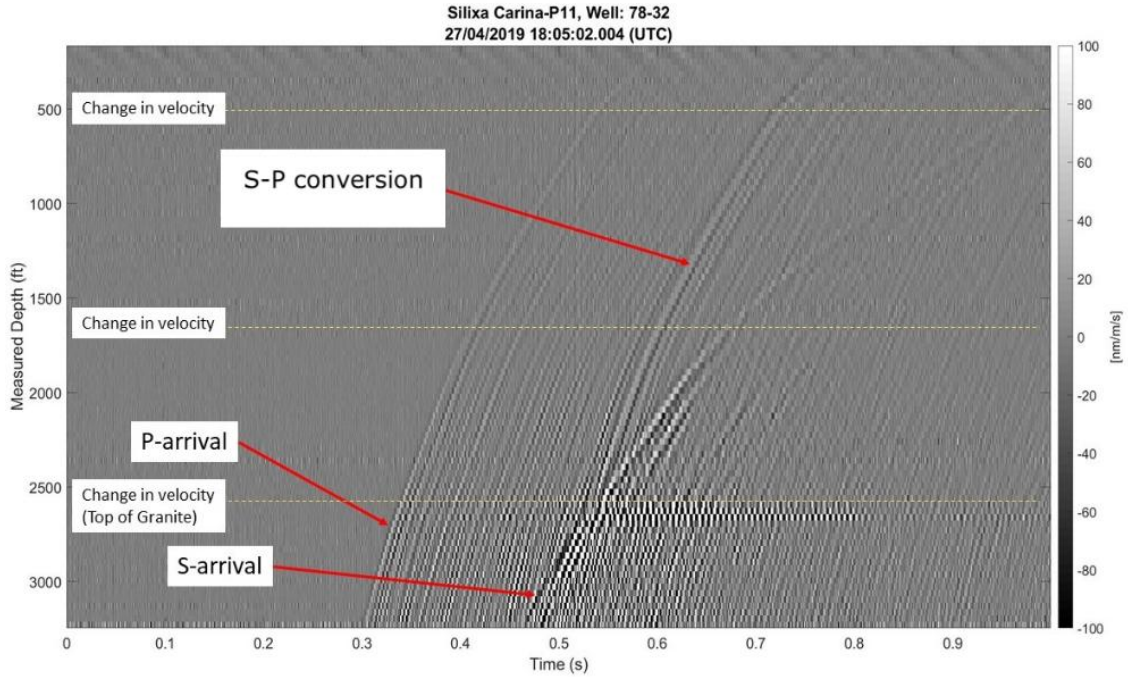




Geothermal Case Study: Utah FORGE

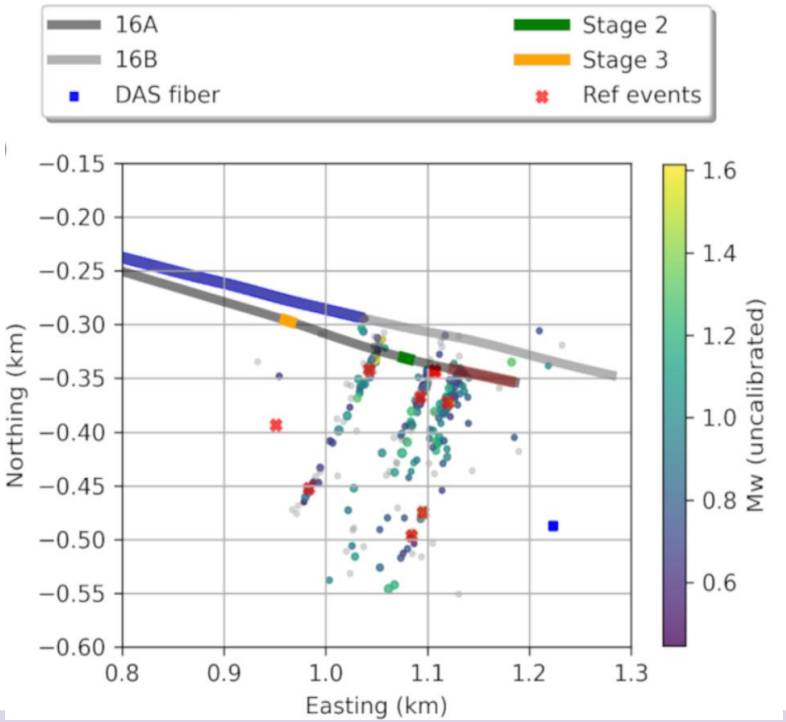
- Department of Energy (DOE) funded
- Provide an underground laboratory for developing and testing innovative tools and stimulation techniques for developing EGS reservoirs.
- Extend existing technologies developed for oil and gas beyond current capabilities to successfully produce electricity from hot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

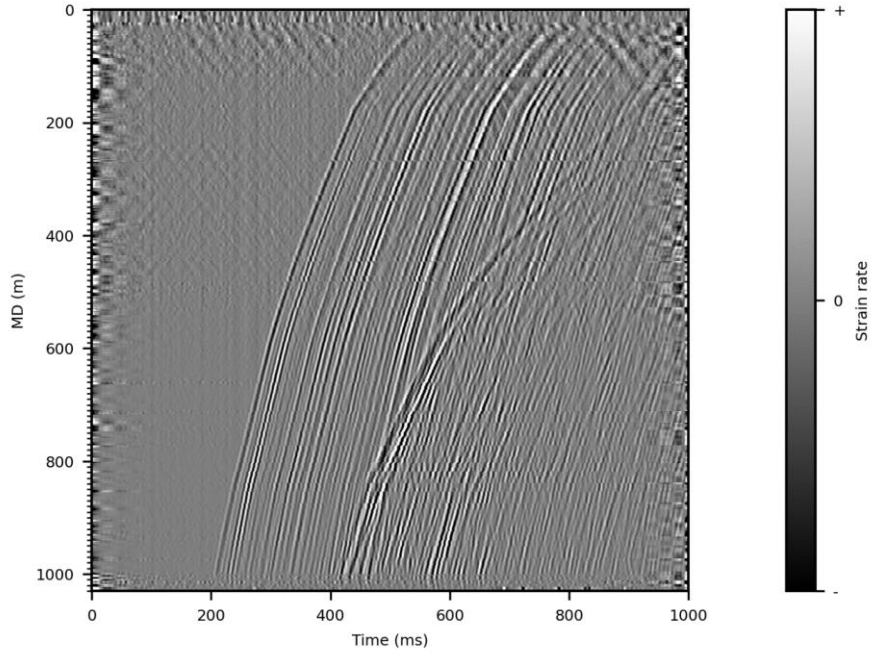
- **Stage 2C:** April 2019
- Single well microseismic monitoring
- Carina system acquisition

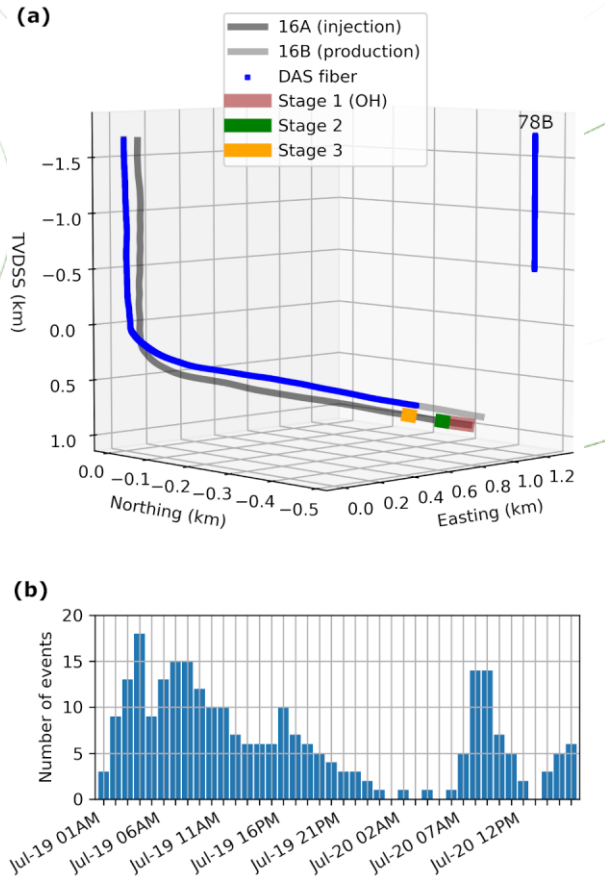


Microseismic Monitoring – 2019 – ongoing

- 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

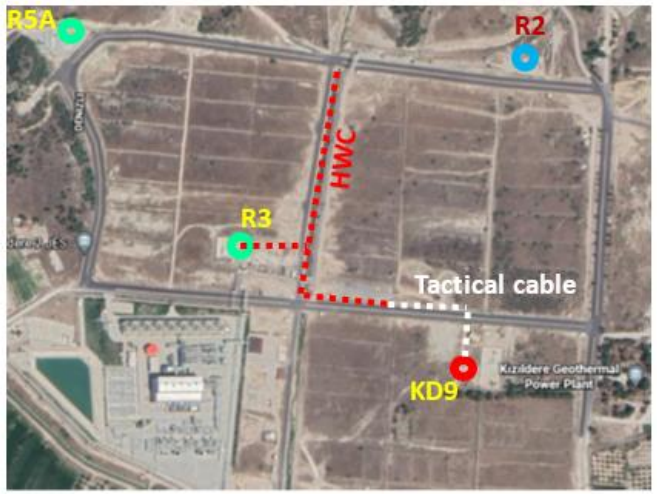
- 260 MWe installed capacity
- 2,000 – 3,500 m reservoir depth
- 220 – 245°C reservoir temperature
- Carbonate reservoir

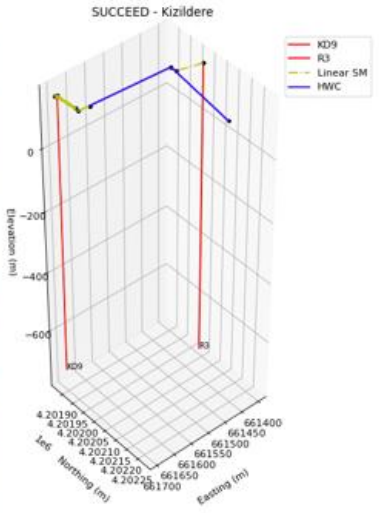
Produced raw gas piped from Kızıldere Unit 2, injected with a compressor/booster system at the injection well @700m depth @ supercritical state

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)



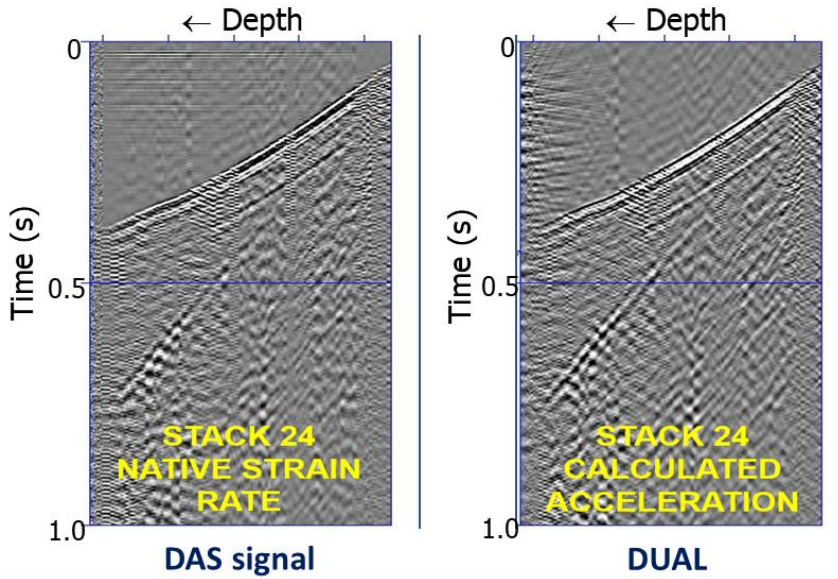


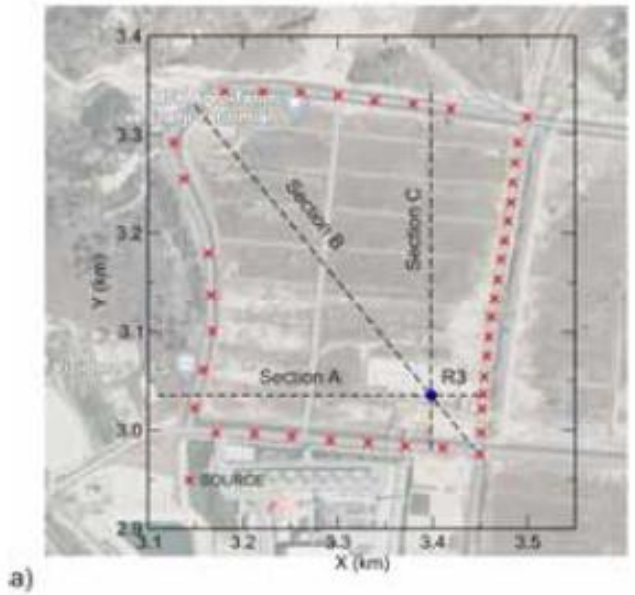
near-offset VSP QC during acquisition

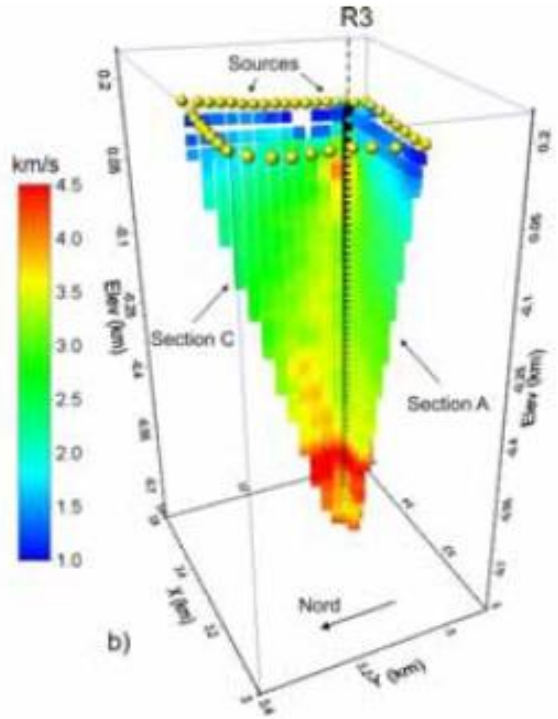
Vertical Seismic Profiling (VSP) and seismic reflection imaging of the reservoir.

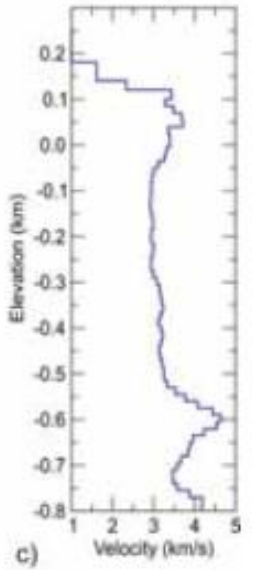
Baseline survey before CO2 injection begins. Aim is to provide time-lapse monitoring of the injection process

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









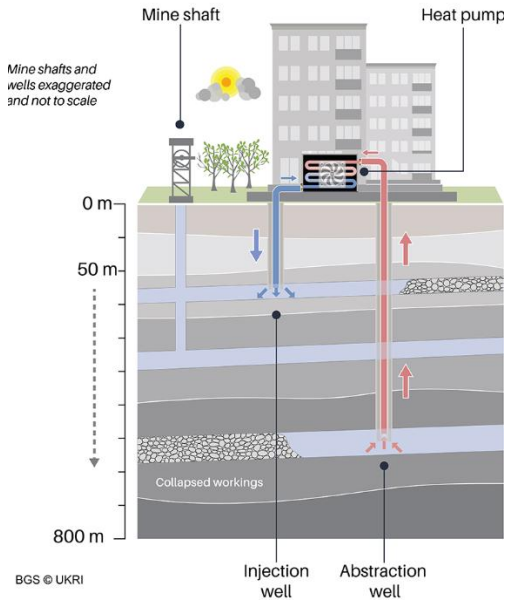
Case Study: Hellisheiði geothermal field, Iceland

- 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

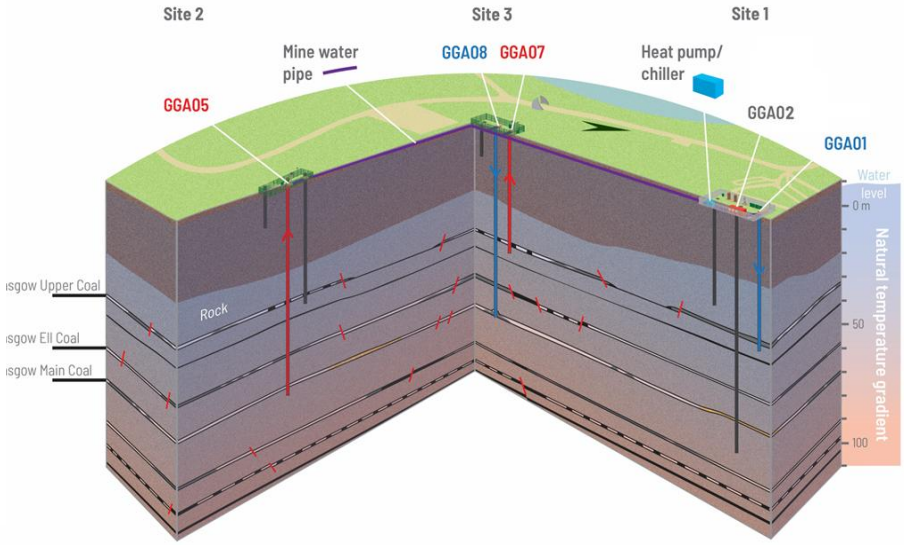
Seismic surveys

- 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

UK GEOS Observatory Glasgow, UK



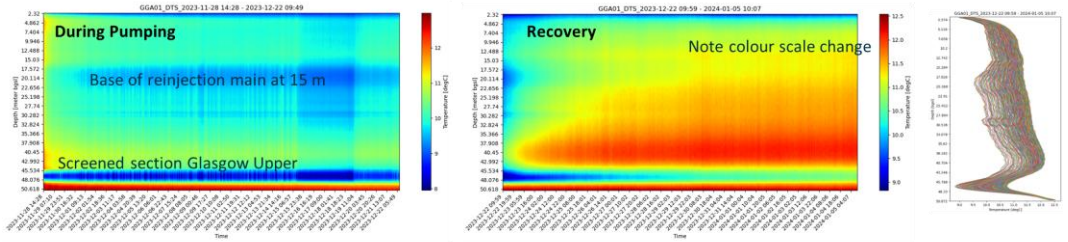
ERT electrodes and fibre optic cable being installed on the outside of the mine water borehole casing and screened section/pre-glued gravel pack



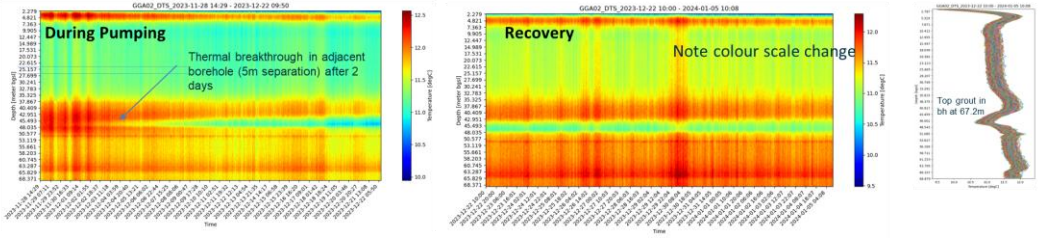
Mine-water heat abstraction from abandoned coal mines

DFOS monitoring enables understanding of processes and interactions

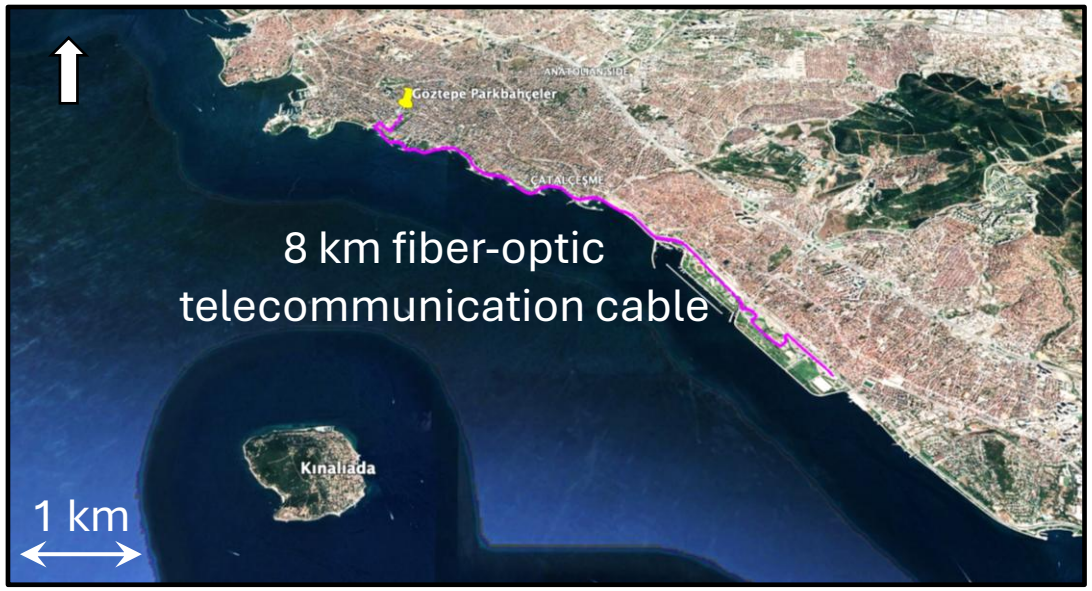
GGA01 – Reinjection borehole



GGA02 – 5m from GGA01



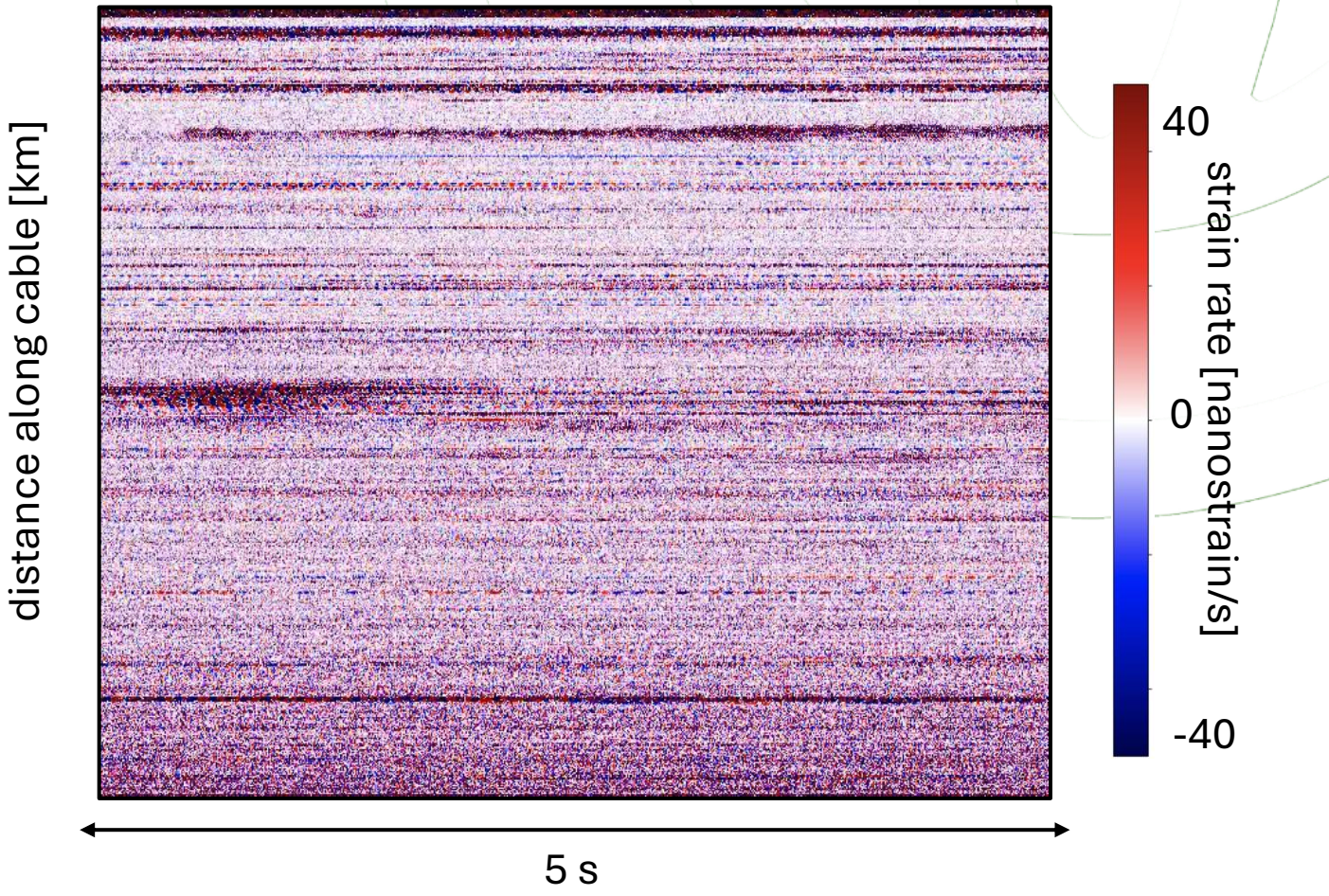
DAS Recording of the M7.8 Gaziantep earthquake Feb 2023



Video courtesy of Andreas Fichtner

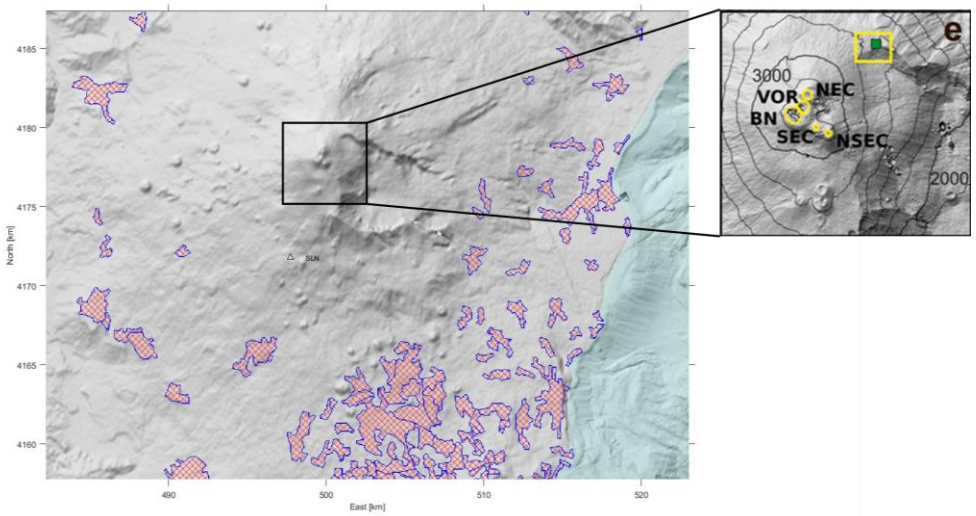
Strain-rate recording - Movie

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



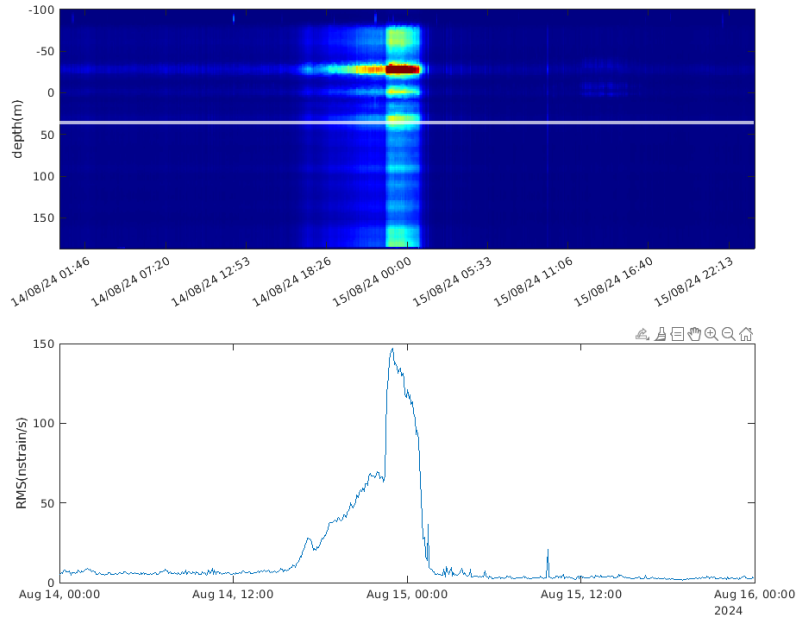
ETNA Volcano Monitoring, Italy

- 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)

Geophysical instruments and data processing

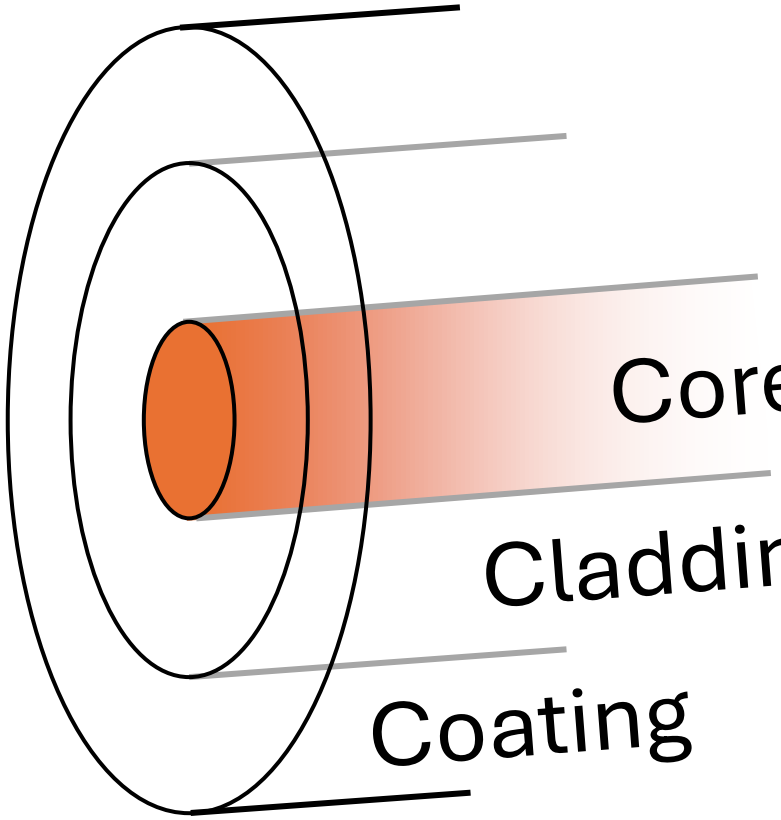
Fibre optics basics - DAS principles

Frantisek Stanek

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

Optical fibre structure



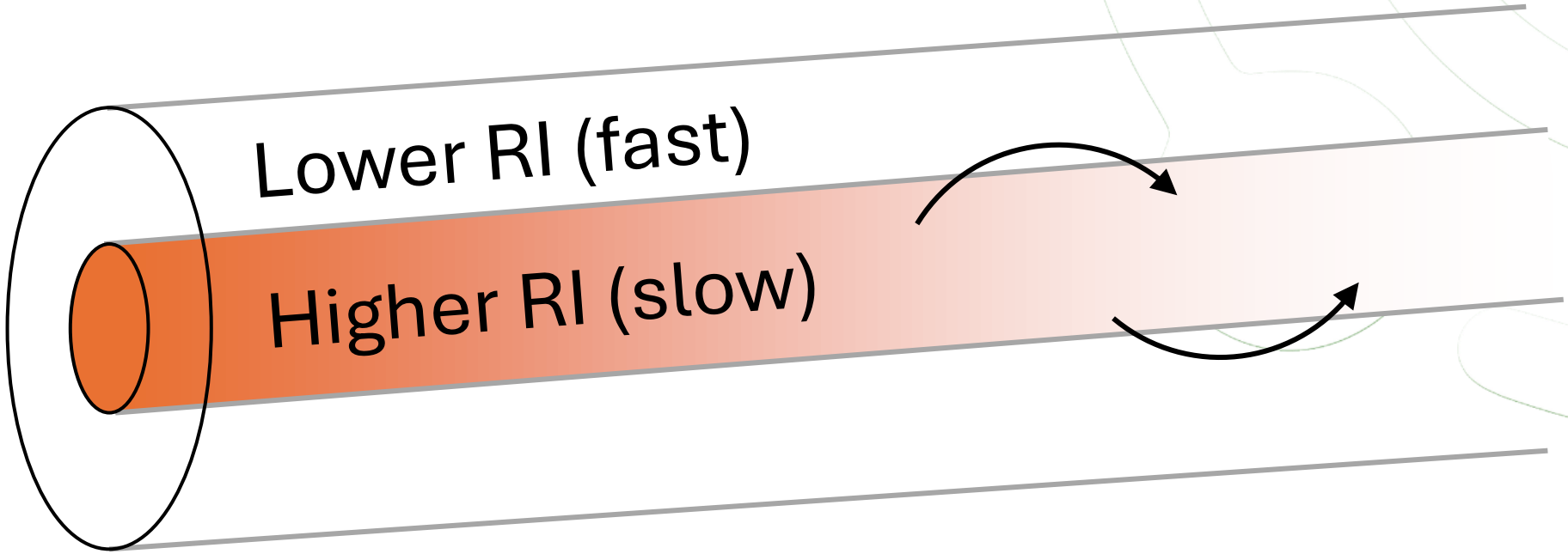
SMF: 9 µm, MMF: 50 µm

125 µm

250 µm

Optical fibre structure

Waveguide effect confines light to core



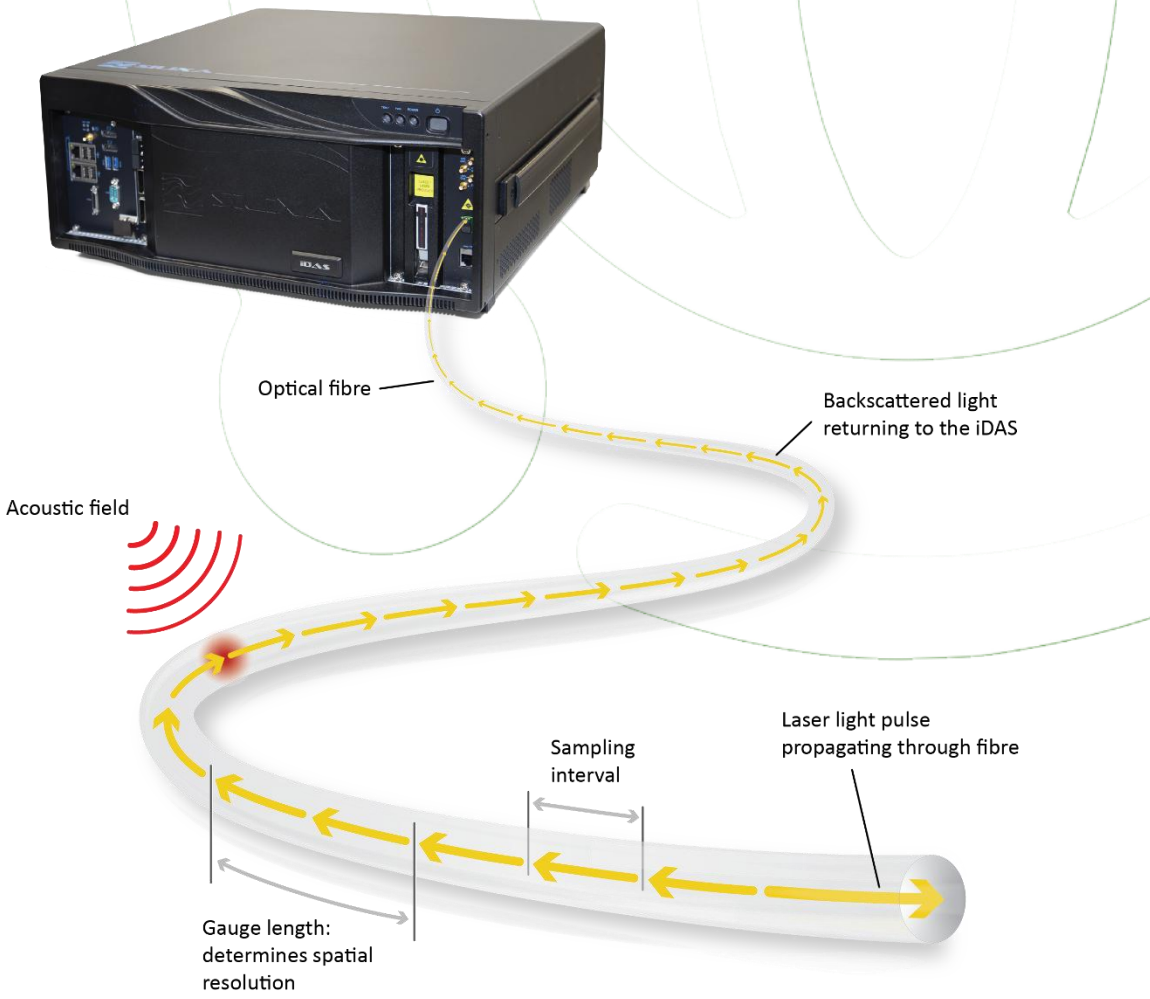
Typical propagation RI (group index) = 1.46
Rule of thumb: Speed of light ≈ 2×10^8 m/s

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



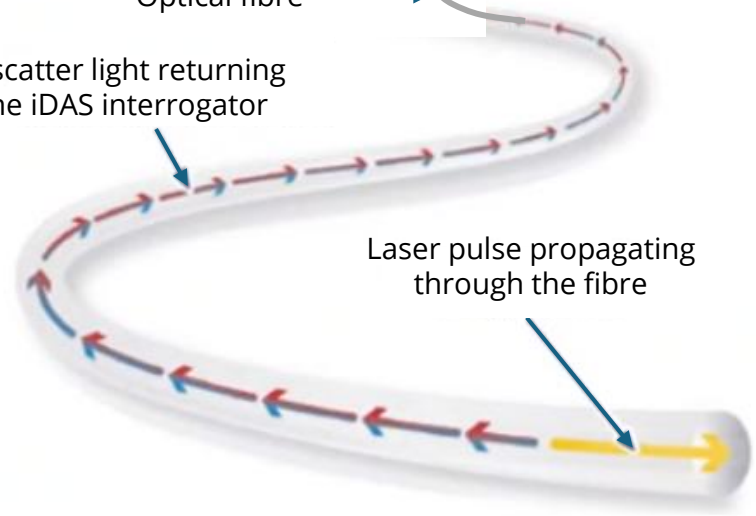
The advantage of true distributed measurements

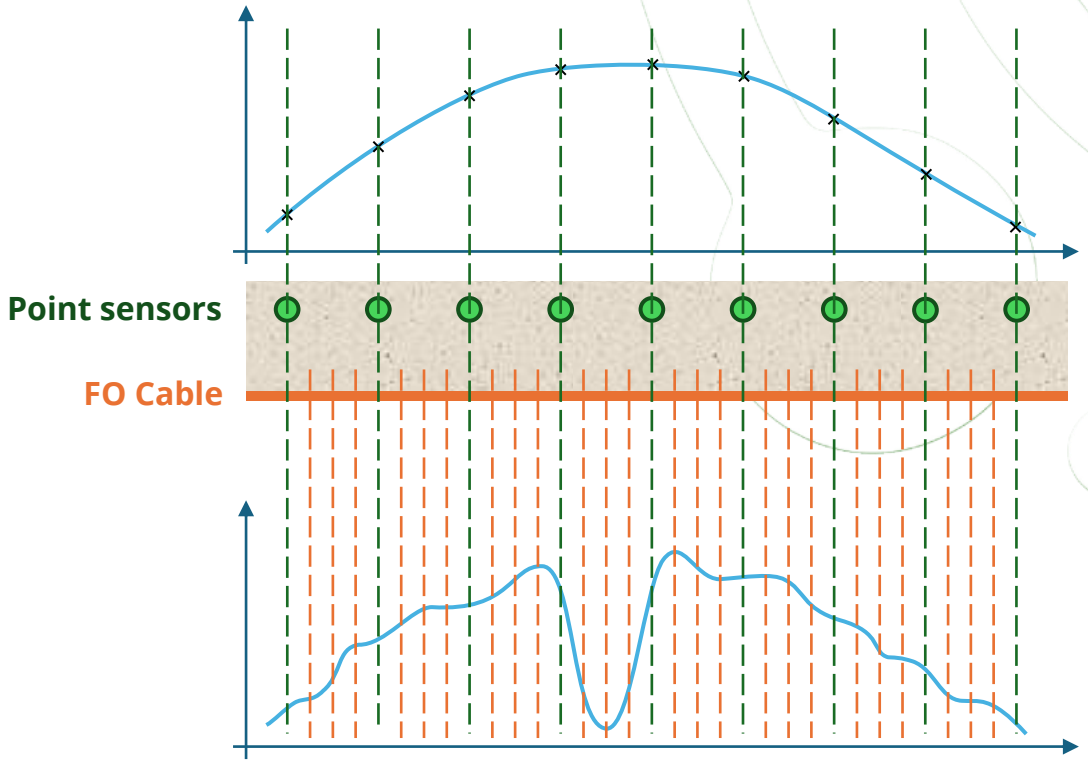
iDAS interrogator

Optical fibre

Backscatter light returning to the iDAS interrogator

Laser pulse propagating through the fibre





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.

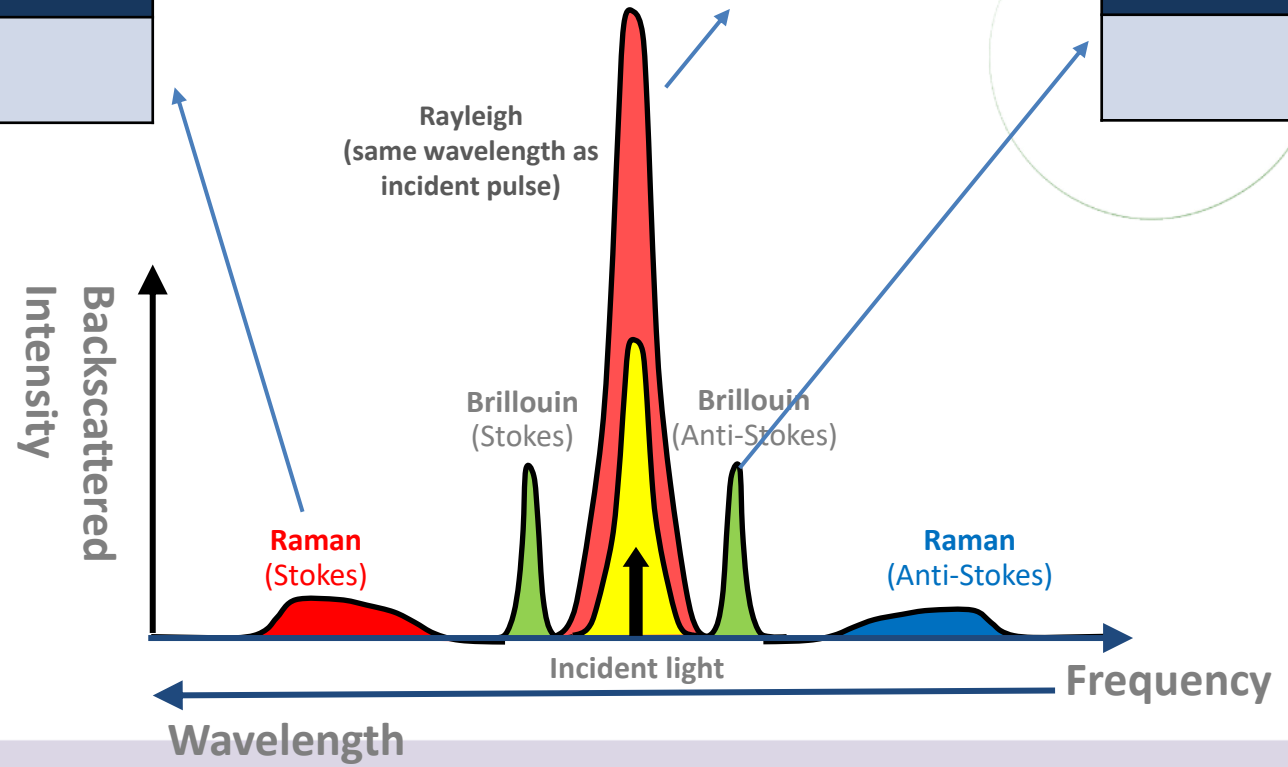
Fibre optics require no electronics at point of measurement.

Backscattered light and different measurements

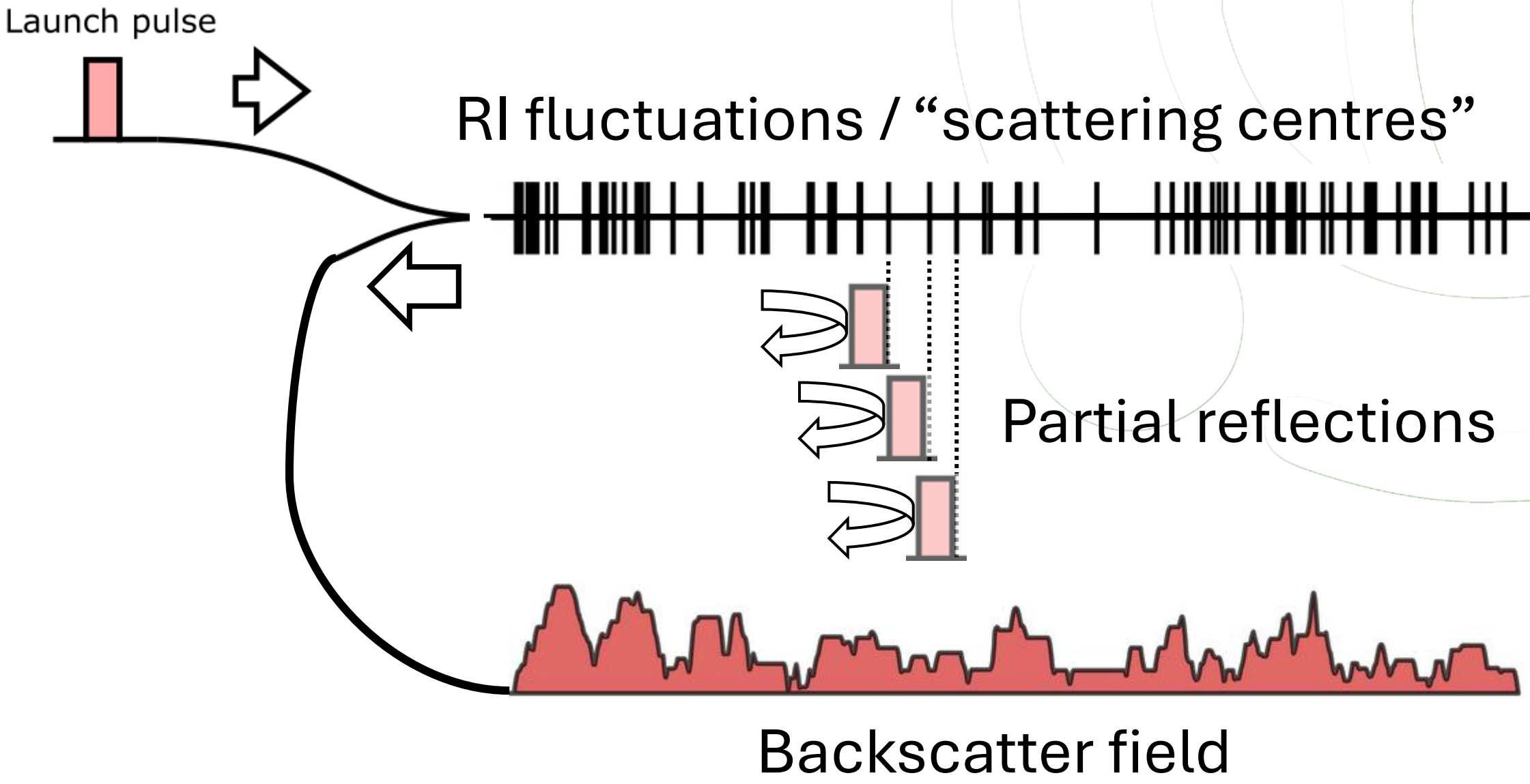
MK2 Ultima	MK2 XT
Temperature (DTS) 0.01°C Resolution	

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

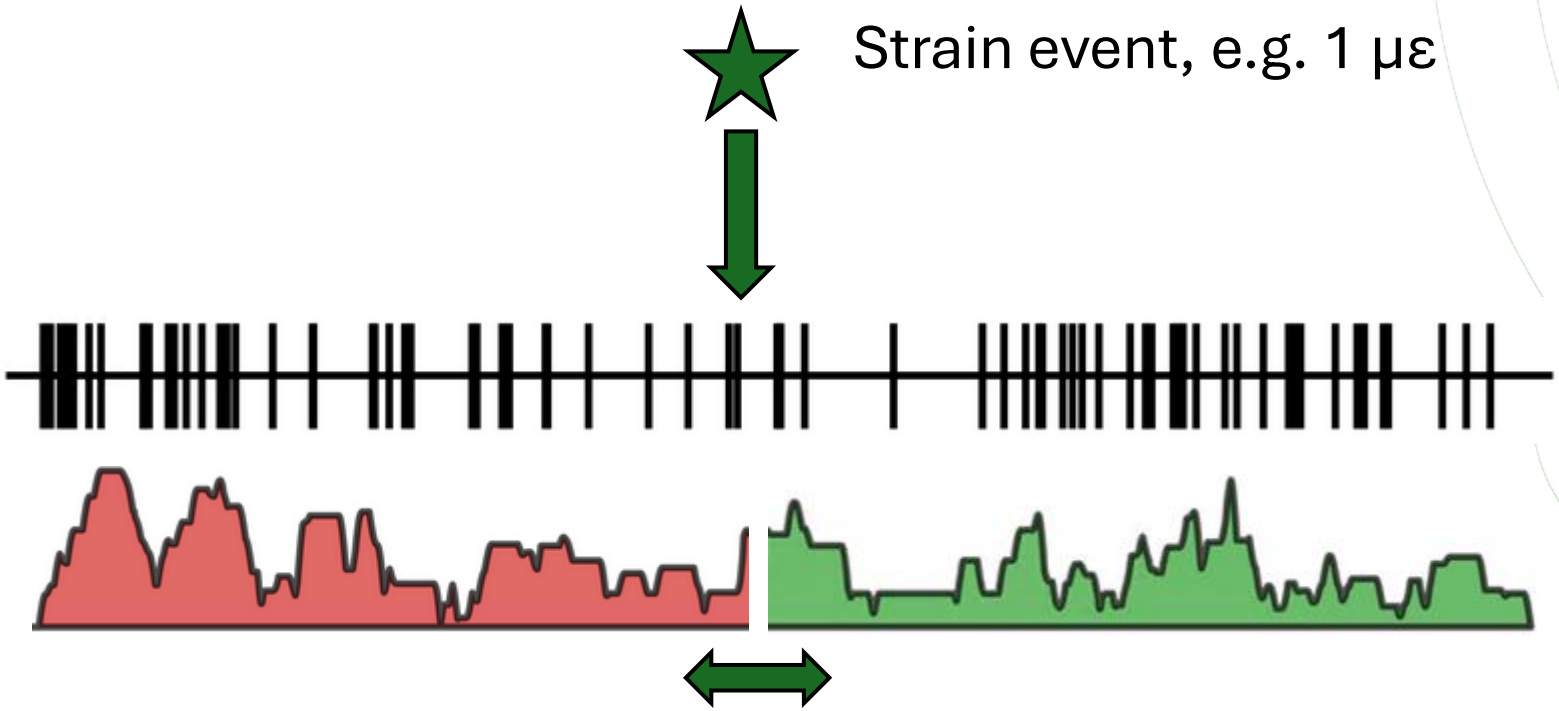
iDSS
Strain (DSS) 1 με Resolution

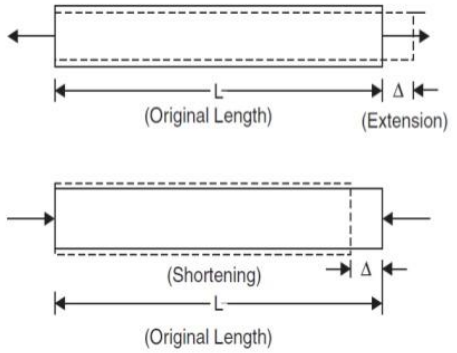


What DAS measures



What DAS measures

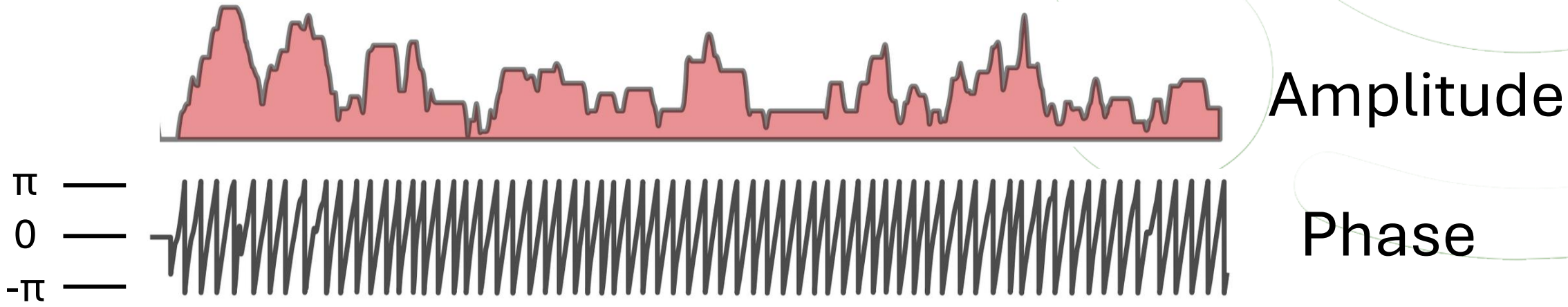




$$strain = \frac{elongation}{original\ length} = \frac{\Delta L}{L}$$

What DAS measures

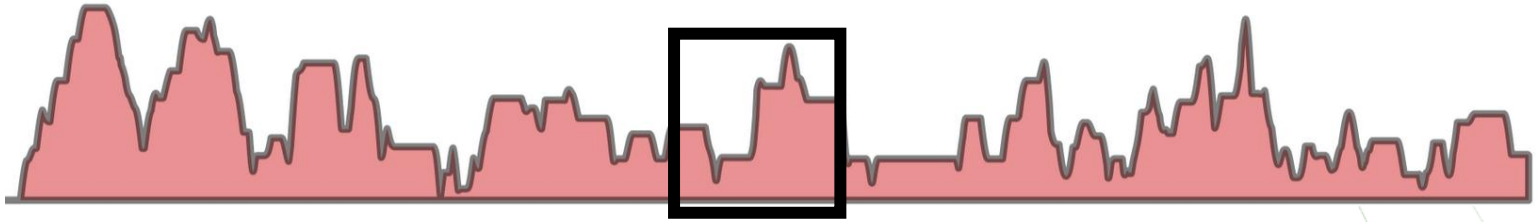
Interferometric detection

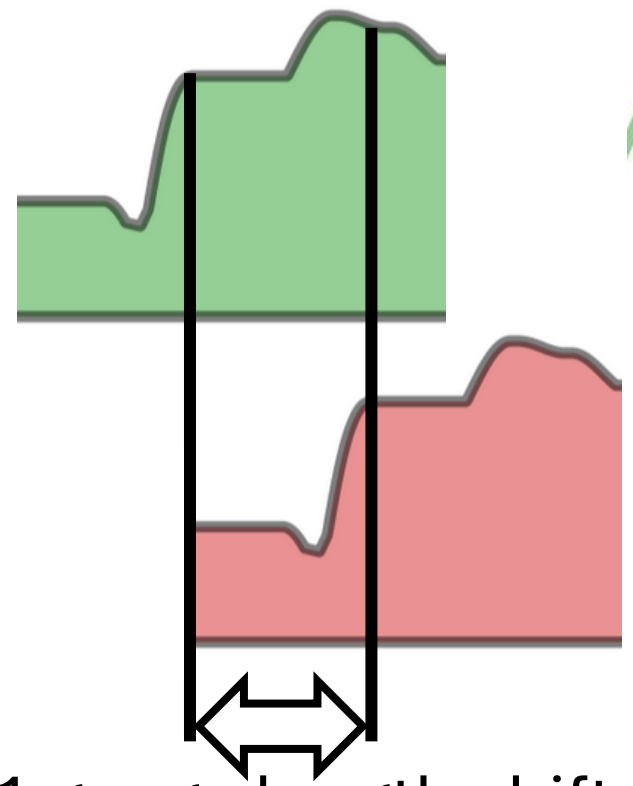


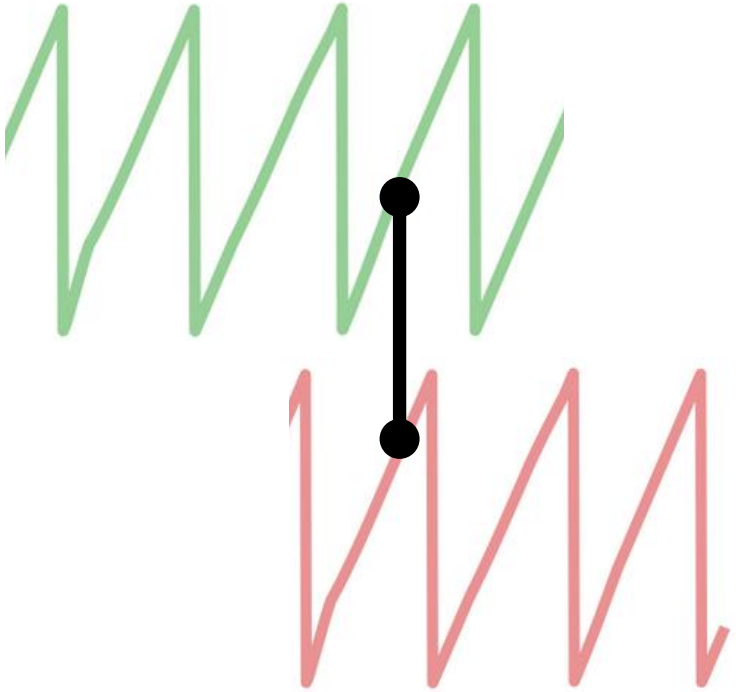
350 nm path delay → π phase change

What DAS measures

Gauge length shift and comparison







1 gauge length shift

DAS = phase difference time evolution $\delta\varphi$

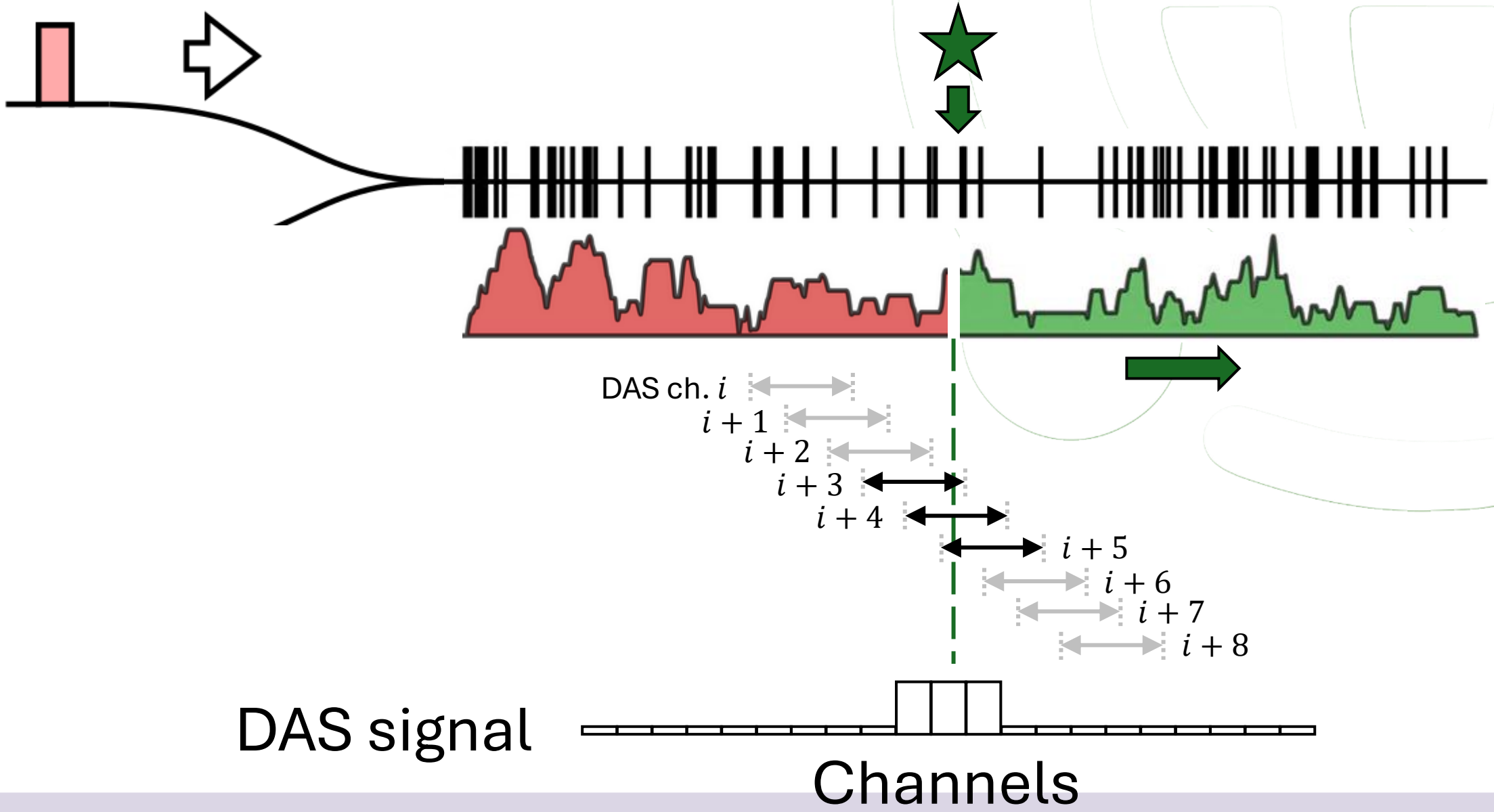
$$\dot{\varepsilon} = \frac{\alpha f_s}{L_G}\delta\varphi$$

$\alpha = 116\text{nm/rad}$

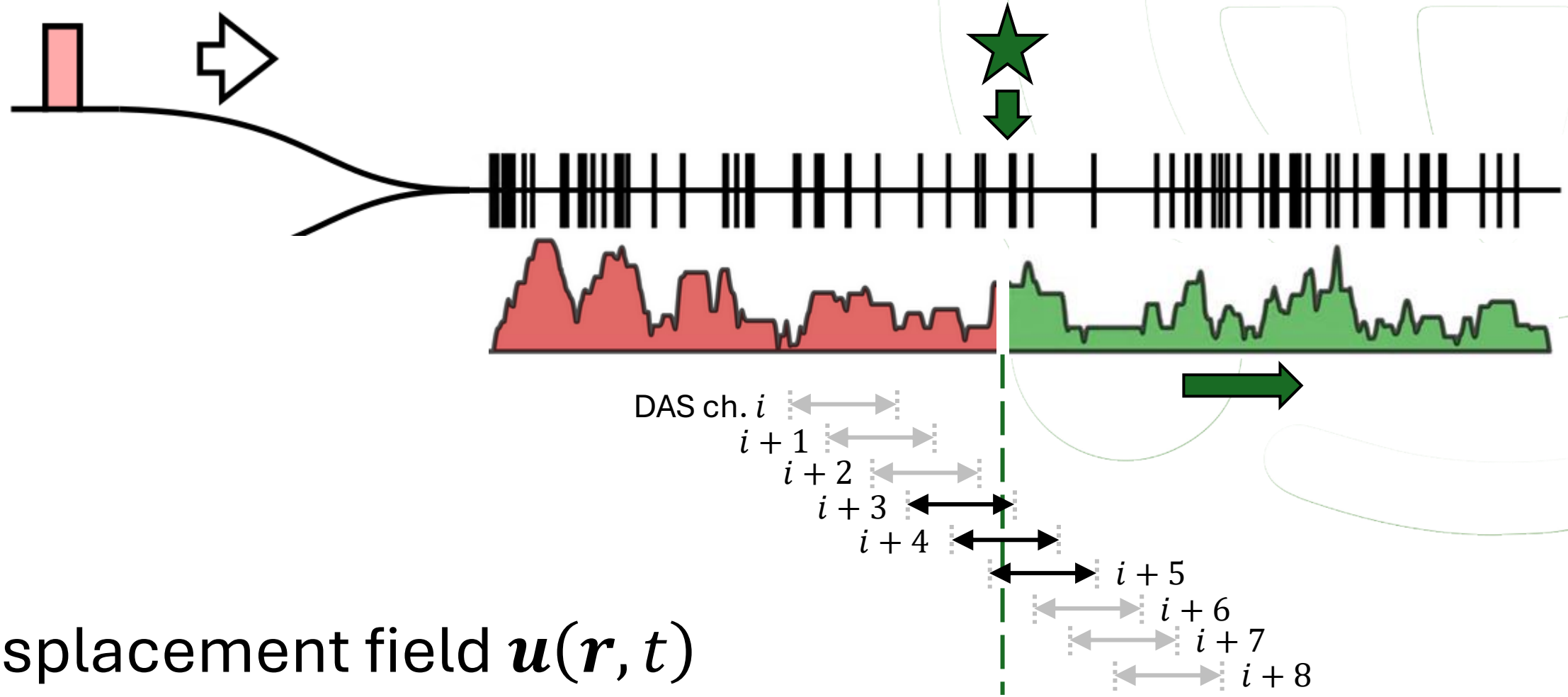
f_s = Sampling frequency

L_G = Gauge length

What DAS measures



What DAS measures

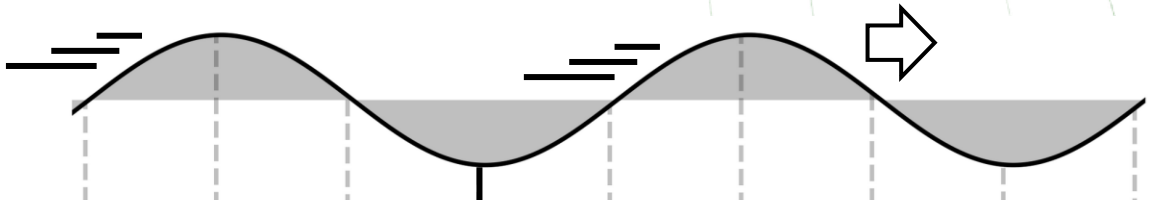


Displacement field $\boldsymbol{u}(\boldsymbol{r}, t)$

DAS signal $\propto \frac{d^2 u_x}{dxdt}$

DAS as particle velocity, spatial derivative

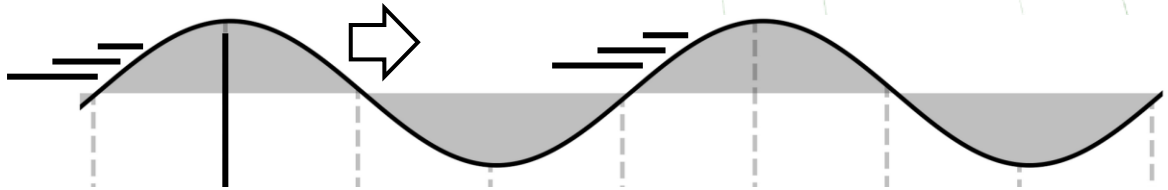
Displacement u_x



Travelling wave

DAS as strain-rate, window-averaged

Displacement u_x



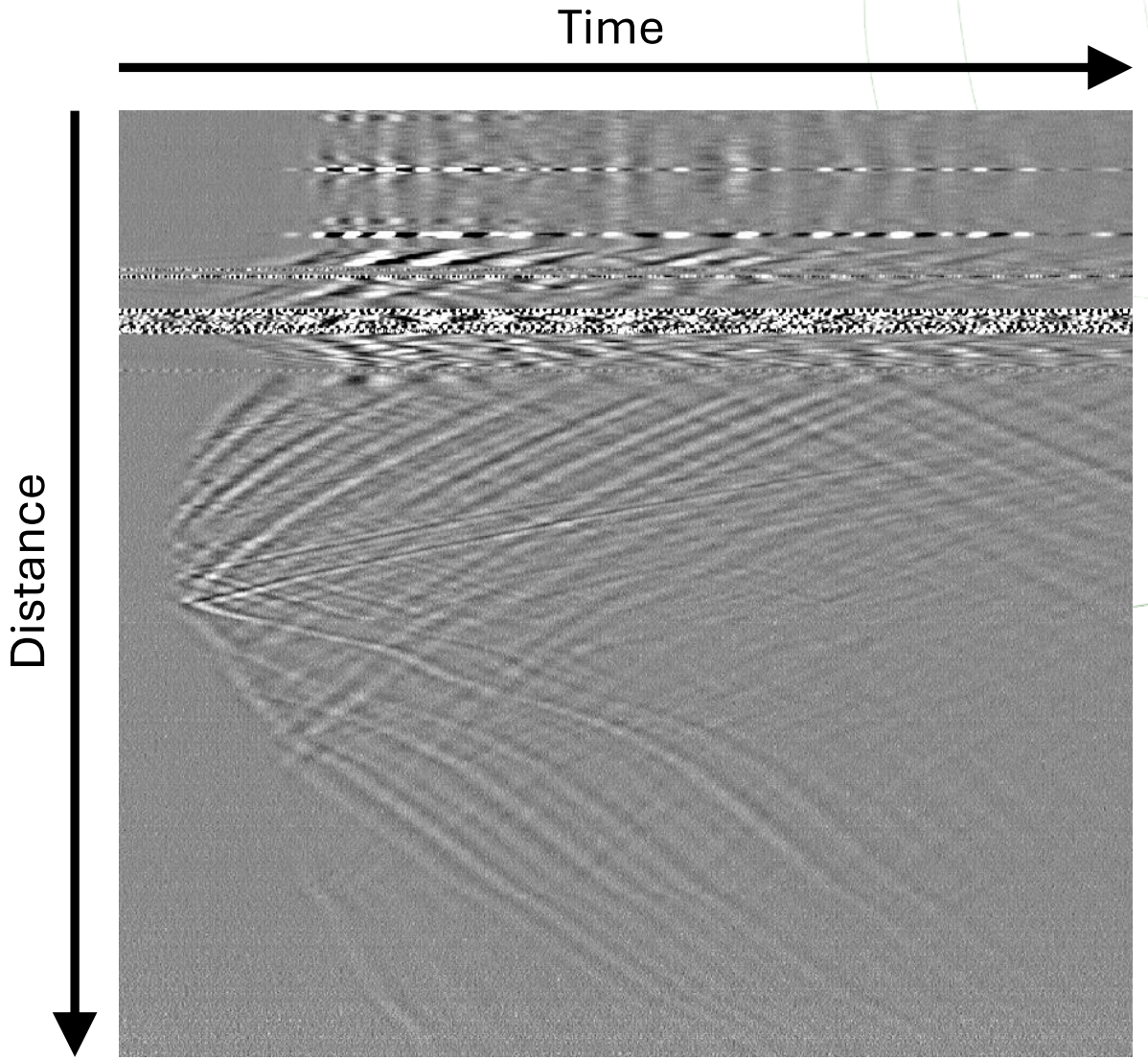
Travelling wave

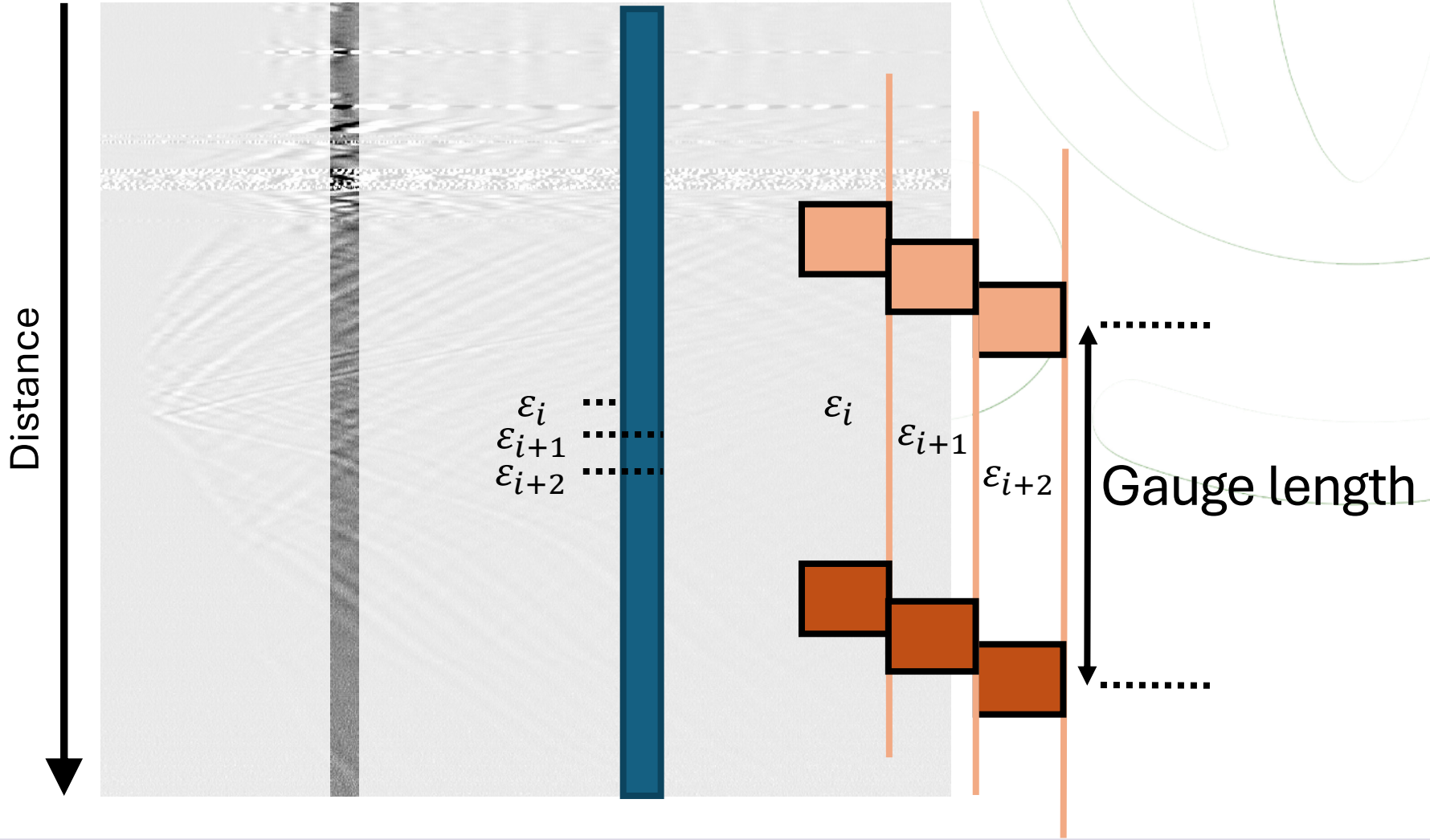
Strain-rate $\dot{\varepsilon}_x = \frac{d^2 u_x}{dxdt}$

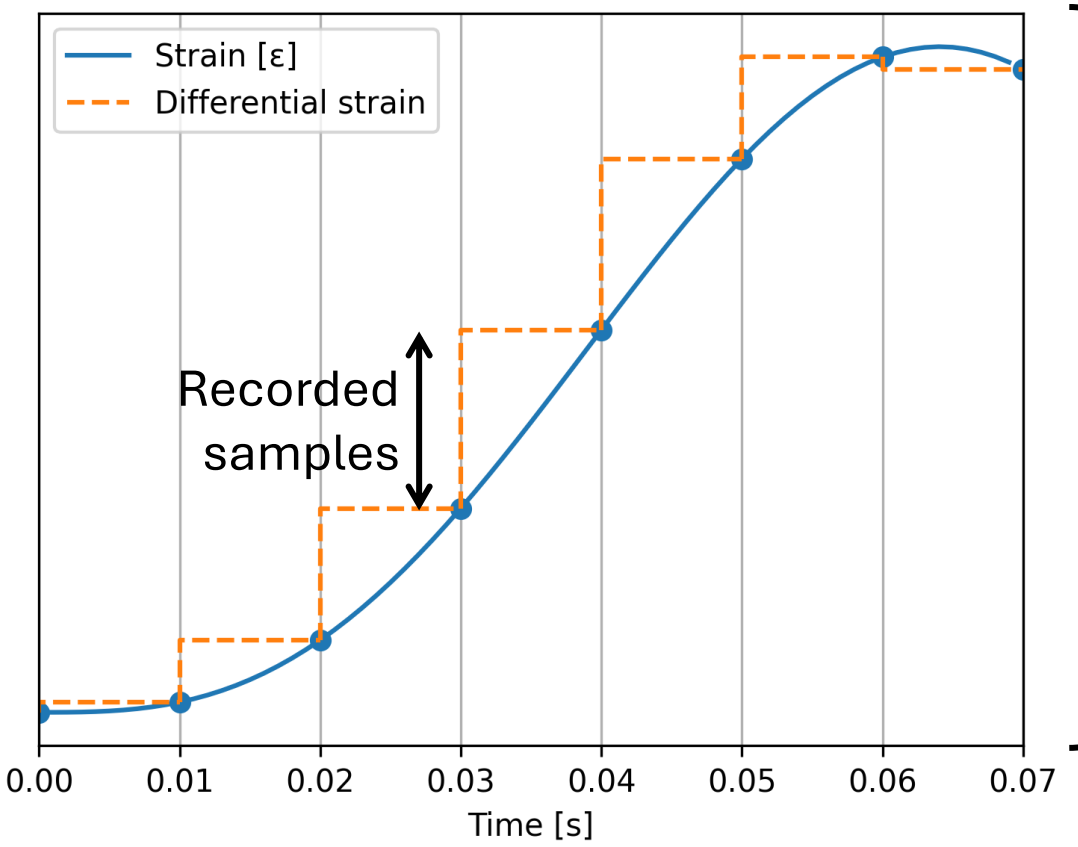
DAS

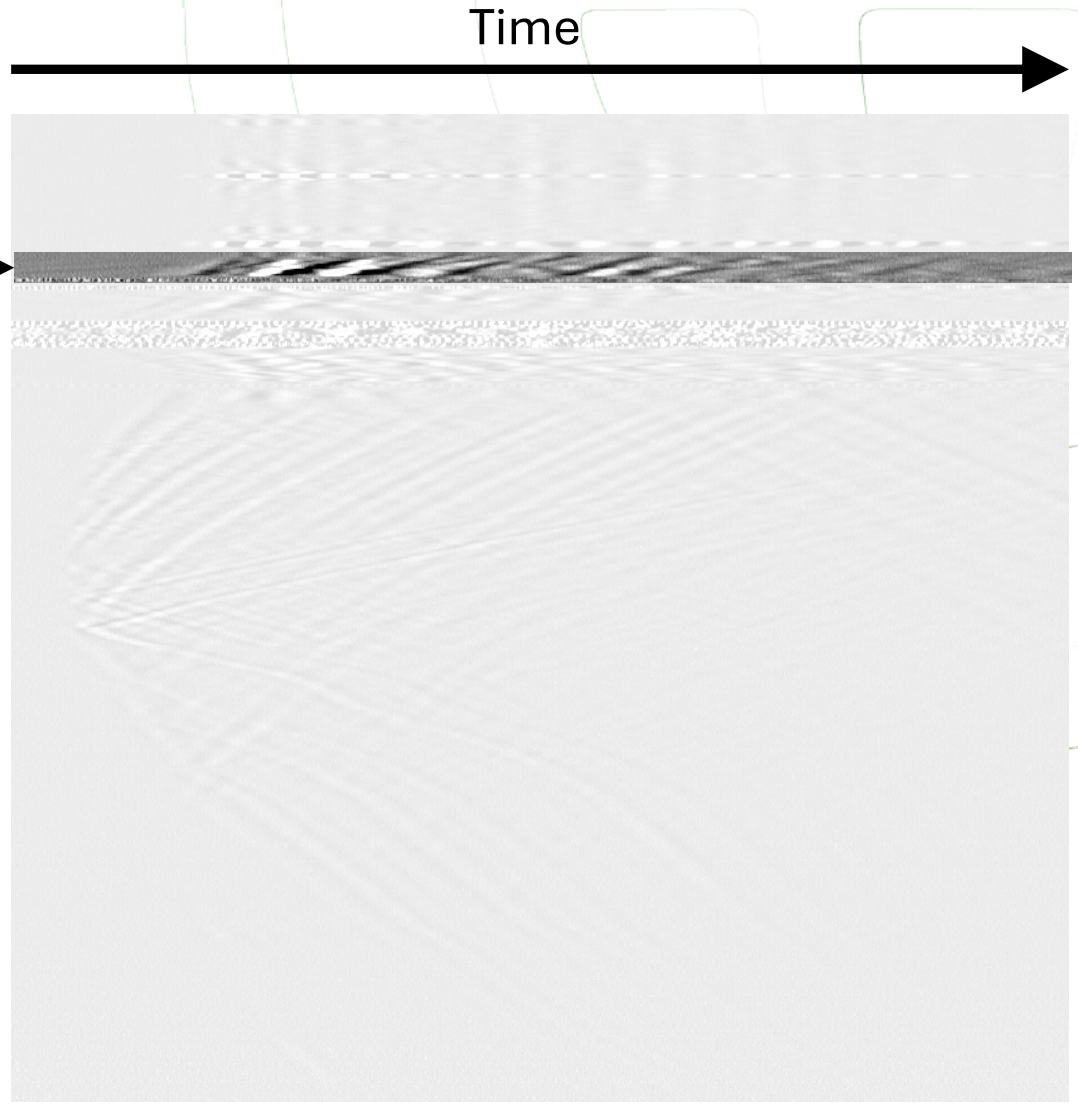
$\dot{\varepsilon}_x * \Pi(x/L_G)$

Output

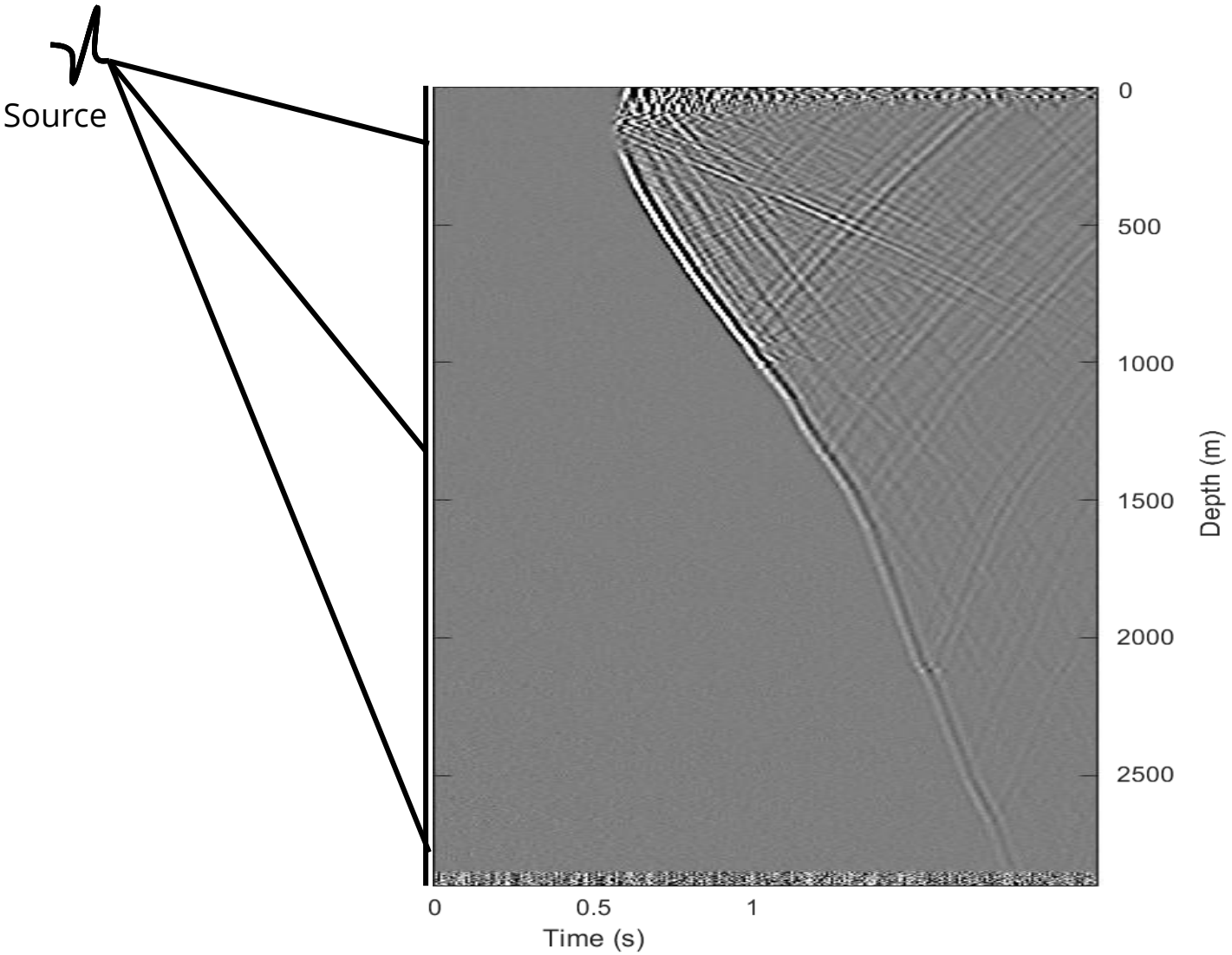



Distance
ε_i
ε_{i+1}
ε_{i+2}
ε_i
ε_{i+1}
ε_{i+2}
Gauge length


Strain [ε]
Differential strain
Recorded samples
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Time [s]


Time

DAS data characteristics



- **DAS measures the *rate of change of strain* in the fibre.**
- **A single point on the fibre creates a *time-series* of the amplitude of the strain rate.**
- **Every point on the fibre is measured at the same time:**
  - **Each point can be called a channel (or receiver).**

iDAS MG example

- Optimised for **high sensitivity, high dynamic range** acoustic detection
- Designed for **standard fibre**
- Single optical channel
- < 1 mHz – 50 kHz detection bandwidth
- Single-gauge model:
  - 10 m GL
  - 45 km range
- Multi-gauge (MG) model:
  - 3, 5, 10, 30 m GL
  - 30 - 50 km ranges respectively

Carina Example

- Optimised for **ultra-high sensitivity, high dynamic range** acoustic detection
- Designed for **Constellation fibre**, situated near or far from the interrogator
- Provides greater sensitivity on standard fibre than iDAS, at greater range.
- Single optical channel
- < 1 mHz – 50 kHz detection bandwidth
- Four gauge lengths as standard:
  - 25 cm (15 km)
  - 2 m (30 km)
  - 10 m (50 km)
  - 30 m (60 km)

THANKS!

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

Geophysical instruments and data processing

DAS configuration best practices

- Frantisek Stanek

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Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
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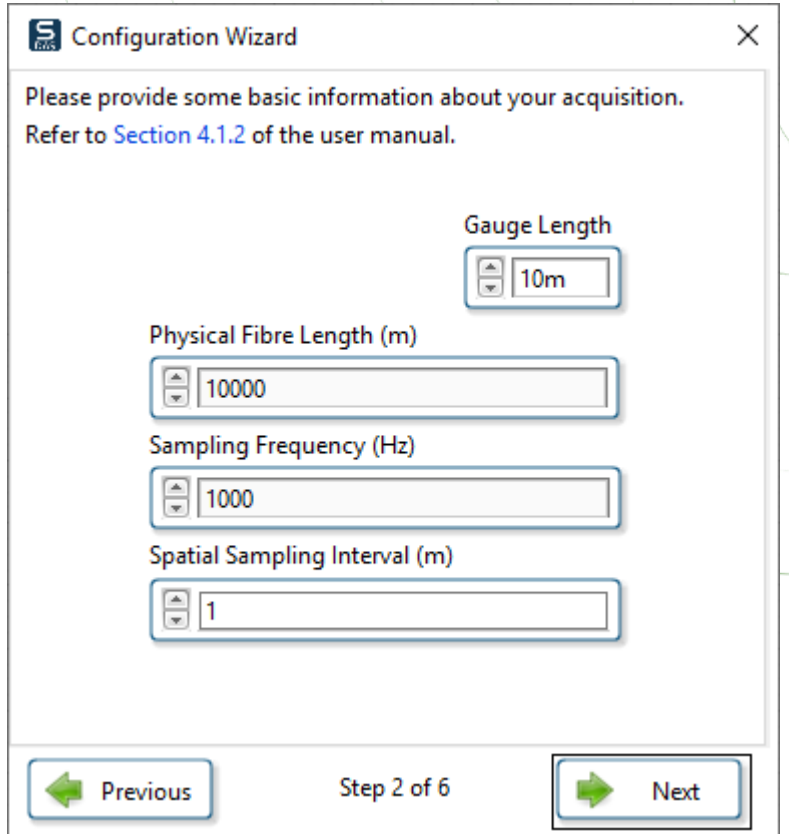
Outline

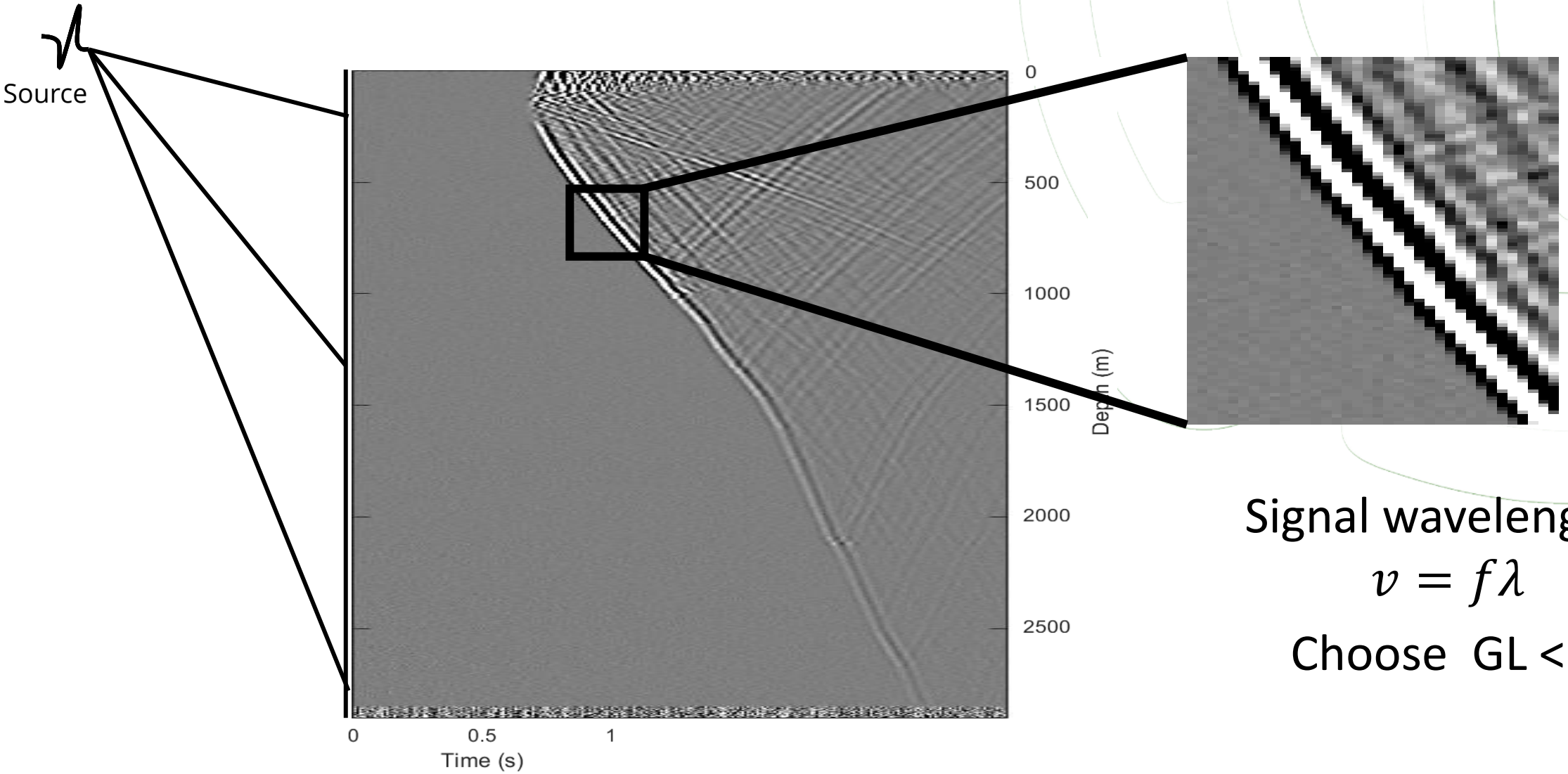
- DAS Setup wizard
- Sampling frequency
- Optical fibre losses
- Gauge length
- Dynamic range
- Comparison with Geophones

Configuration Wizard

- Gauge Length
- Physical Fibre Length
- Sampling Frequency
- Spatial Sampling Interval



Gauge length



Signal wavelength?

$$v = f\lambda$$

Choose GL < λ

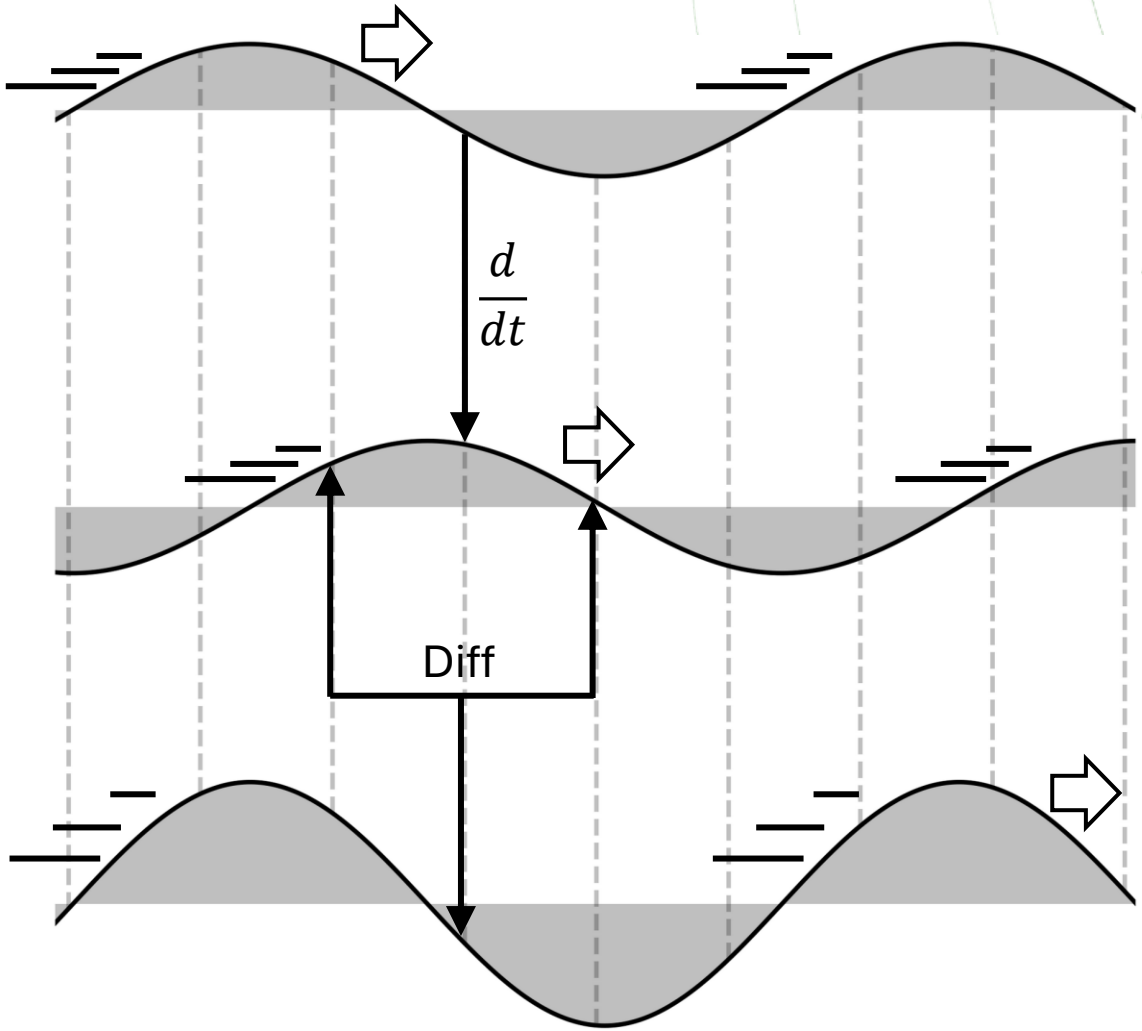
Gauge length

Displacement u_x

Velocity

DAS

= velocity differential



Travelling wave

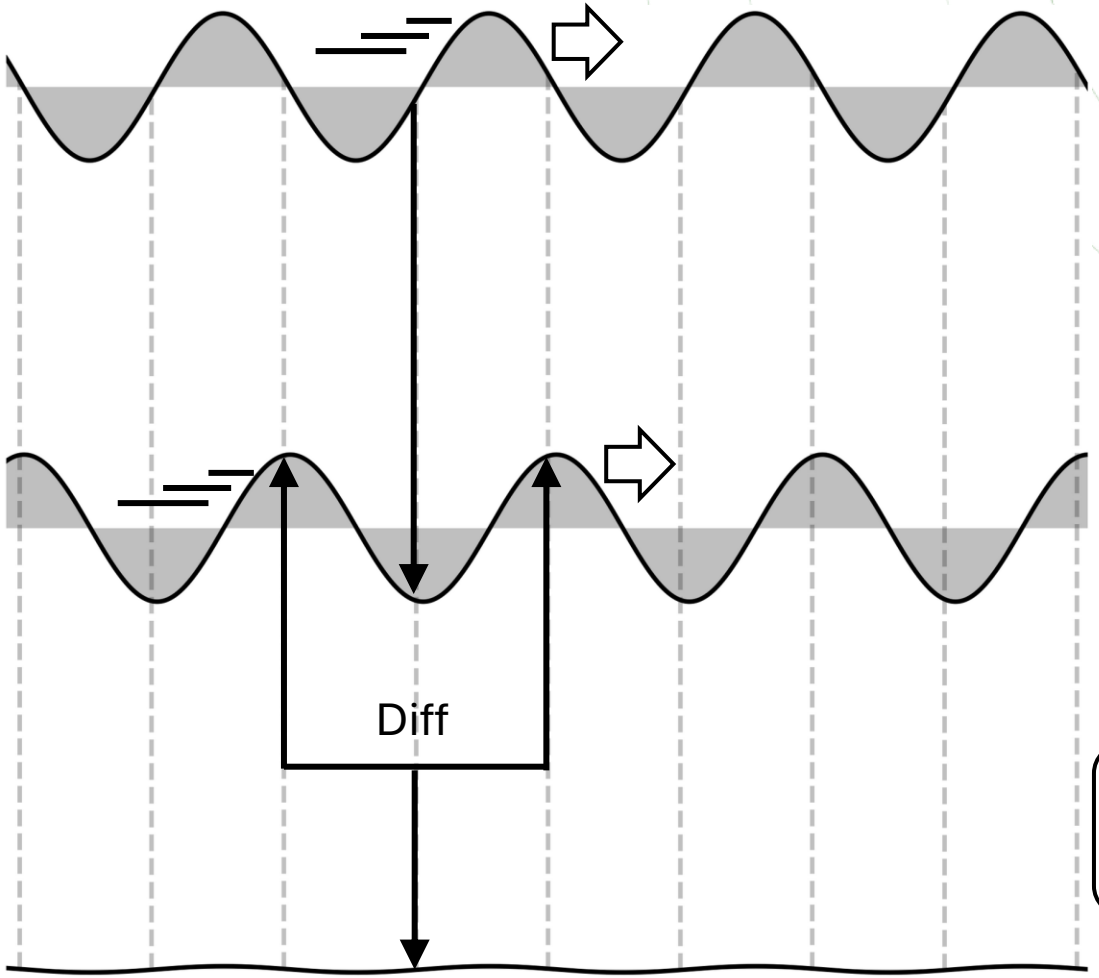
GL < λ/2
Good sensitivity

Gauge length

Displacement u_x

Velocity

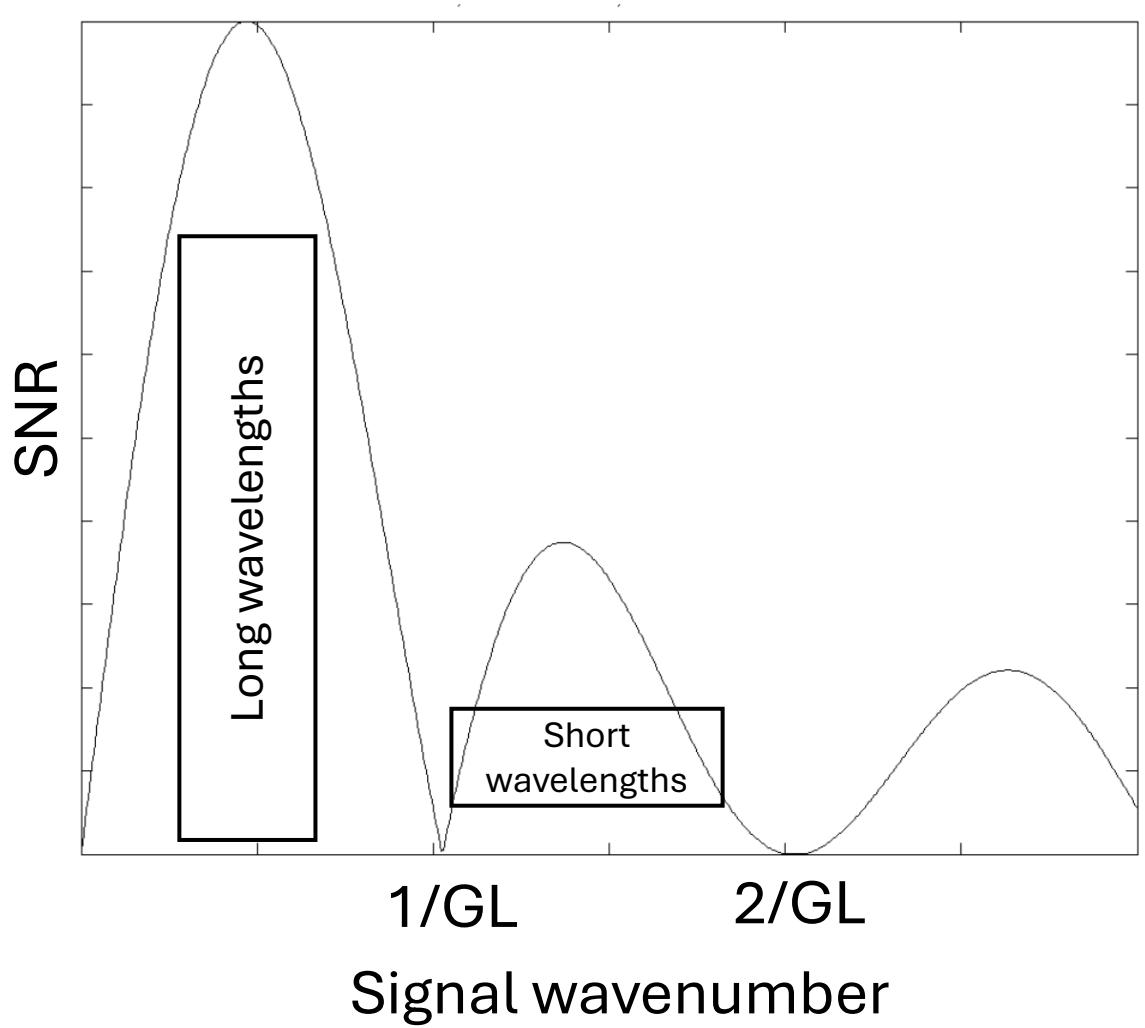
DAS
= velocity differential



Travelling wave

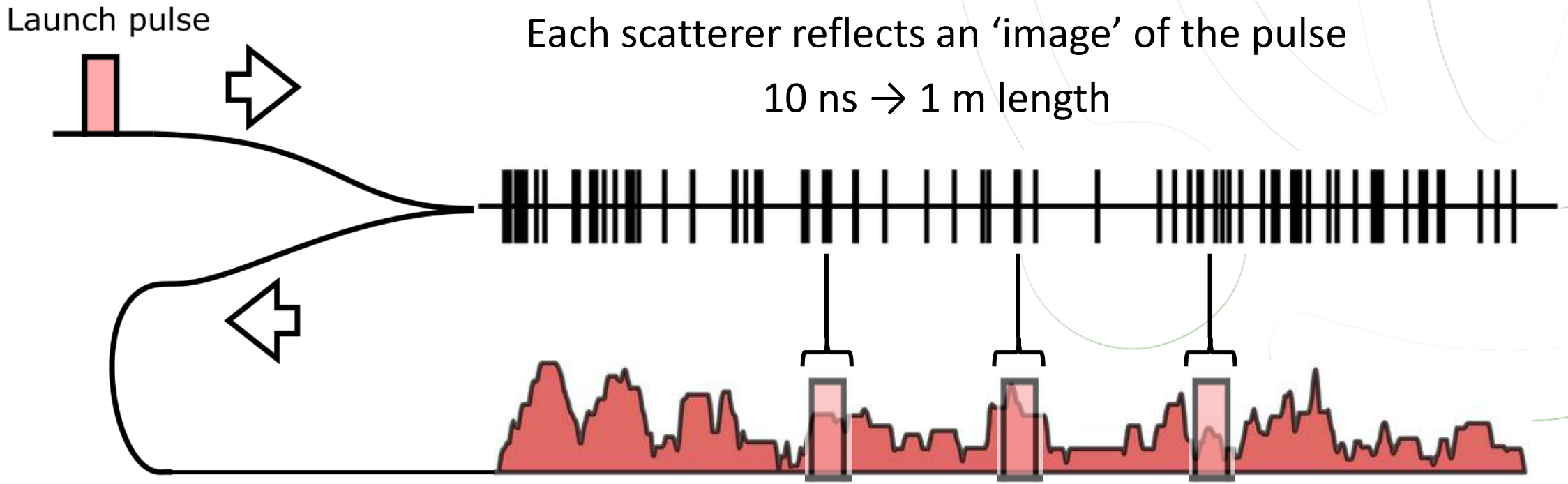
GL ≈ λ
Zero sensitivity

Gauge length



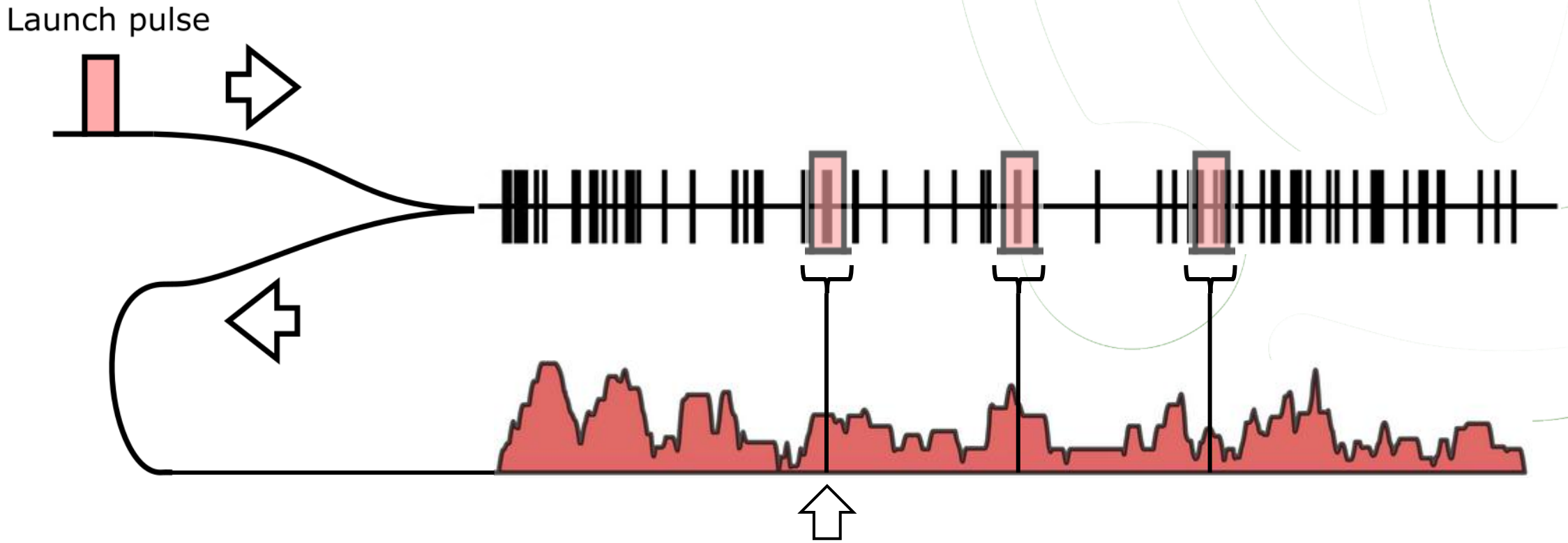
Signal wavenumber – as projected along the fibre

How Pulse Width relates to Gauge Length



One point on fibre contributes to ‘pulse length’ in signal

How Pulse Width relates to Gauge Length

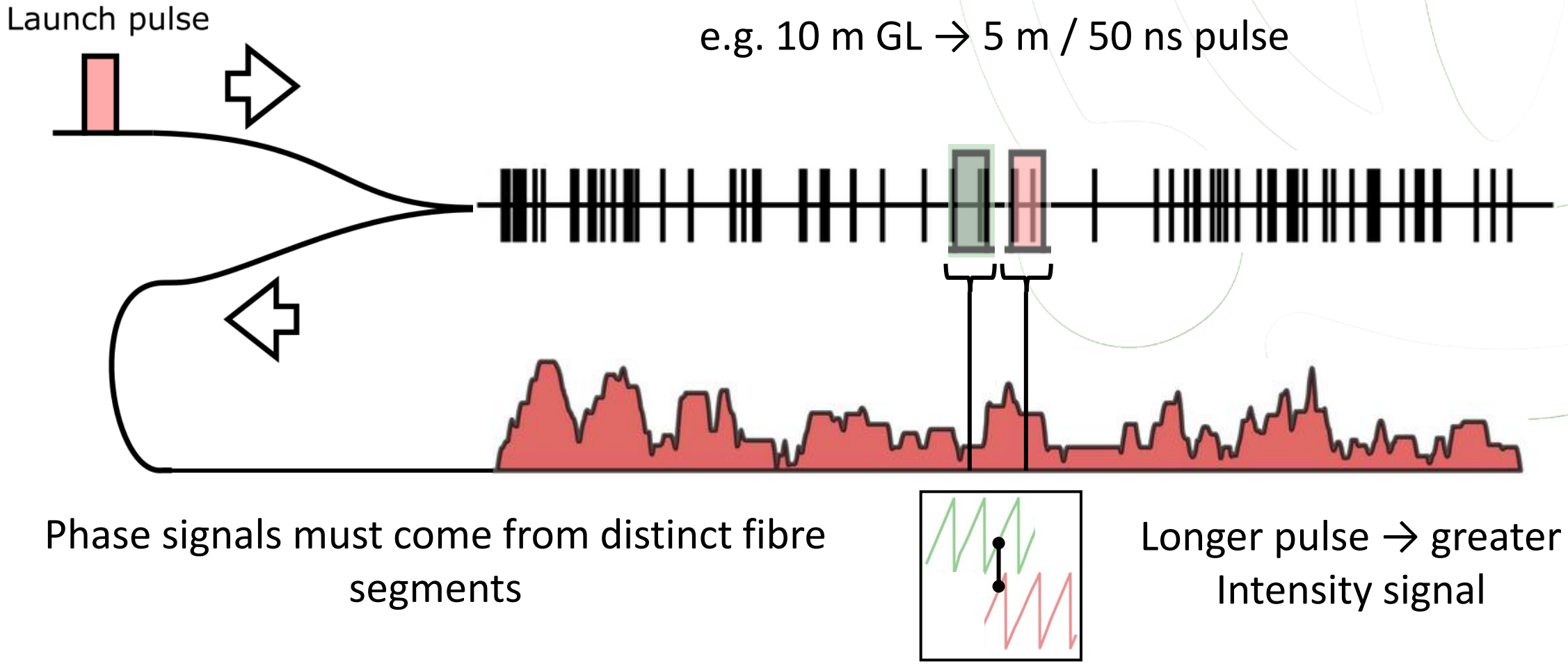


Instantaneous signal comes from ‘pulse length’ of fibre

How Pulse Width relates to Gauge Length

Rule: Pulse length = Gauge length ÷ 2

e.g. 10 m GL → 5 m / 50 ns pulse



Phase signals must come from distinct fibre segments

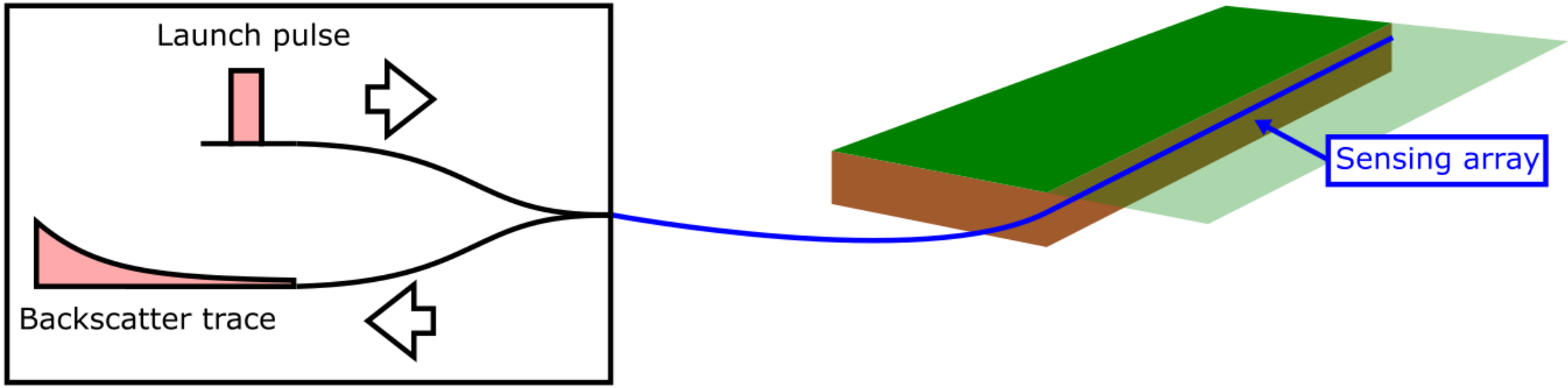
Longer pulse → greater Intensity signal

Gauge Length

Gauge length defines:

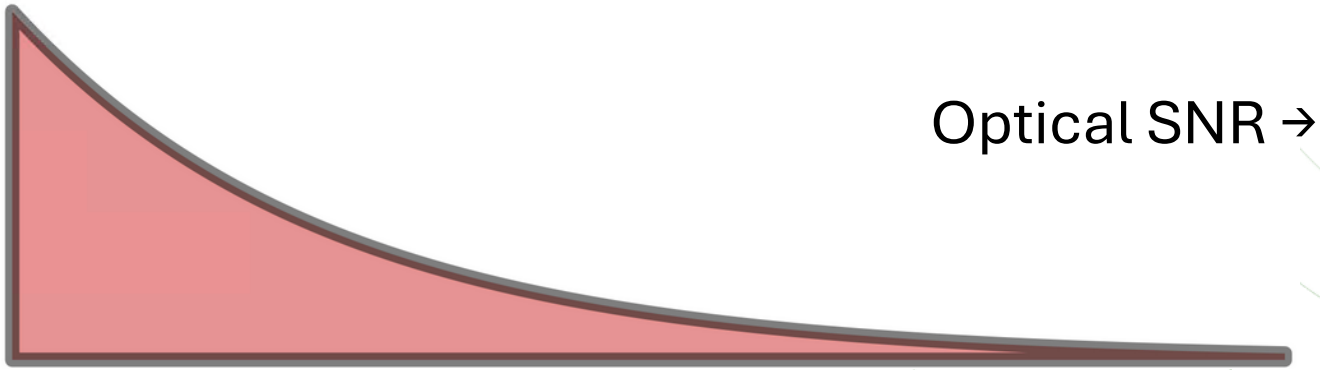
- Minimum clearly detectable wavelength
- Pulse width (optical SNR)

Physical Fibre Length



Physical Fibre Length

Detector signal

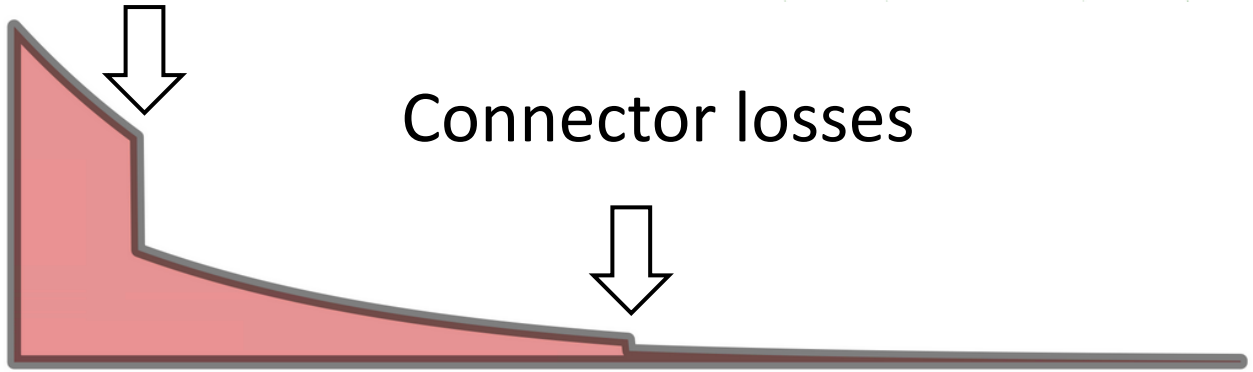


Optical SNR → acoustic SNR

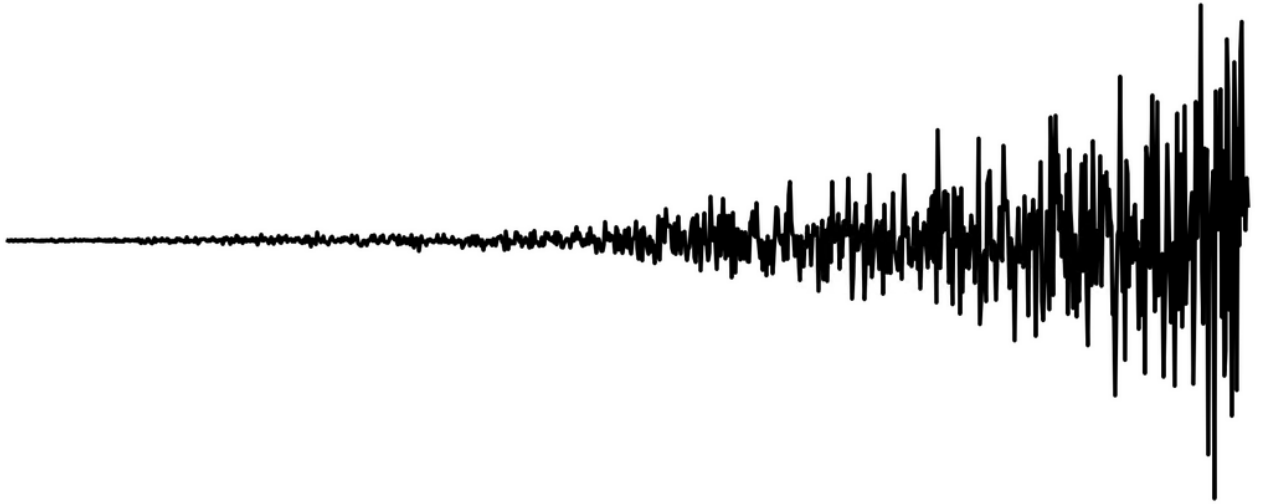
Acoustic noise

Physical Fibre Length

Detector signal

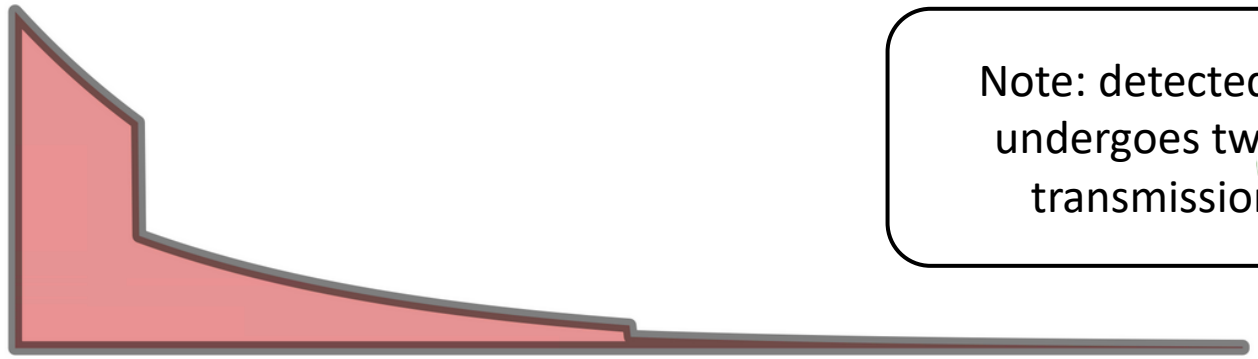


Acoustic noise



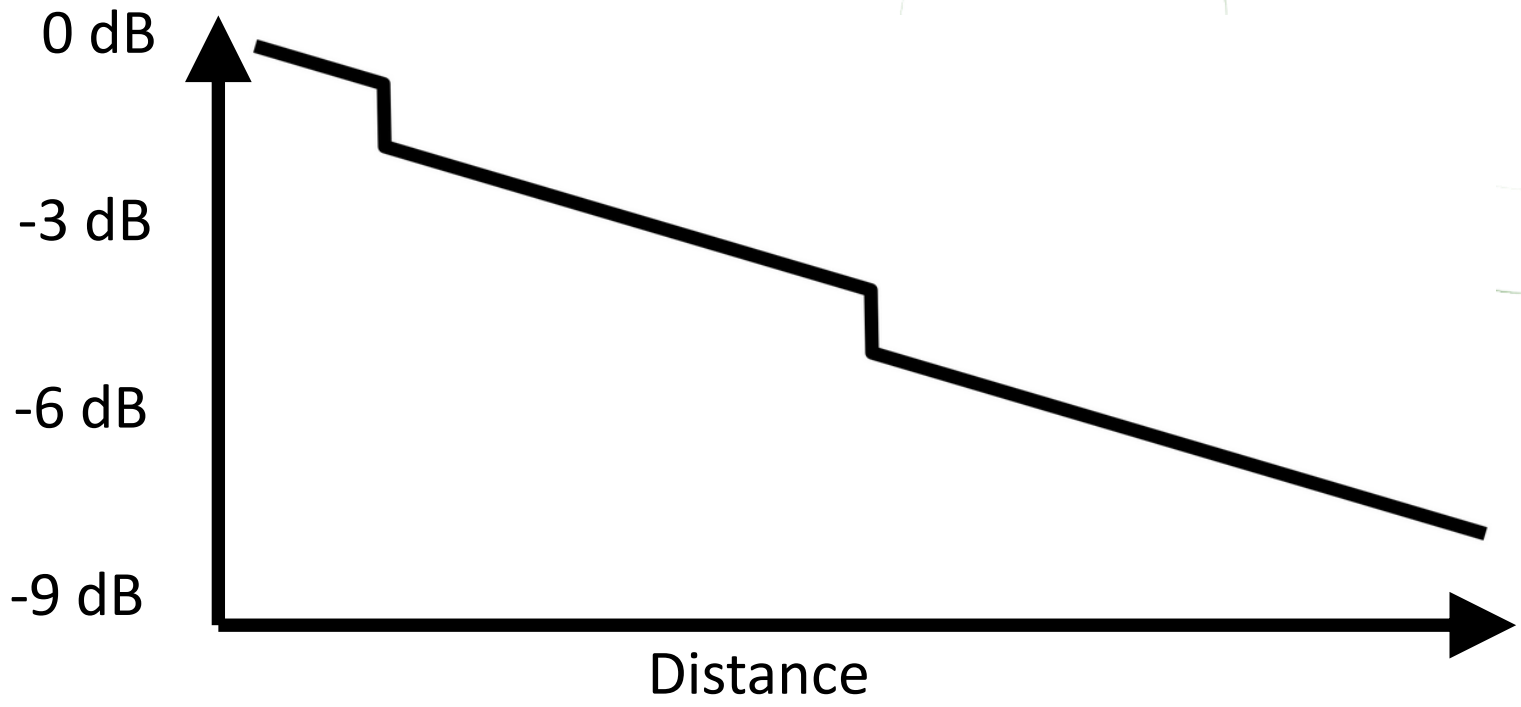
Physical Fibre Length

One-way transmission T_1



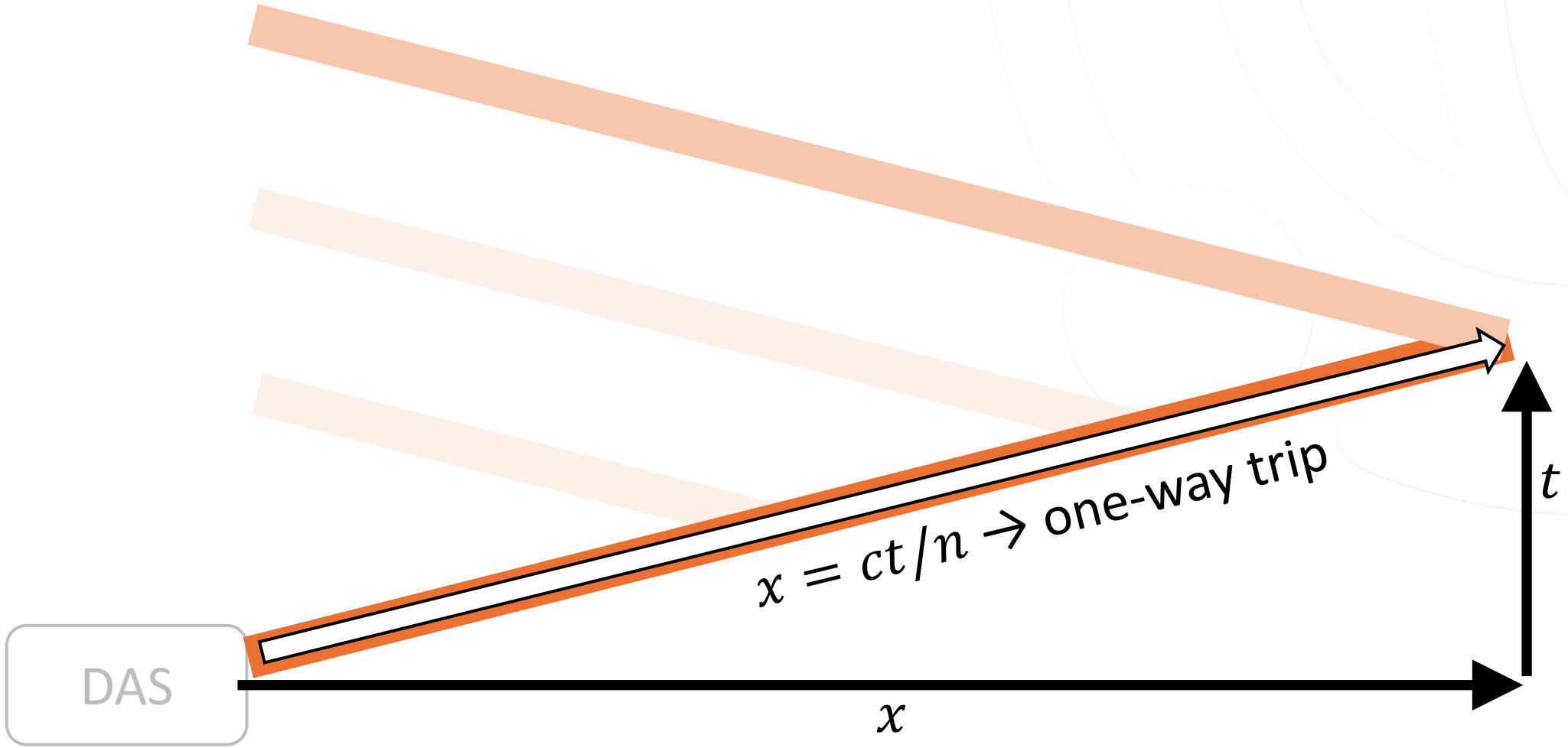
Note: detected signal undergoes two-way transmission T^2

OTDR = $10 \log_{10} T_1$

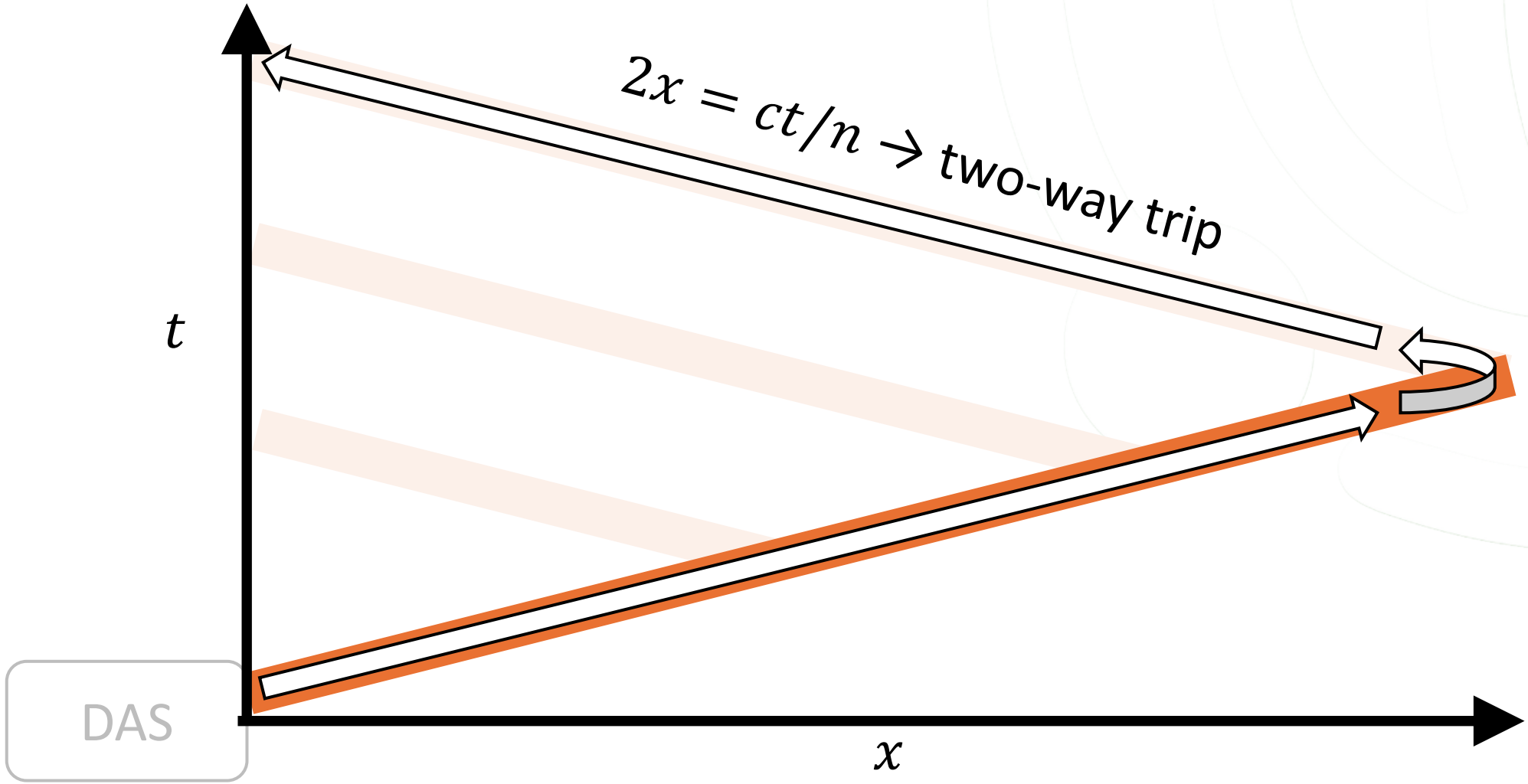


Physical Fibre Length

Physical Fibre Length



Physical Fibre Length



Physical Fibre Length

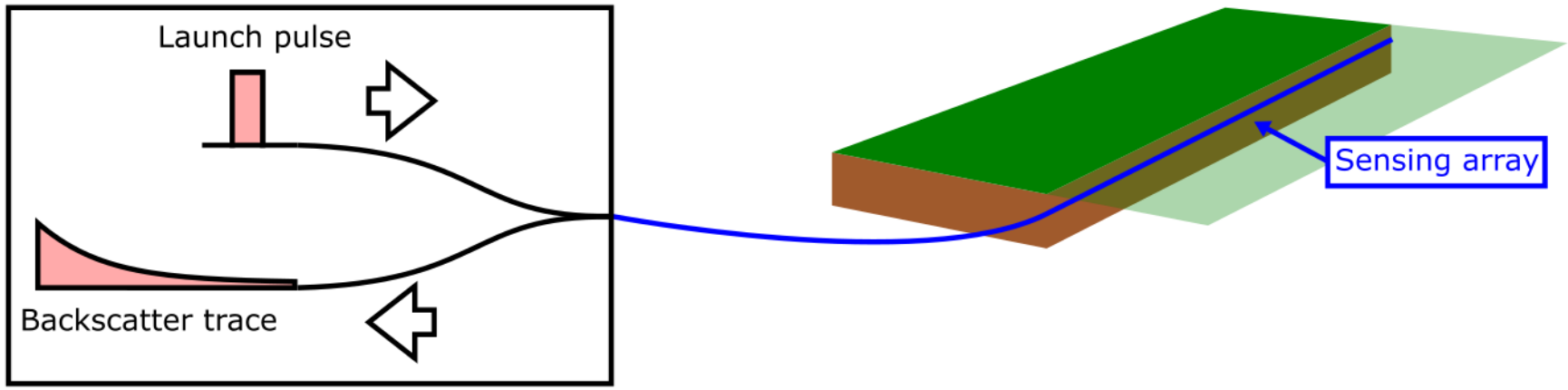
Maximum Laser Pulse Frequency:

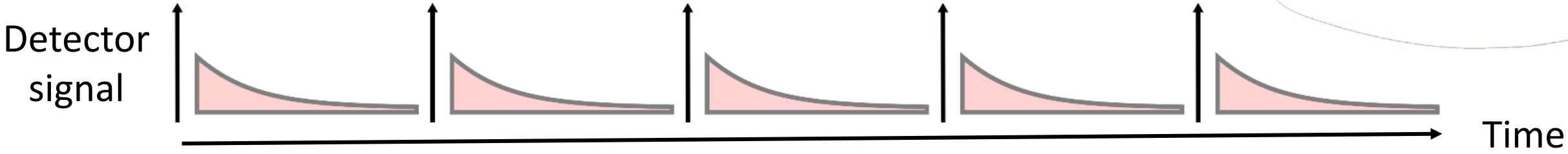
$$f_{MAX} \approx \frac{10^8 \mathrm{m/s}}{L} = \frac{100\ \mathrm{kHz}}{L\ [\mathrm{km}]}$$

- 10 km fibre: $f_{MAX} \approx 10\ \mathrm{kHz}$
- 30 km fibre: $f_{MAX} \approx 3.3\ \mathrm{kHz}$

Rule of thumb:
10 km at 10 kHz

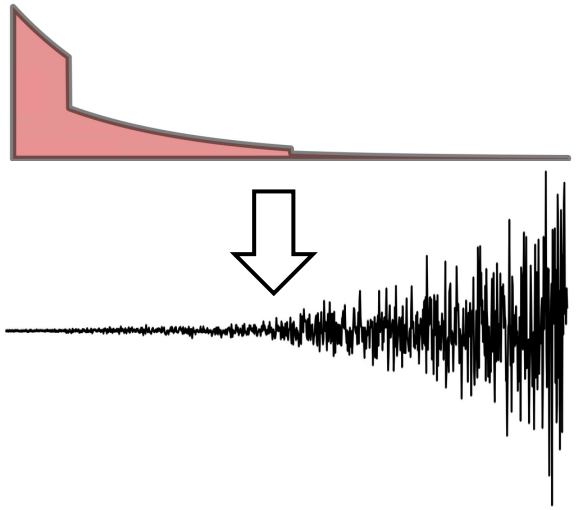
Physical Fibre Length

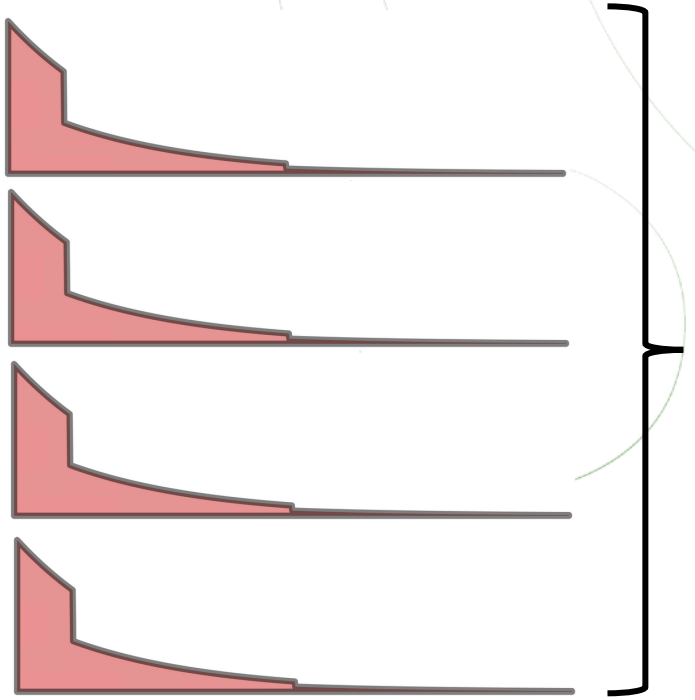




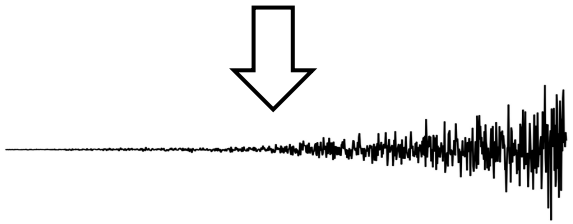
Physical Fibre Length

Can you average traces over time?





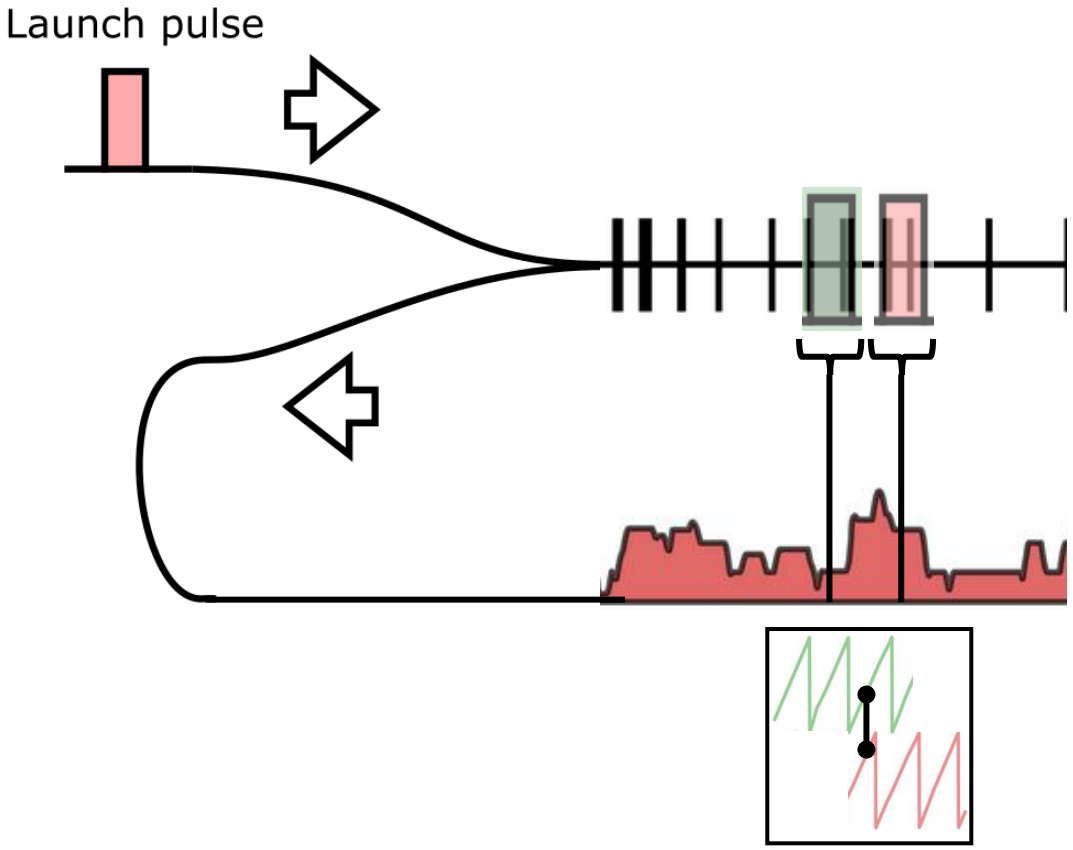
Average before processing



- Reduced acoustic bandwidth
- Lower data rate
- Optical SNR resilience

"Time decimation"

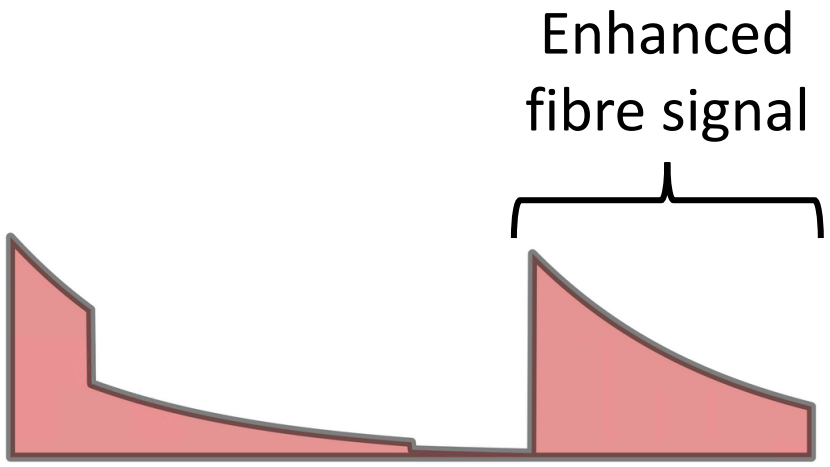
Dynamic range



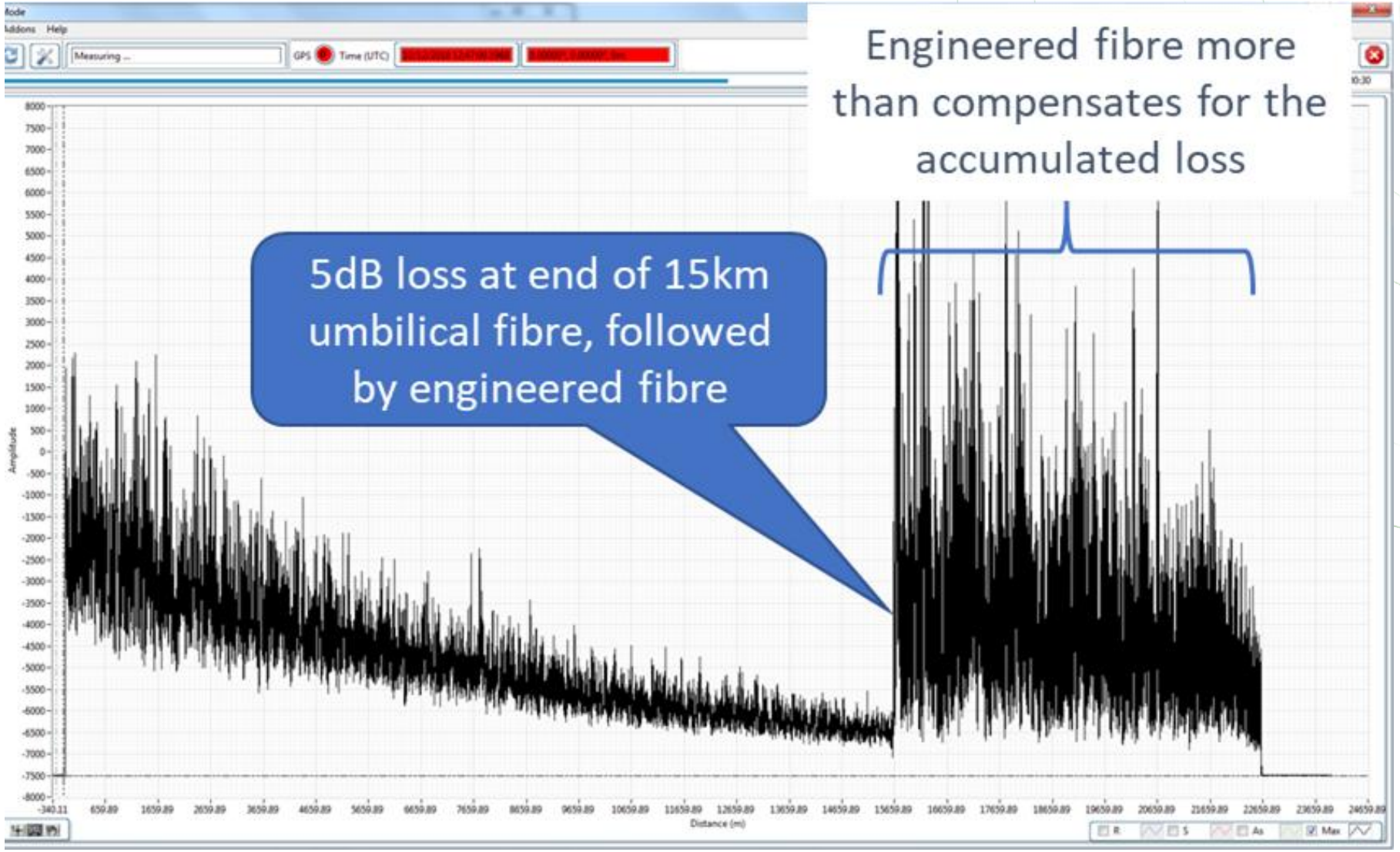
- Raw DAS data = phase change across:
  - 1 gauge length
  - 1 time sample
- Signal ∝ GL
- Signal ∝ $1/F_S$
- Maximum signal = π

Maximum dynamic range when:
- Shorter fibre
- Highest sampling frequency
- Shortest gauge length

Can you use enhanced backscatter fibre?



Physical Fibre Length

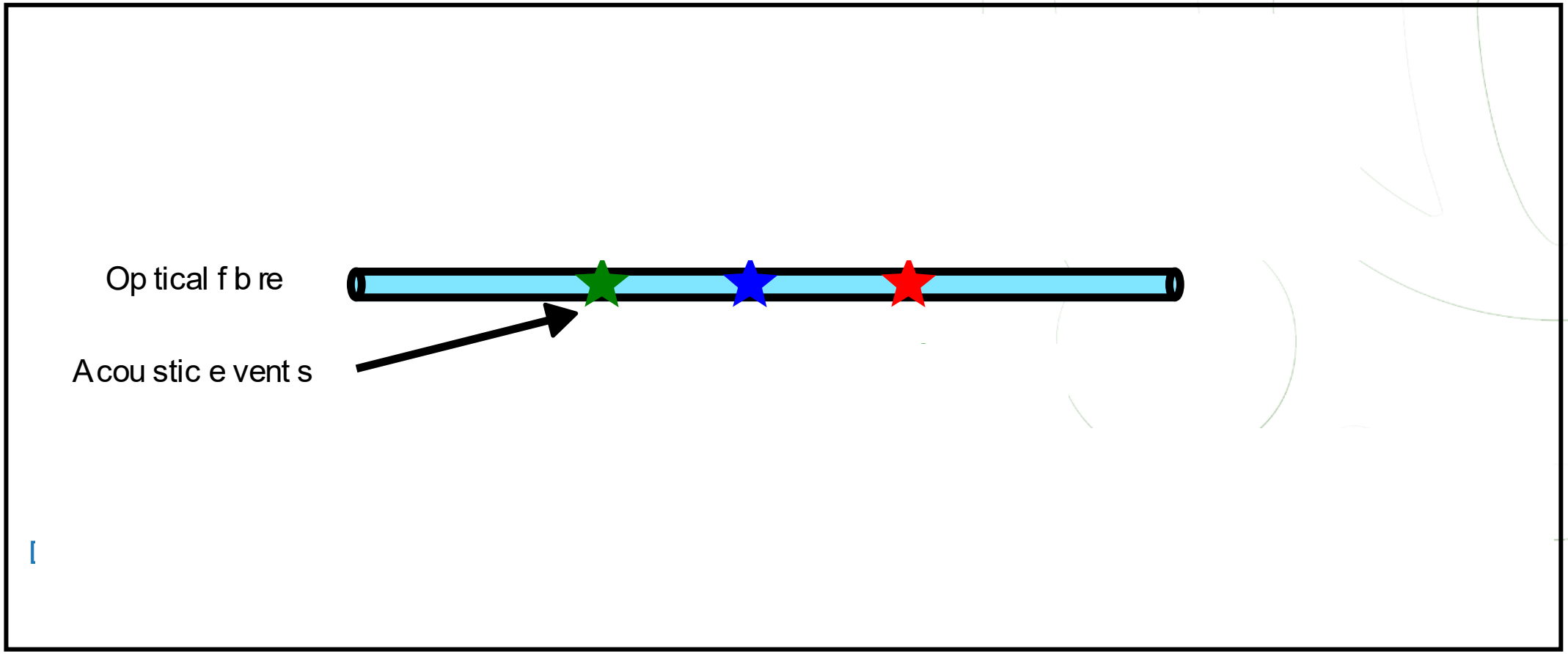


Physical Fibre Length

Physical fibre length affects:

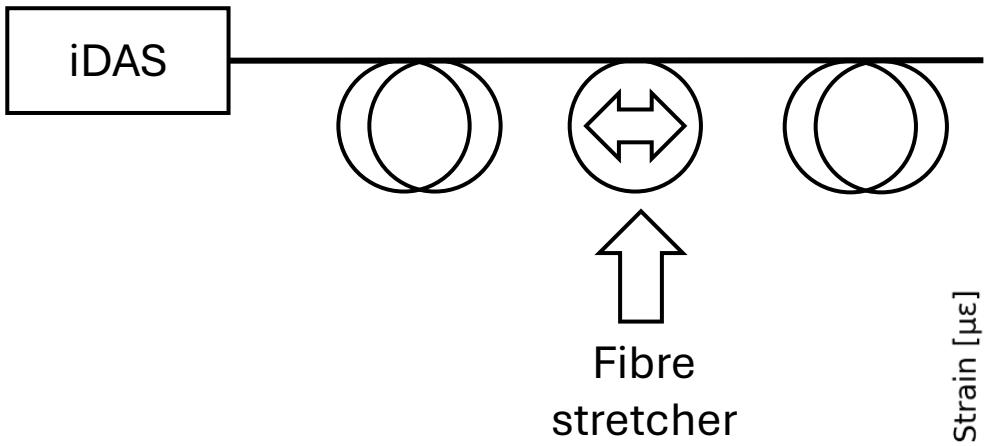
- Maximum sampling frequency
- Dynamic range limit
- Optical signal profile and SNR

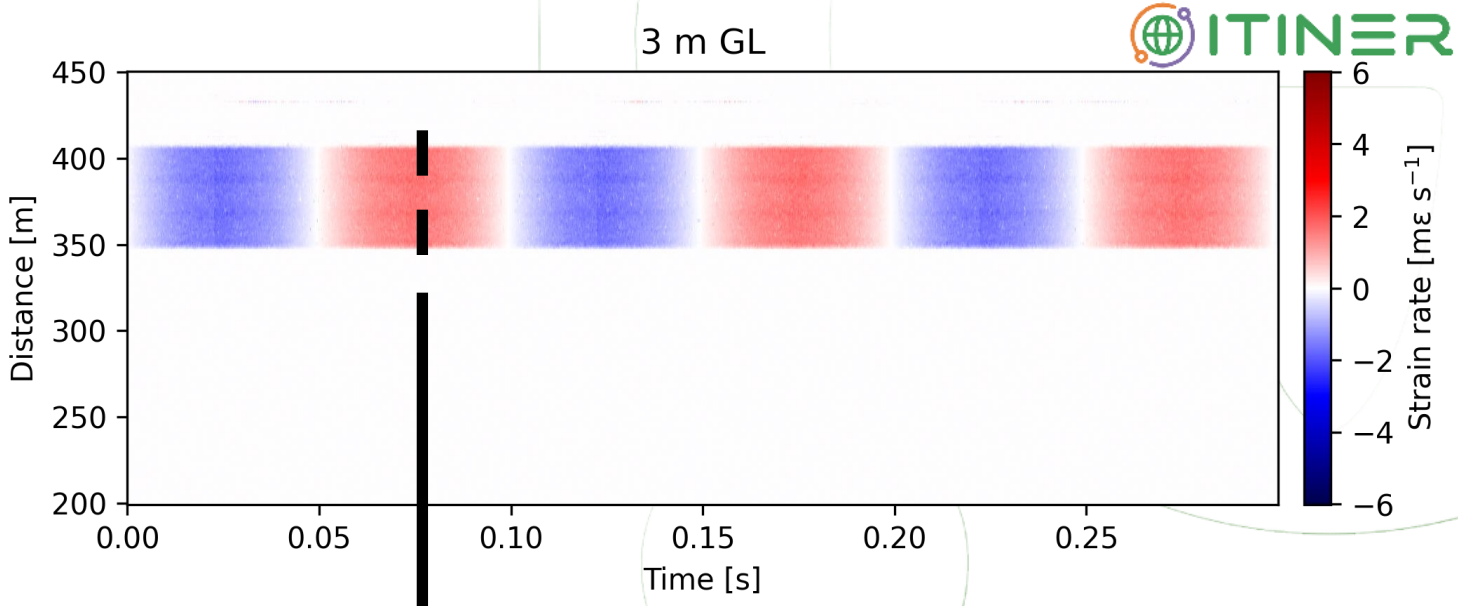
Spatial Sampling Interval

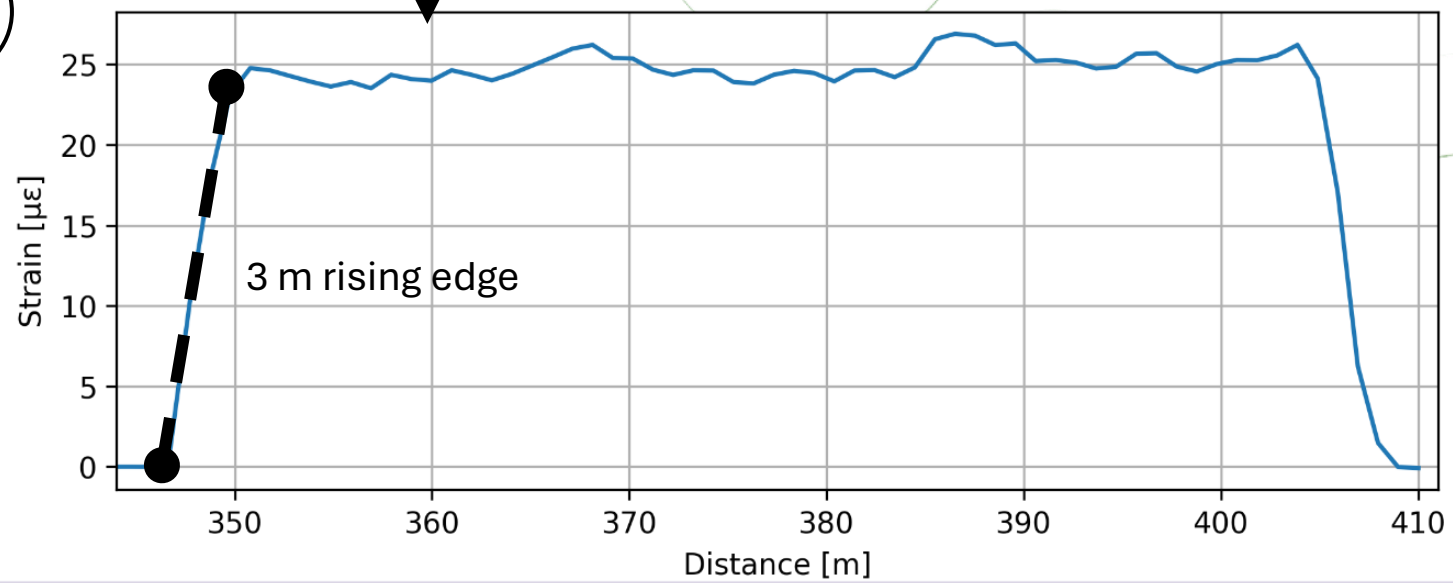


Rule of thumb: Gauge length ÷ 10

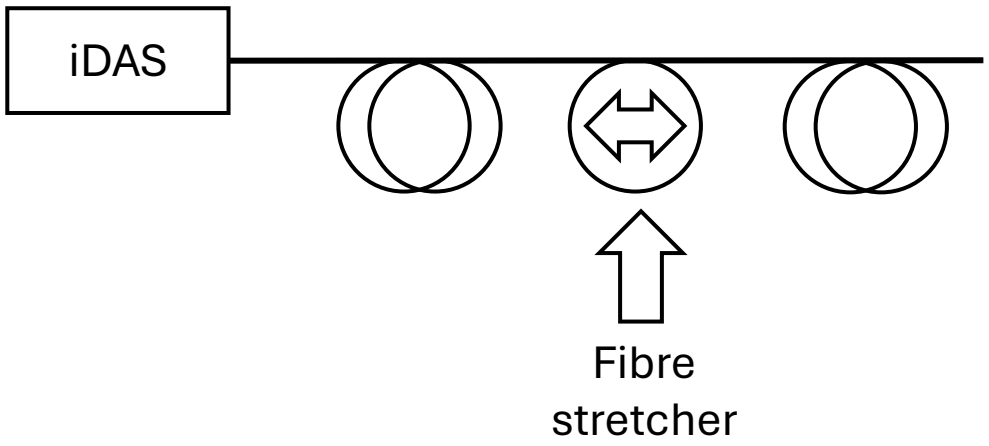
Spatial Sampling Interval

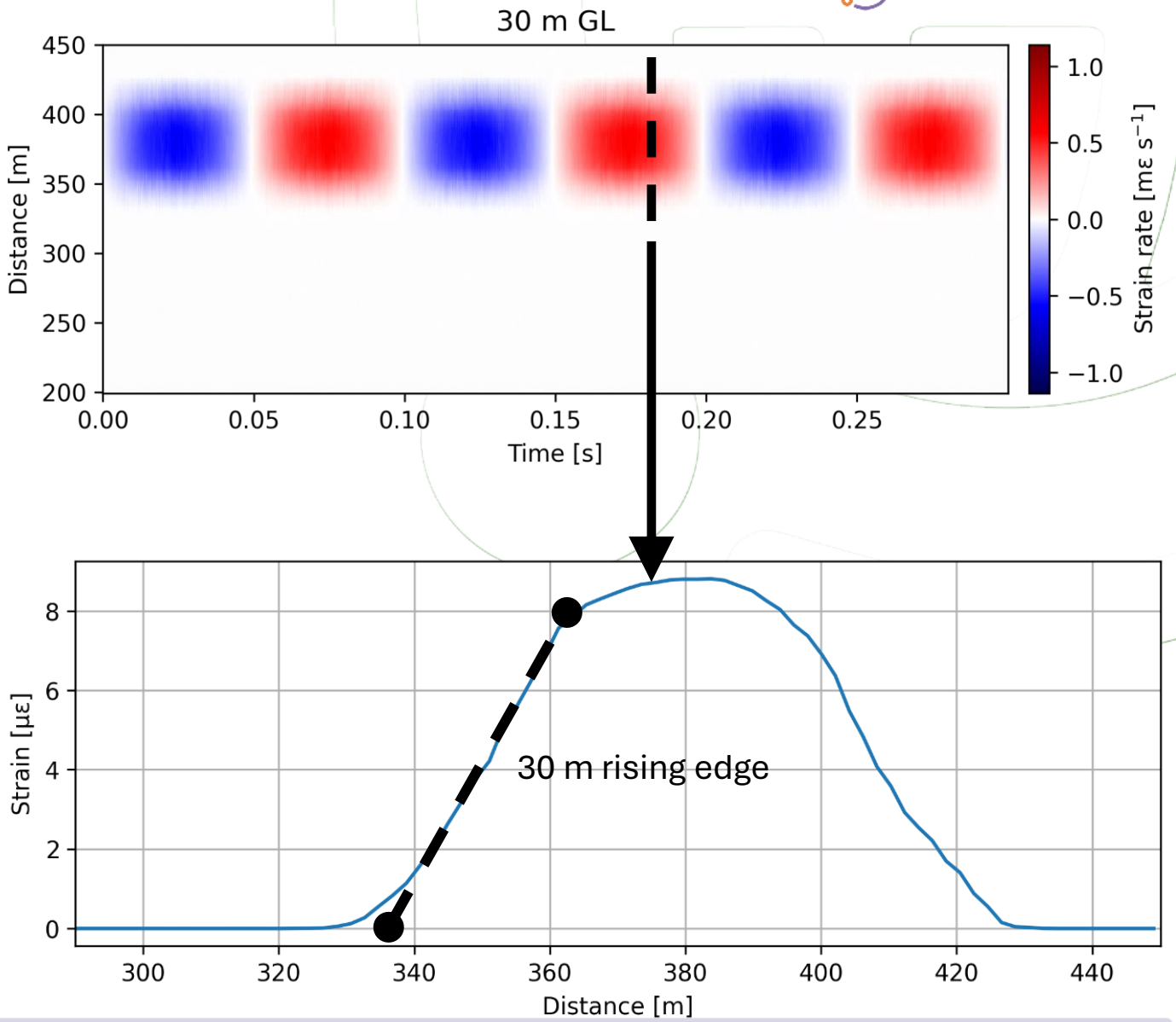






Spatial Sampling Interval



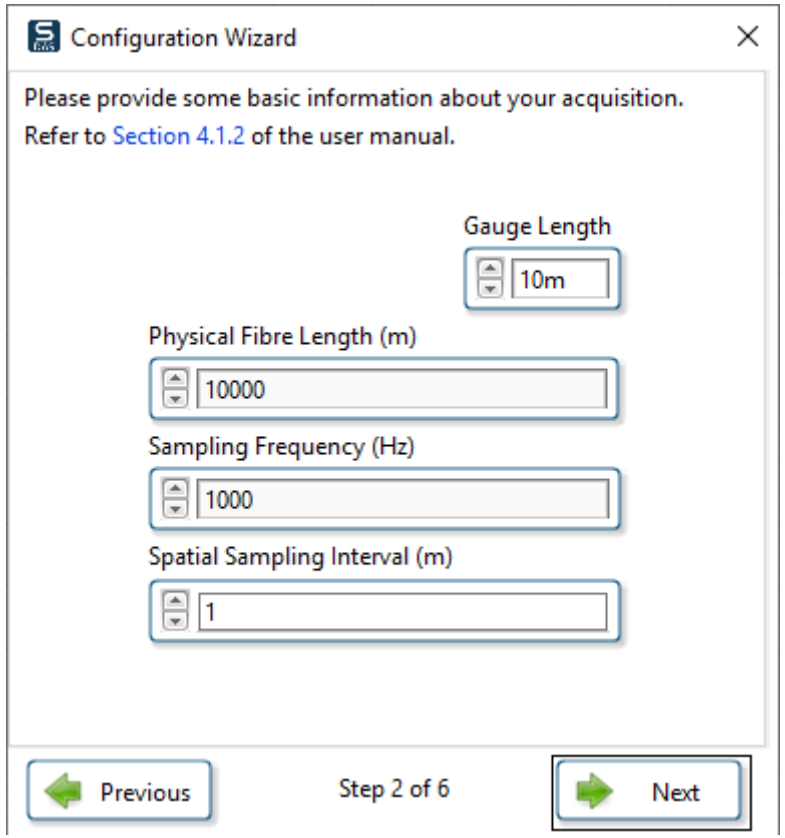


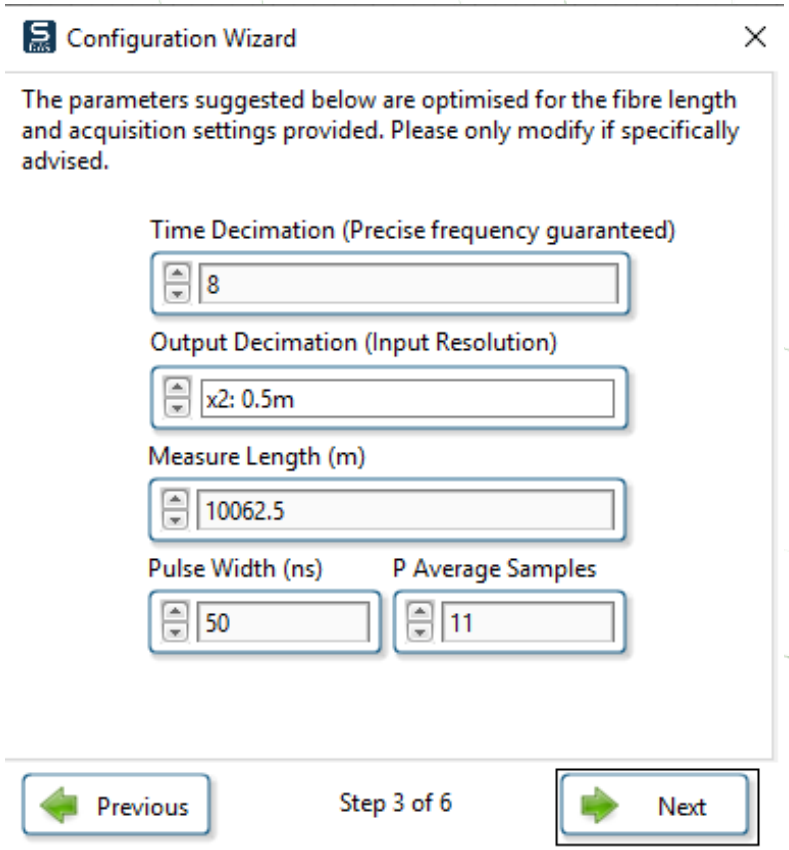
Spatial Sampling Interval

Spatial Sampling Interval affects:

- Maximum spatial resolution
- Data rate

Configuration Wizard

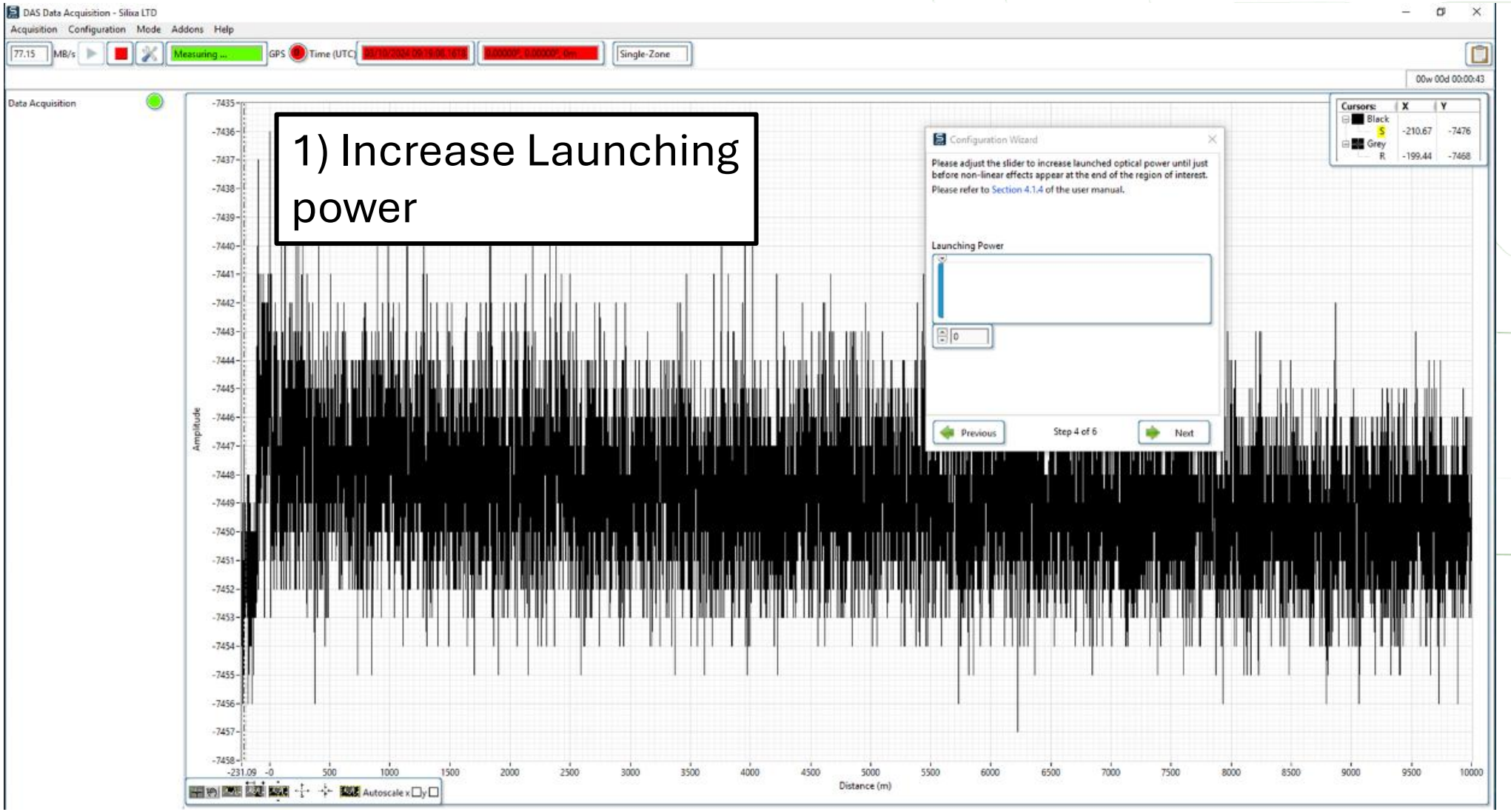




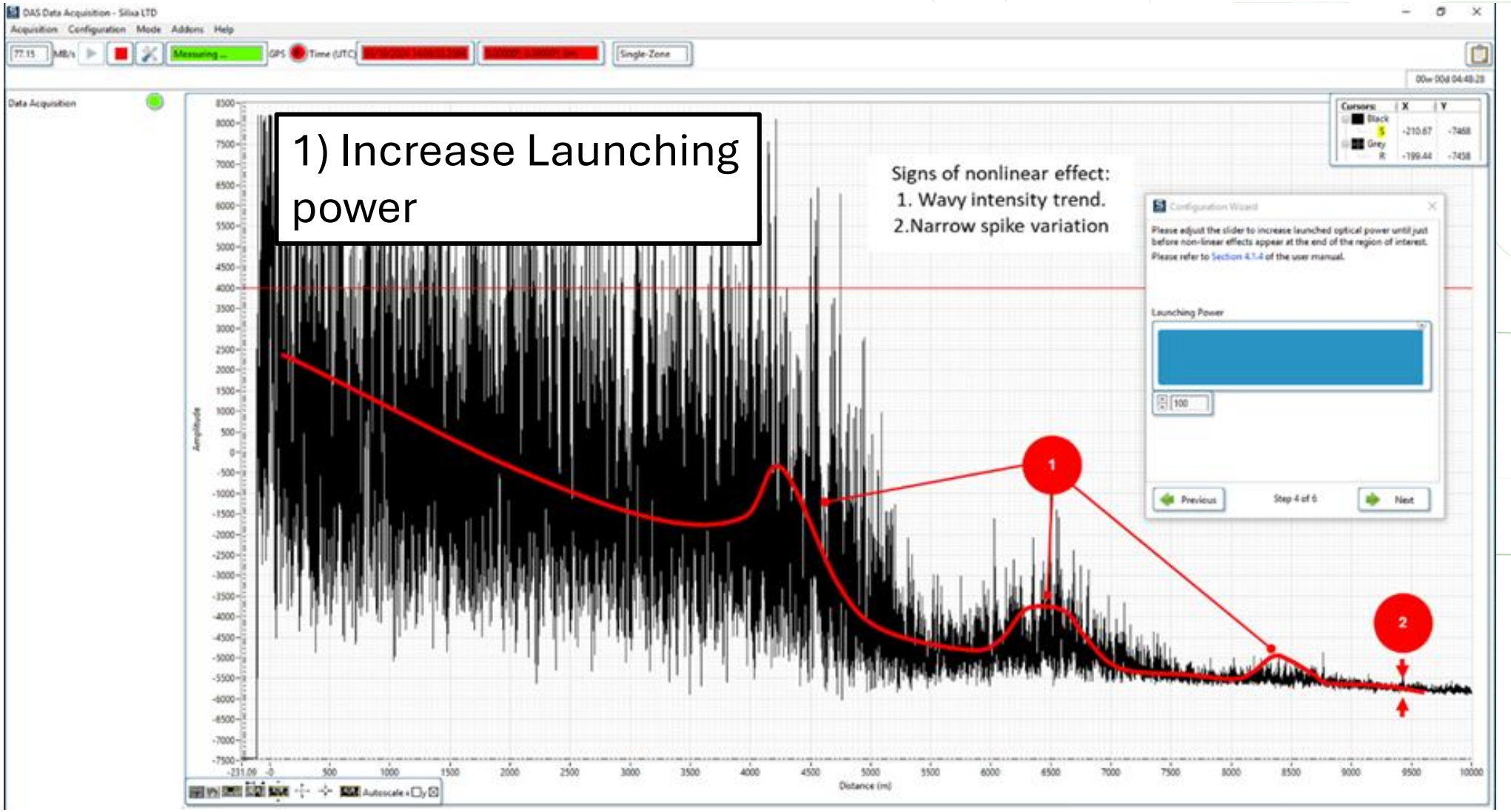
User parameters

Internal parameters – do not change

Configuration Wizard

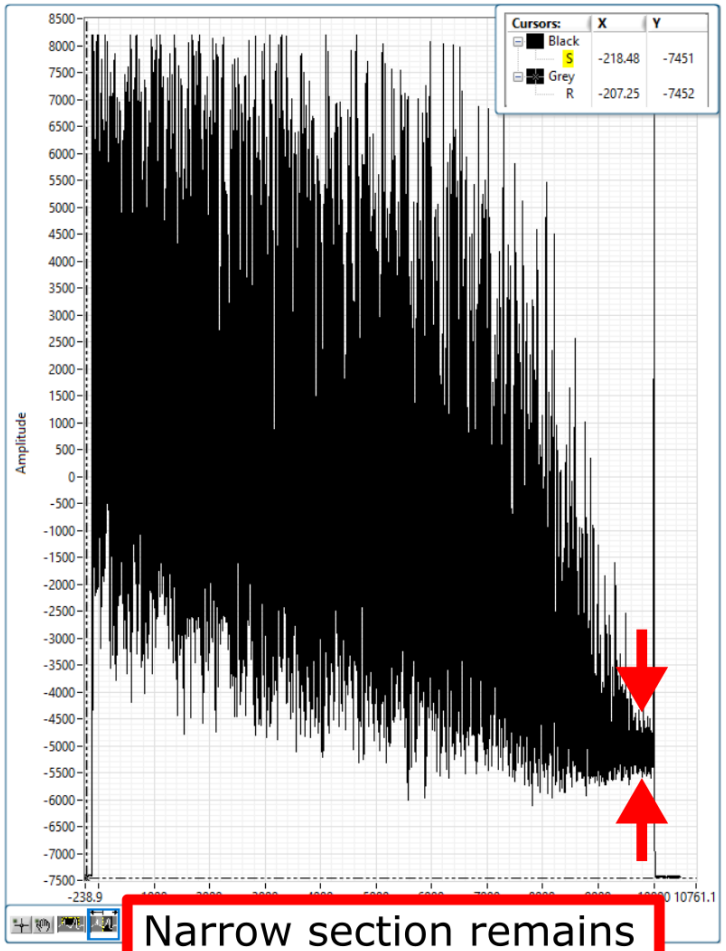


Configuration Wizard



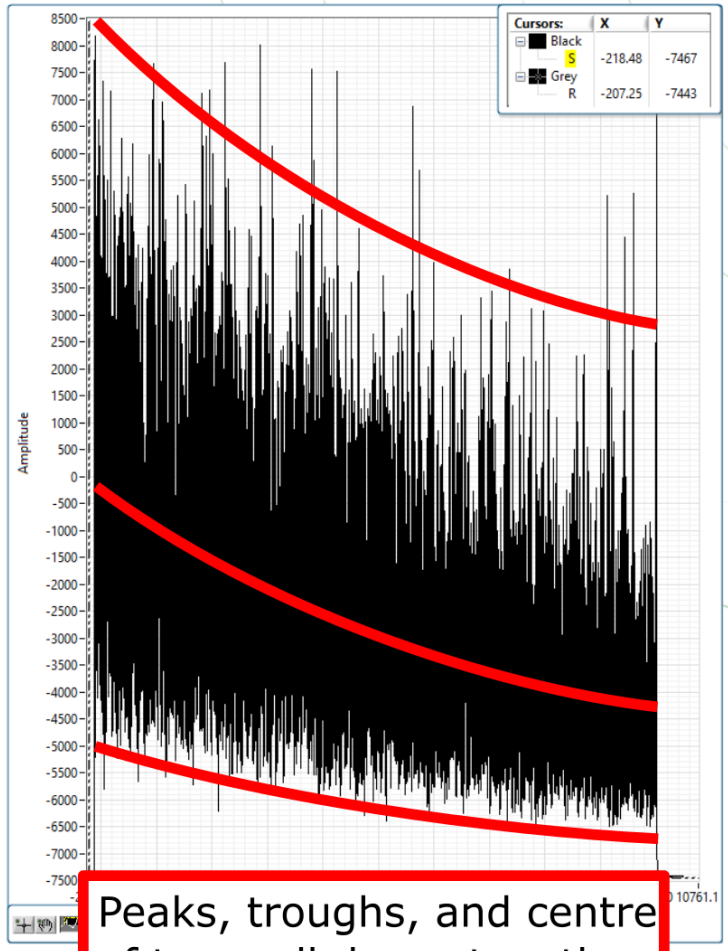
Configuration Wizard

Optical power still too high



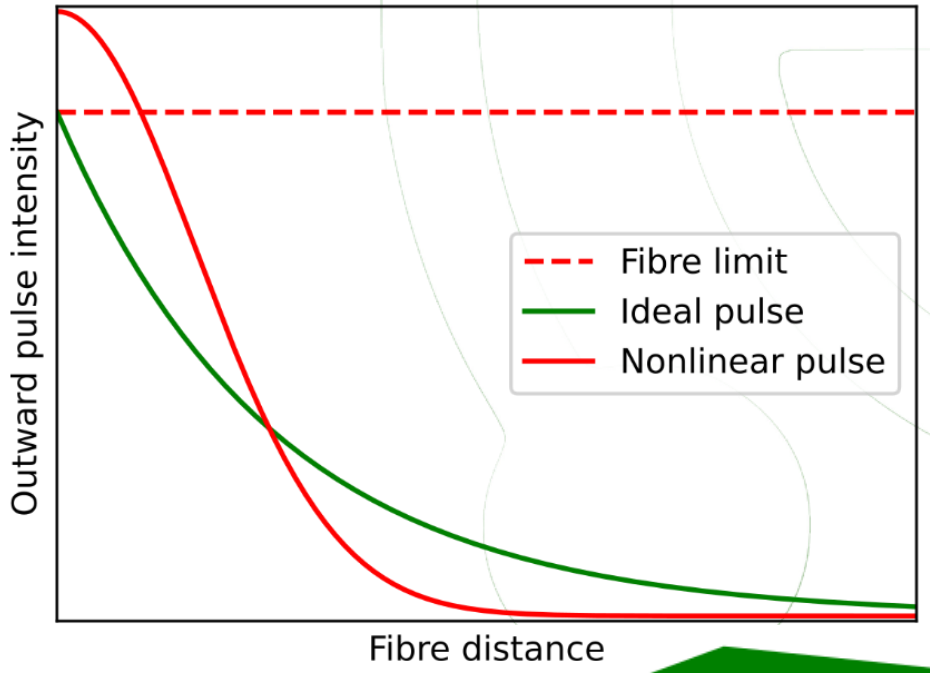
Narrow section remains

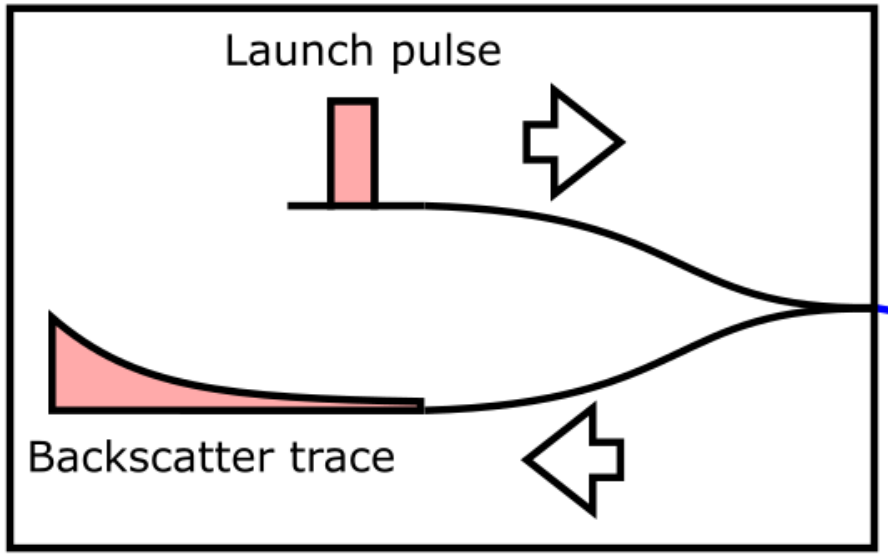
Optical power ideal

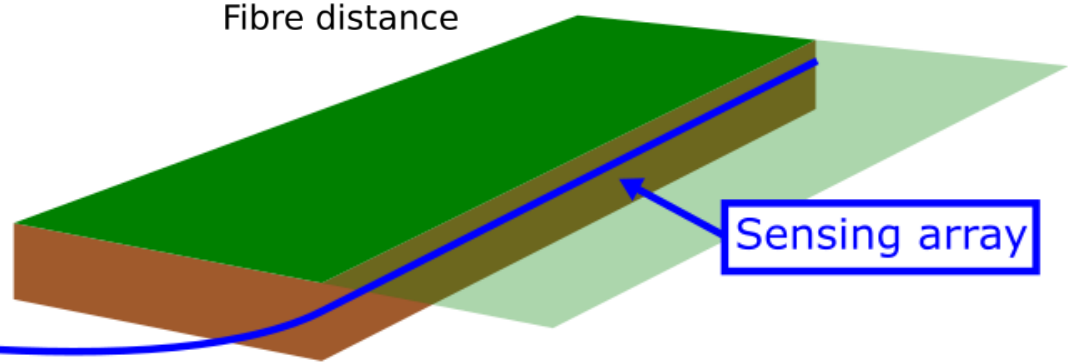


Peaks, troughs, and centre of trace all decay together

Configuration Wizard

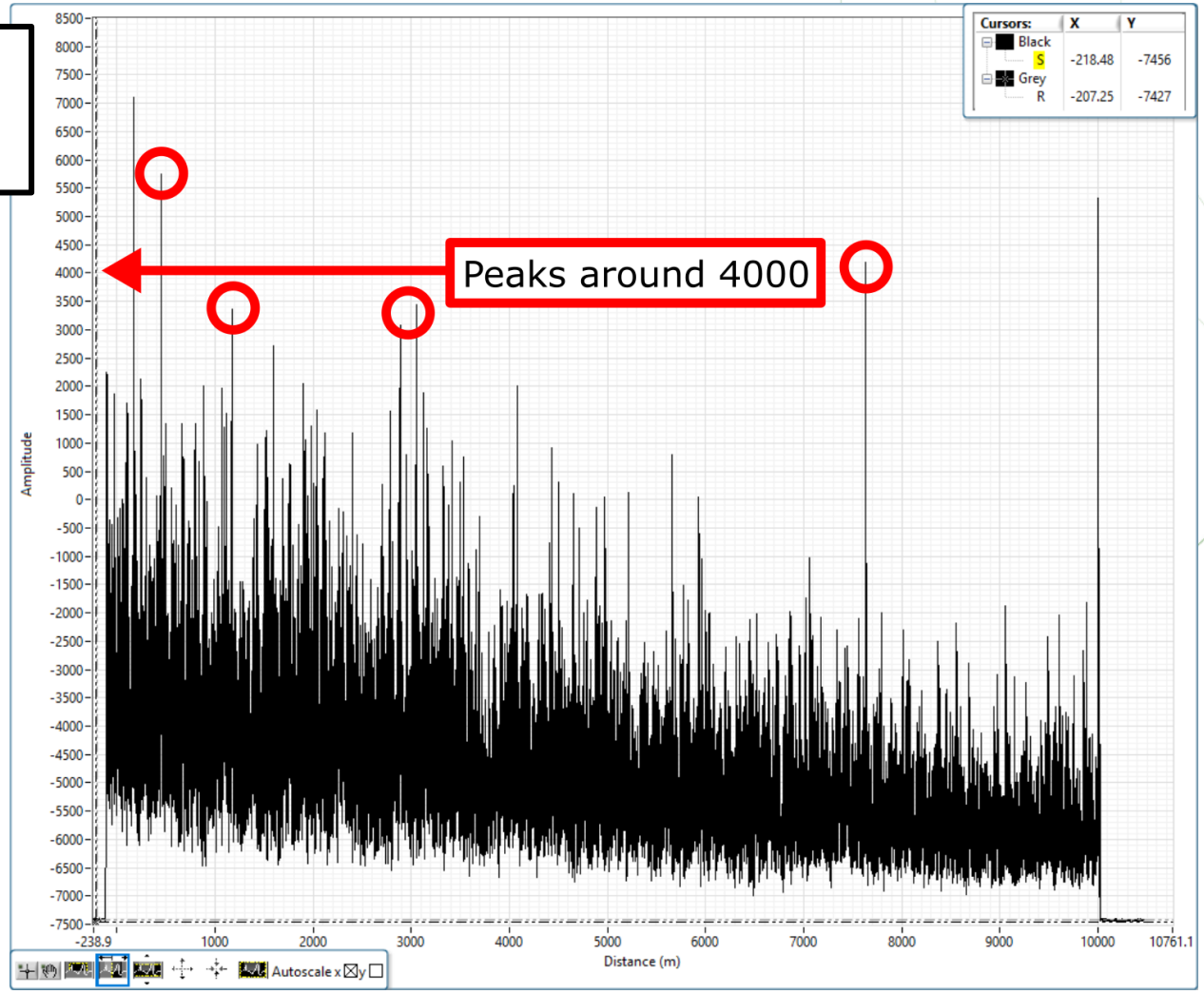




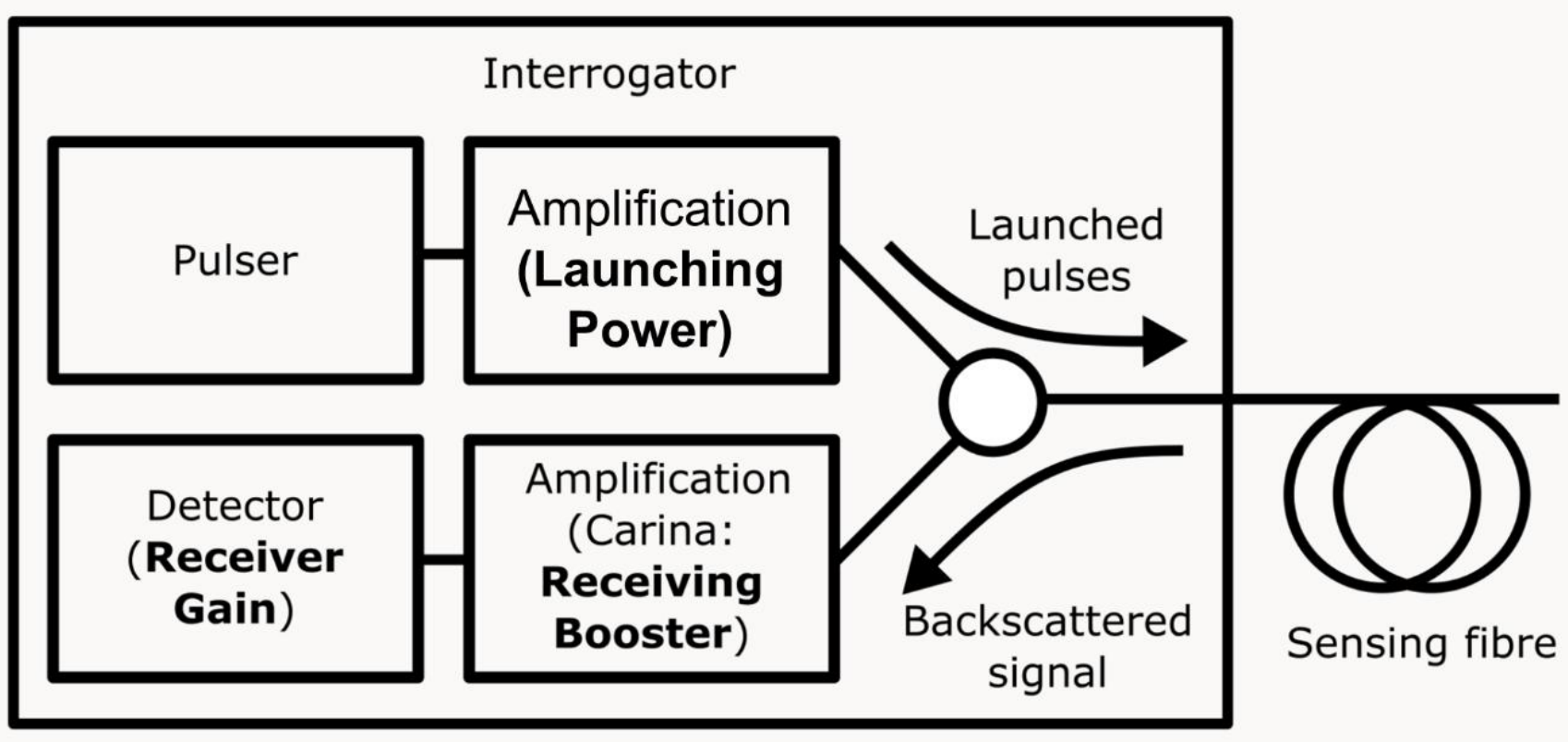


Configuration Wizard

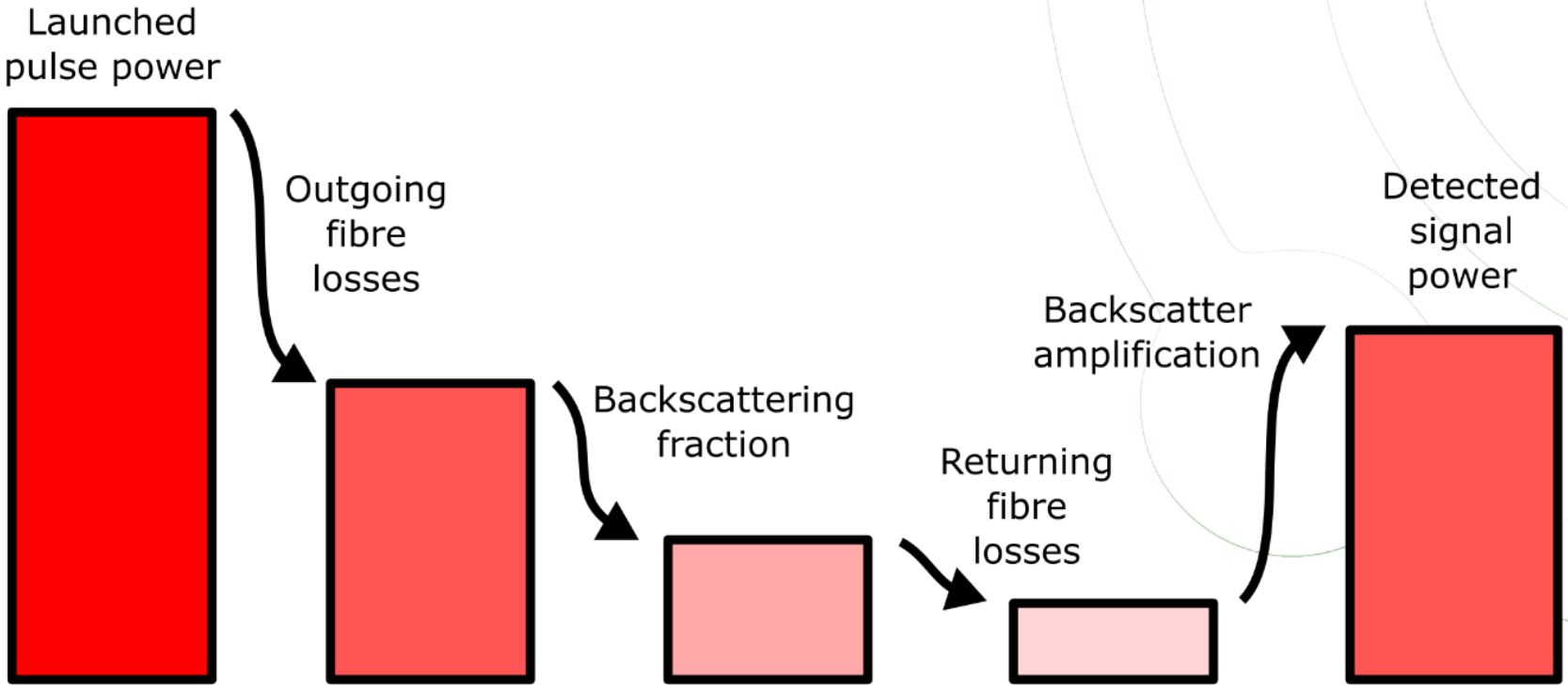
2) Increase Receiver amplifier power



Configuration Wizard

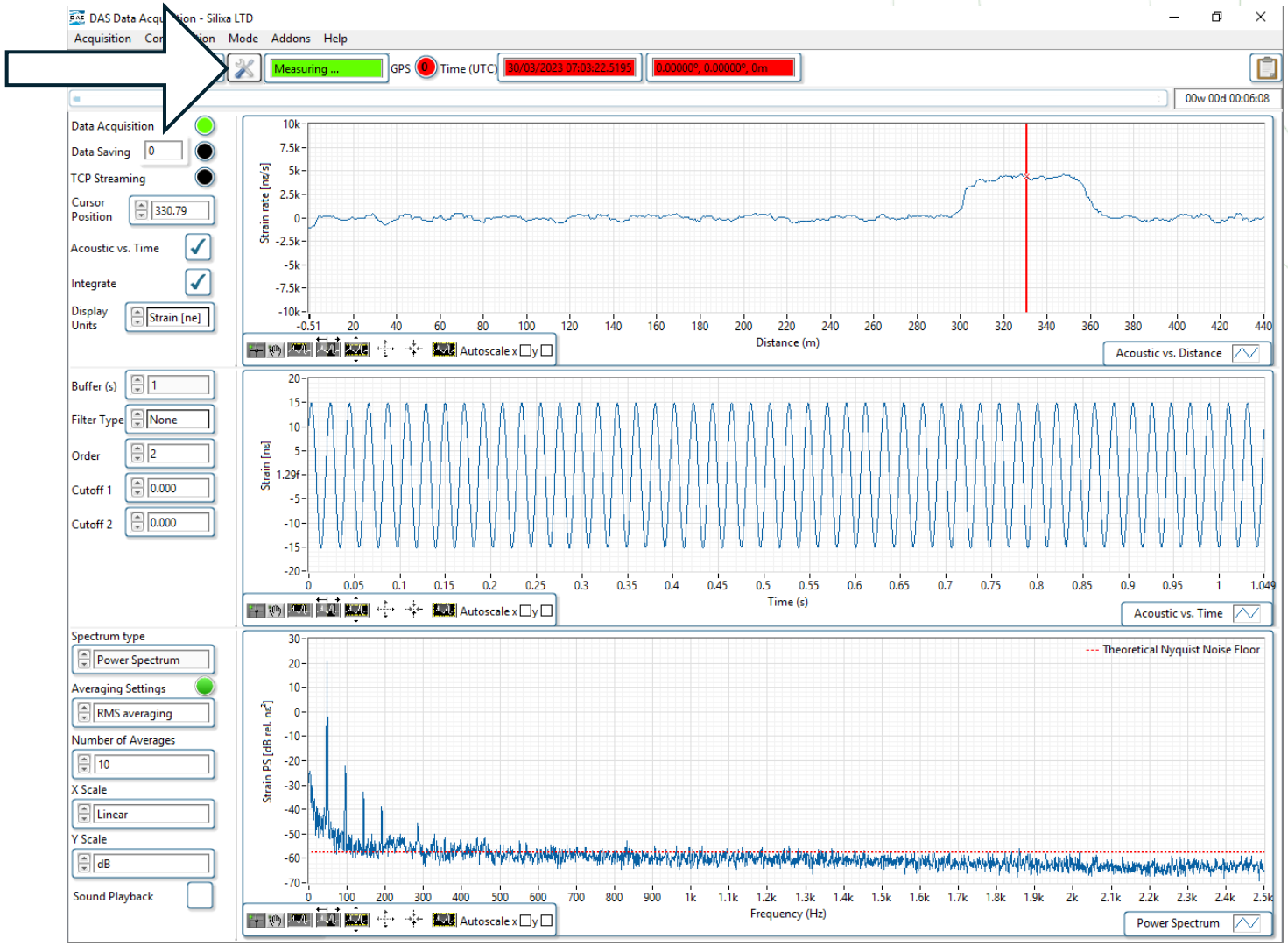


Configuration Wizard

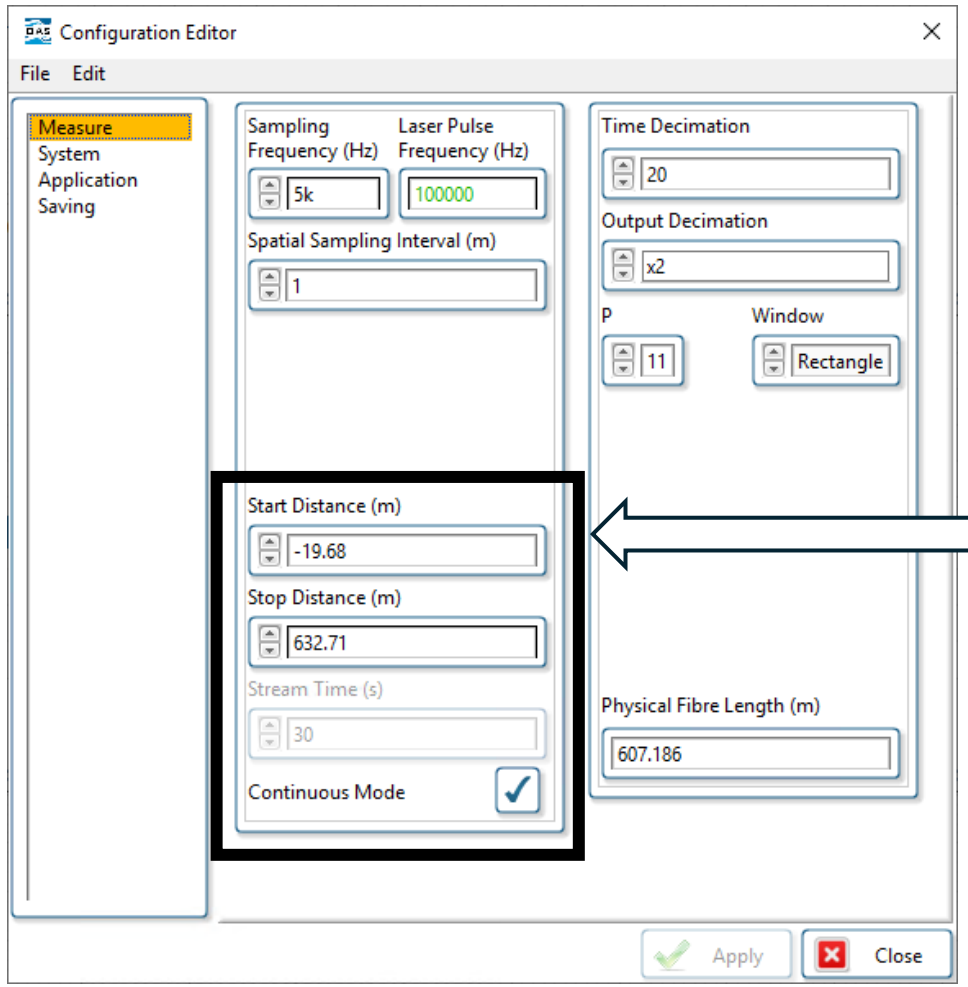


Configuration

Remaining settings to adjust



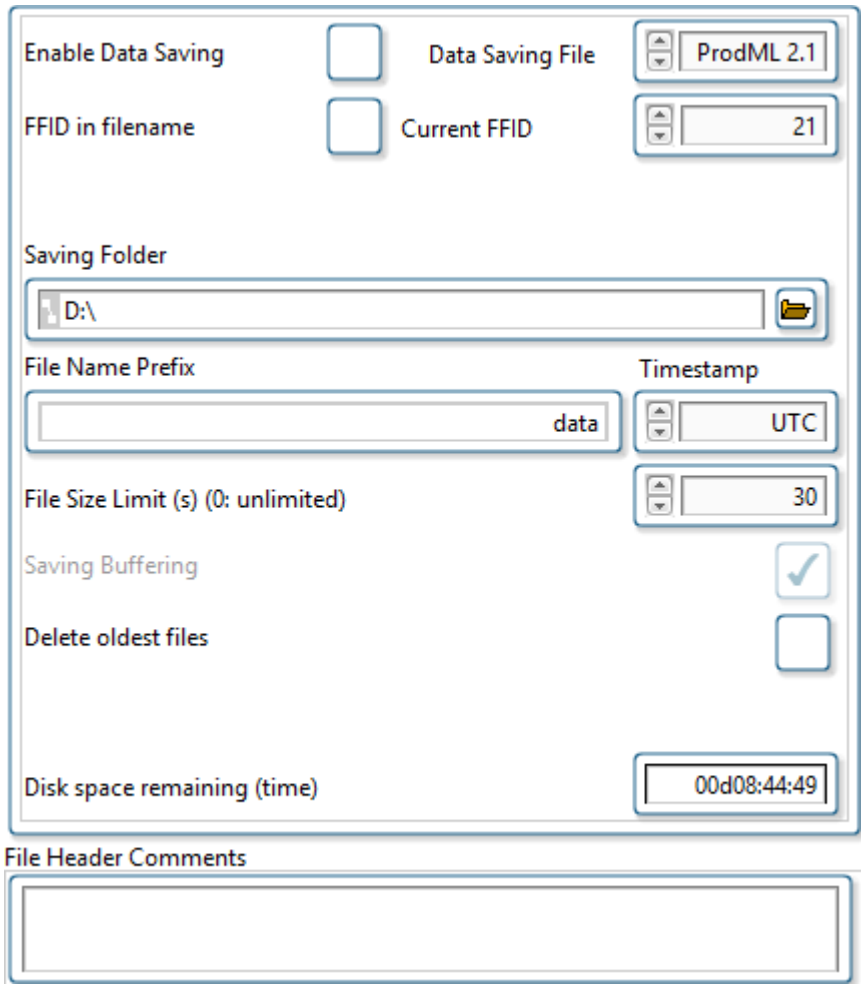
Configuration Editor



- Only change these
- Change other settings via wizard

Configuration Editor

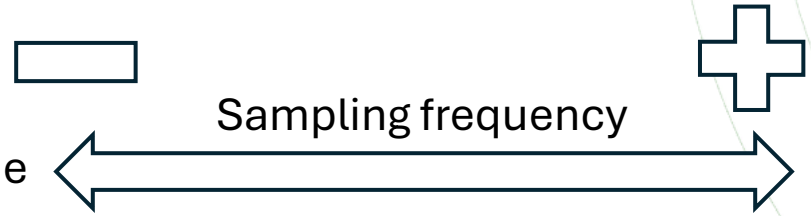
Saving settings

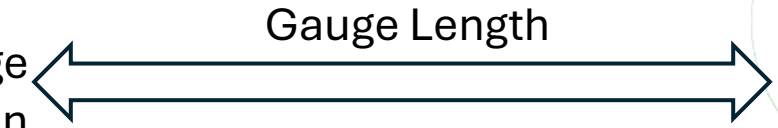


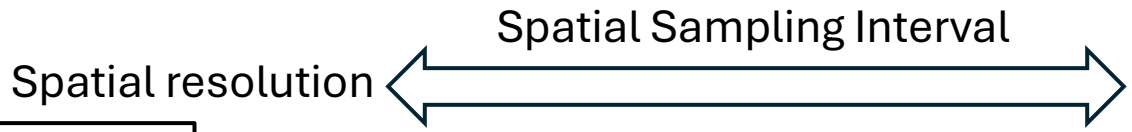
Settings trade-offs

Dynamic range:
- Maximum Sampling Frequency (shorter fibre)
- Minimum Gauge Length

Finer spatial resolution
- Shorter Gauge Length
- Shorter Spatial Sampling Interval





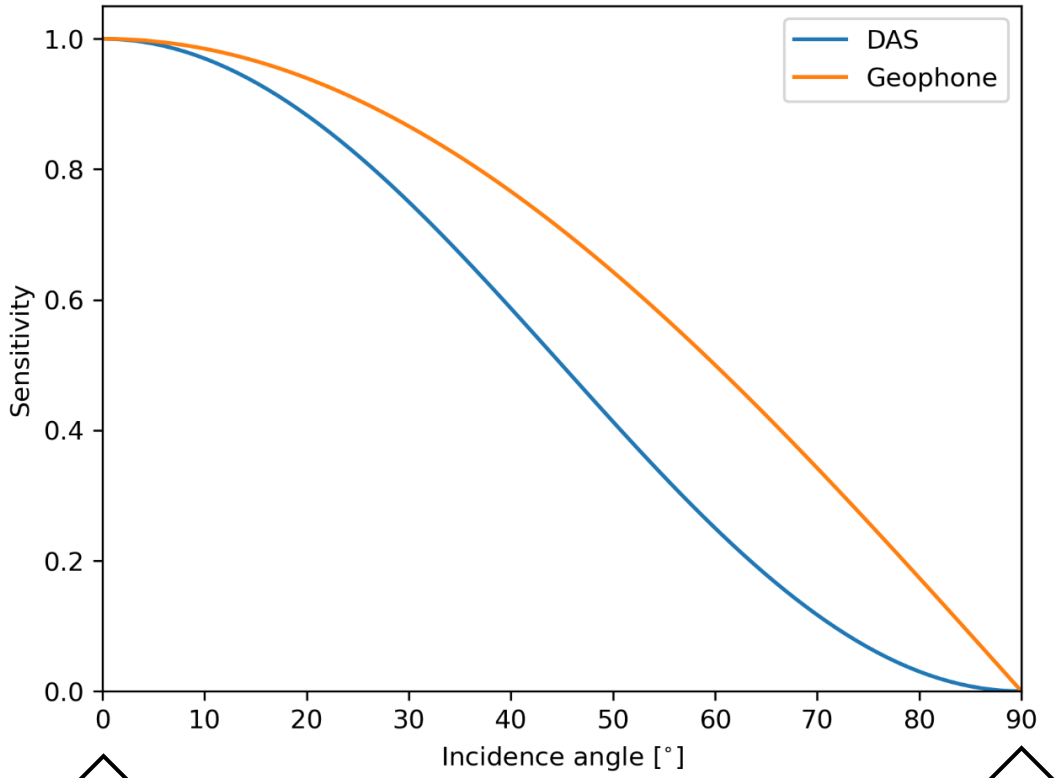


Minimum data rate:
- Lower Sampling Frequency
- Coarser Spatial Sampling Interval
- Shorter saving fibre range

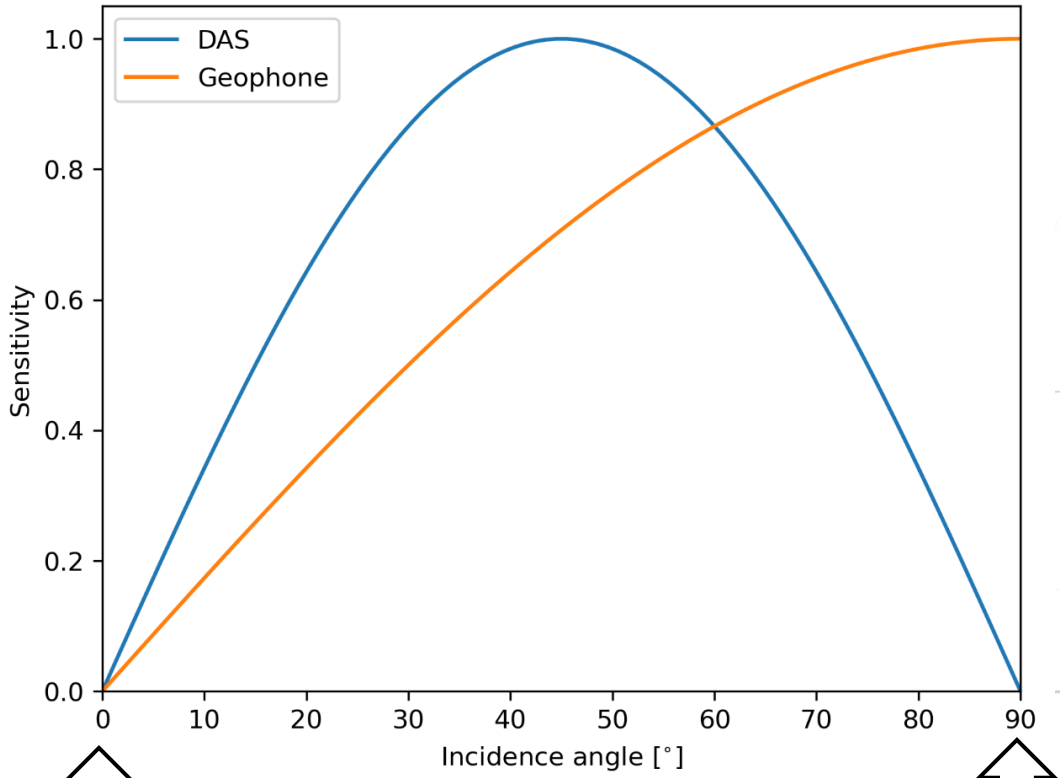
Maximum acoustic SNR
- Longer Gauge Length
- Minimum fibre losses
- Enhanced fibre (Constellation)
- Optimal Laser Pulse Frequency

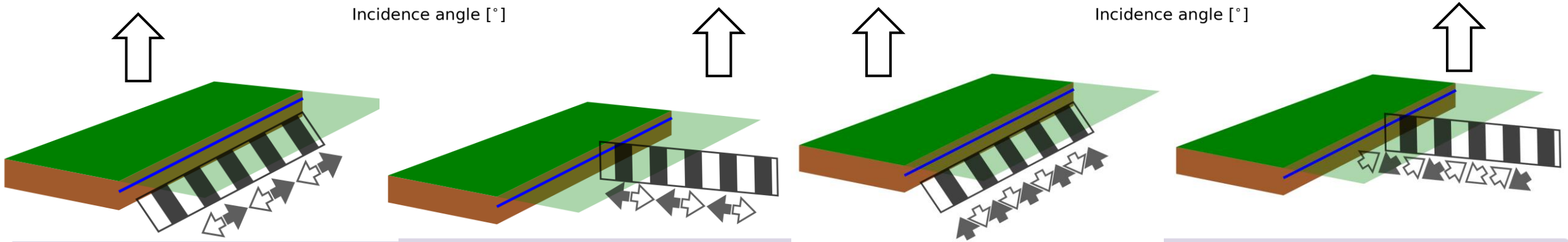
Comparison with Geophones

P-waves



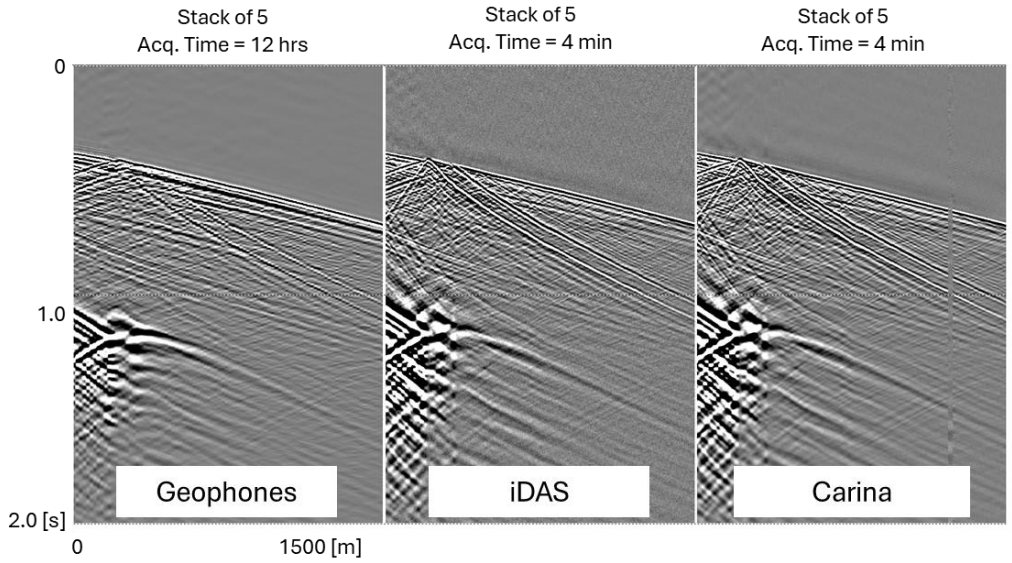
S-waves



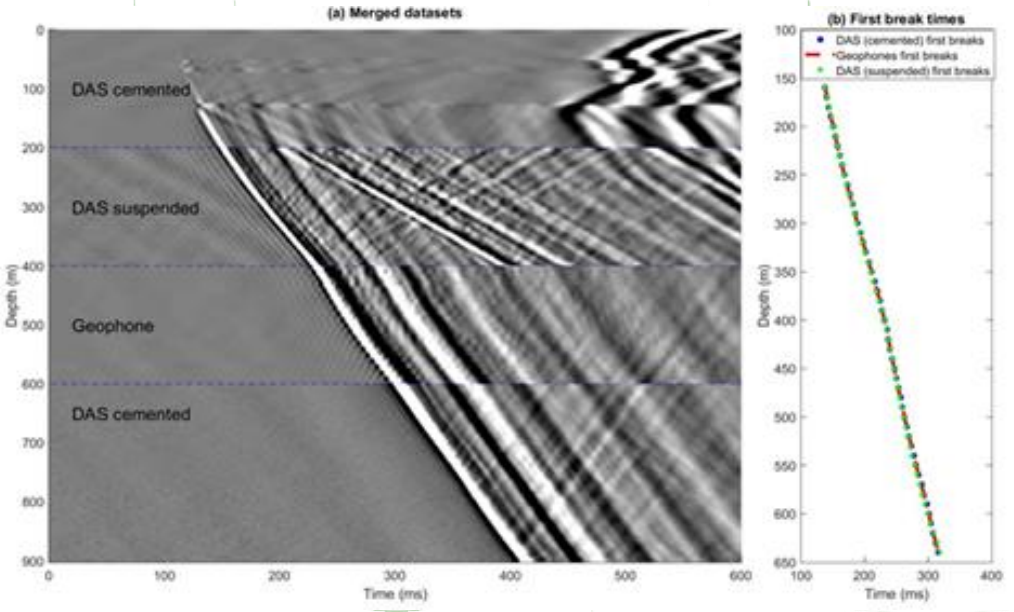


Comparison with Geophones

	iDAS	Geophone
Spatial sampling	From 0.25 m	Typically tens of m
Installation type	Flexible	Wireline logging
VSP	Record the entire wellbore with one shot	Several string positions required to cover wellbore
Response Bandwidth	0.001Hz to 50kHz	0.05Hz to few kHz
4D VSP	Repeatability @ low cost	More complex acquisition at higher cost
Data format	Standard seismic formats	Standard seismic formats
Data viewer	Real time data visualisation	Real time data visualisation



Courtesy of Curtin University



Correa, J., et al., 2017. DAS Versus Geophones: a Quantitative Comparison of a VSP Survey at a Dedicated Field Laboratory. In Fourth EAGE Borehole Geophysics Workshop.

THANKS!

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
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Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Geophysical instruments and data processing

Seismic Survey Design and Best Practice

- Frantisek Stanek

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Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Introduction

This presentation describes the necessary requirements for performing an active seismic survey, with particular emphasis on performing tasks from a remote location

The presentation covers the following areas:

- Basic aims of an active seismic survey
- Pre-job planning
- Equipment requirements including installation, connections and set up
- Networking best-practices
- Depth calibration
- Typical job workflows, QC and deliverables
  - Continuous acquisition with shot extraction
  - Triggered acquisition
  - Vibroseis sources
- Seismic QC and Common Issues
- Considerations and limitations for performing jobs remotely

Active Seismic

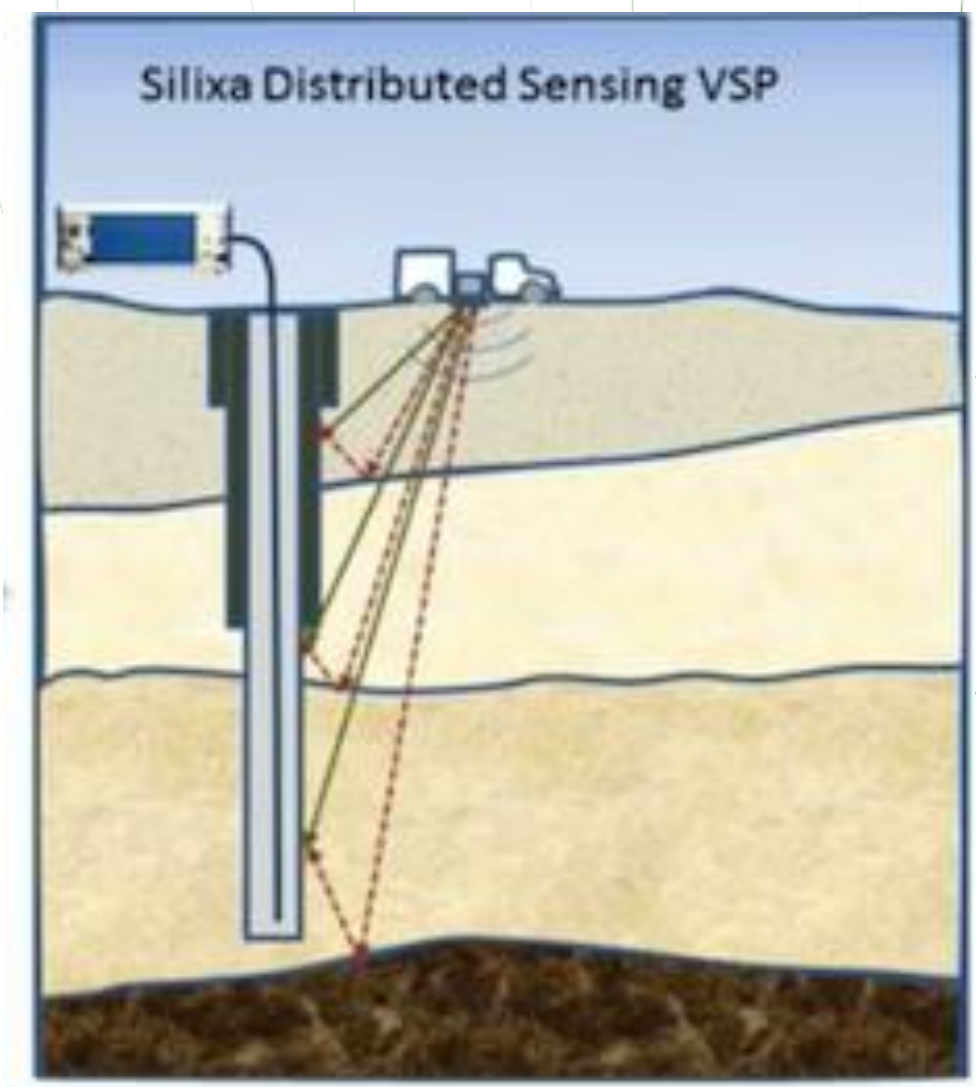
- Overall aim: To map subsurface layers of rock, and to detect changes over time

- Methods:

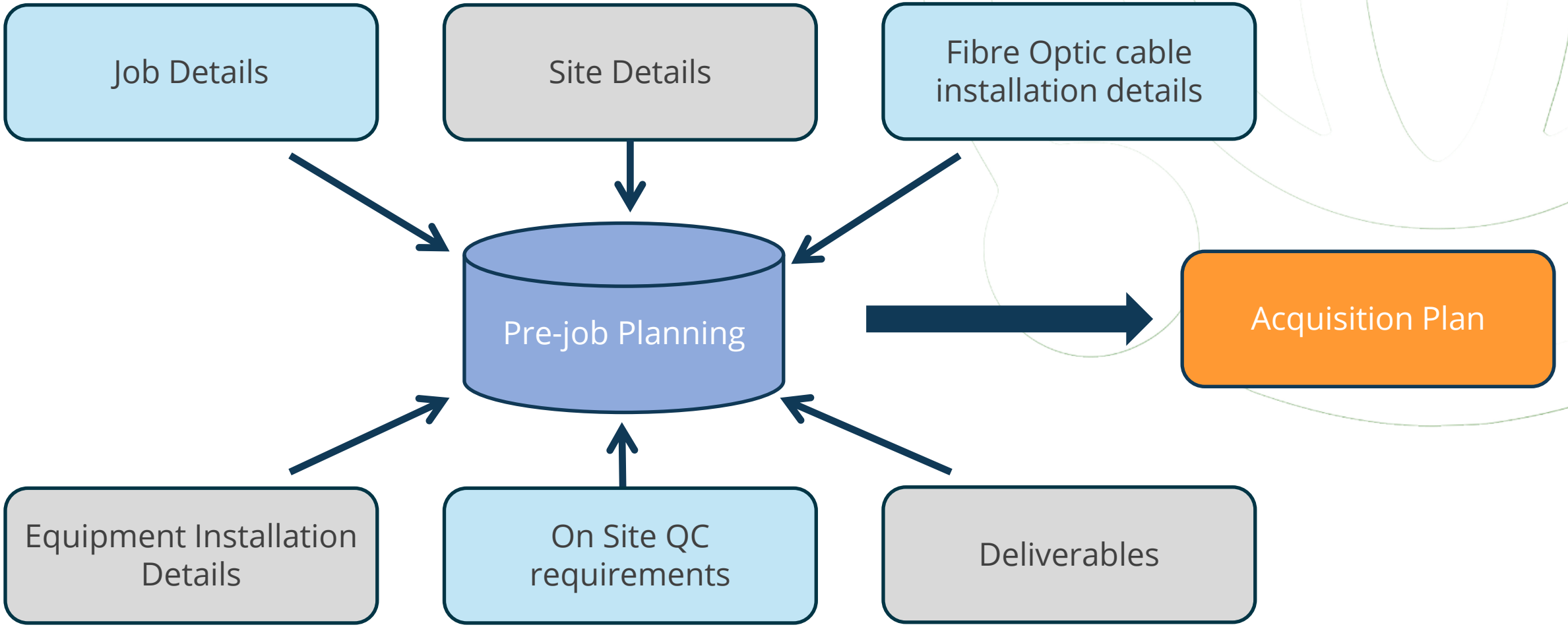
    - Measure direct travel times of the sound from the surface to each receiver

    - Use sound that reflects from the boundaries between each layer to create an image

- Common Deliverables:
    - In field QC plots and shot files
    - Early-stage processing (e.g. corridor stack for ZOVSP)
    - 3D imaging
    - 4D difference



Pre-job Planning Elements



Pre-job planning

Job Details

- Aim of the survey (including the size, depth and orientation of the imaging target)
- Type of survey, e.g. Zero-Offset, 2D, 3D, 4D
- Source details (frequency range, power, control)

Site Details

- Location: How to get you and equipment there, local weather etc, what infrastructure is there?
- Well details: locations, completion diagrams, deviation surveys
- Trench layout if applicable (e.g. GPS coordinates)

Fibre Optic cable installation details

- Cable type, number and types of fibres
- Installation method
- Access to fibre

Equipment Installation Details

- Power supply, temperature, humidity, vibration
- Internet access
- Desk or rack space
- ATEX areas

On Site QC requirements

- Real-time visualisation
- SNR, timing, signal quality
- Operational QC (missed shots / triggers)

Deliverables

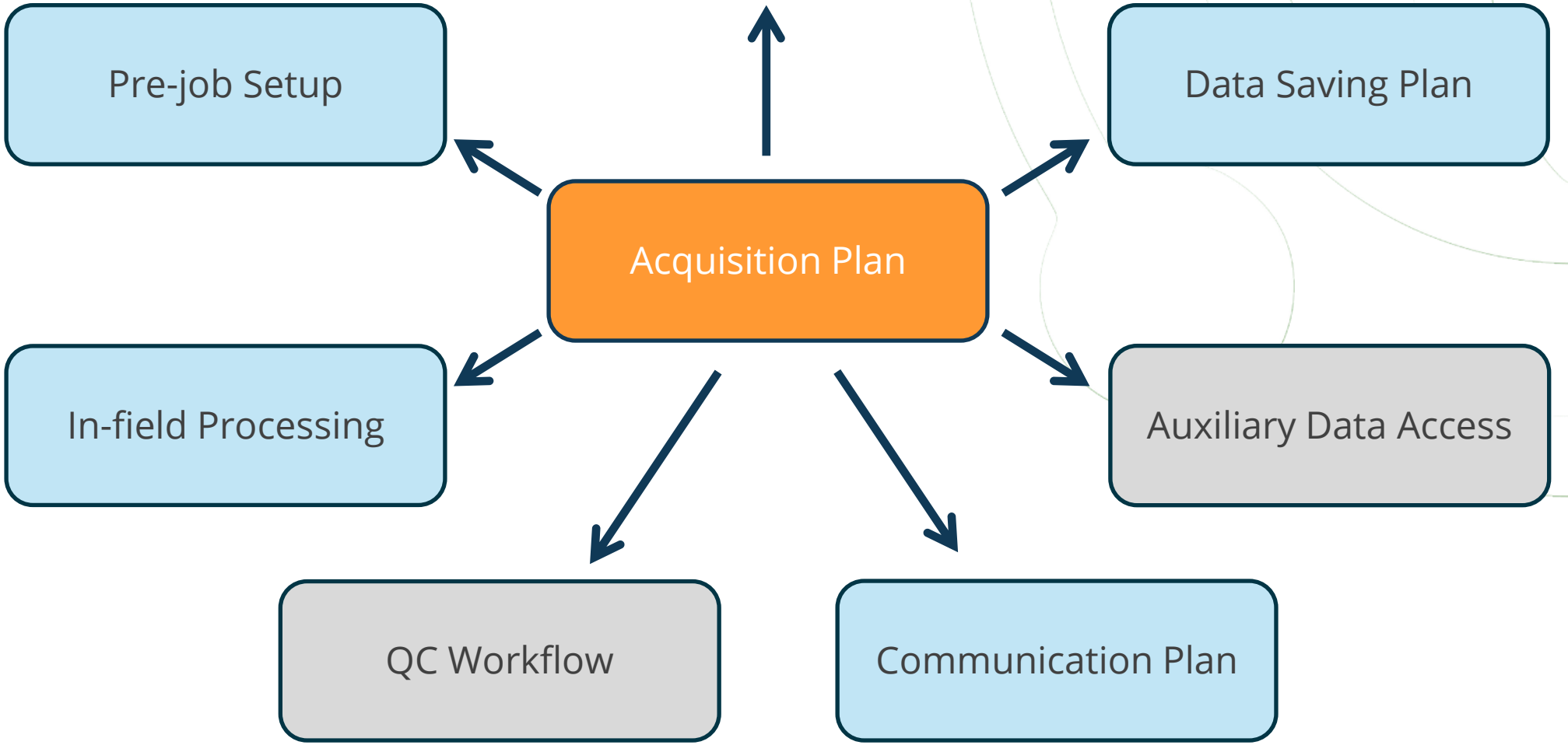
- Data: file format, file length, delivery method, number of copies
- Reports: Presentations, word documents, auxiliary files (e.g. NAV files)
- Deadlines

Get as much information as you can

This may require talking to lots of different parties

Start thinking about potential problems and how to mediate

Pre-job planning Elements



Acquisition Plan

Pre-job Setup

- How long will it take? (normally at least 1 day, maybe 2)
- Where will equipment be, where is power coming from?
- How will depth calibration be completed?

Acquisition Settings

- Sampling frequency, gauge length
- Continuous or triggered acquisition
- Data rates

Data Saving Plan

- File format
- Folder structure
- Required disk space
- Backup plan

Auxiliary Data Access

- NAV file format and contents
- How will these files be transferred to you?
- Do those files need manipulation before SW can read them?

In-field Processing

- Shot extraction required?
- Data curation e.g. decimation, common mode filtering
- Correlation, Stacking
- SEGY header formatting and customisation

QC Workflow

- What QC plots will provide the right information?
- Shot / Receiver gather, SNR, frequency spectrum
- How will those be generated?

Communication Plan

- How to communicate with others on site about what is happening and when?
- What is the current shot point? When should we start / stop recording?
- What should happen in the event of issues? How are decisions made?

A good acquisition plan saves time and money during the survey

Get it right first time and avoid delays or having to come back and reshoot!

Equipment

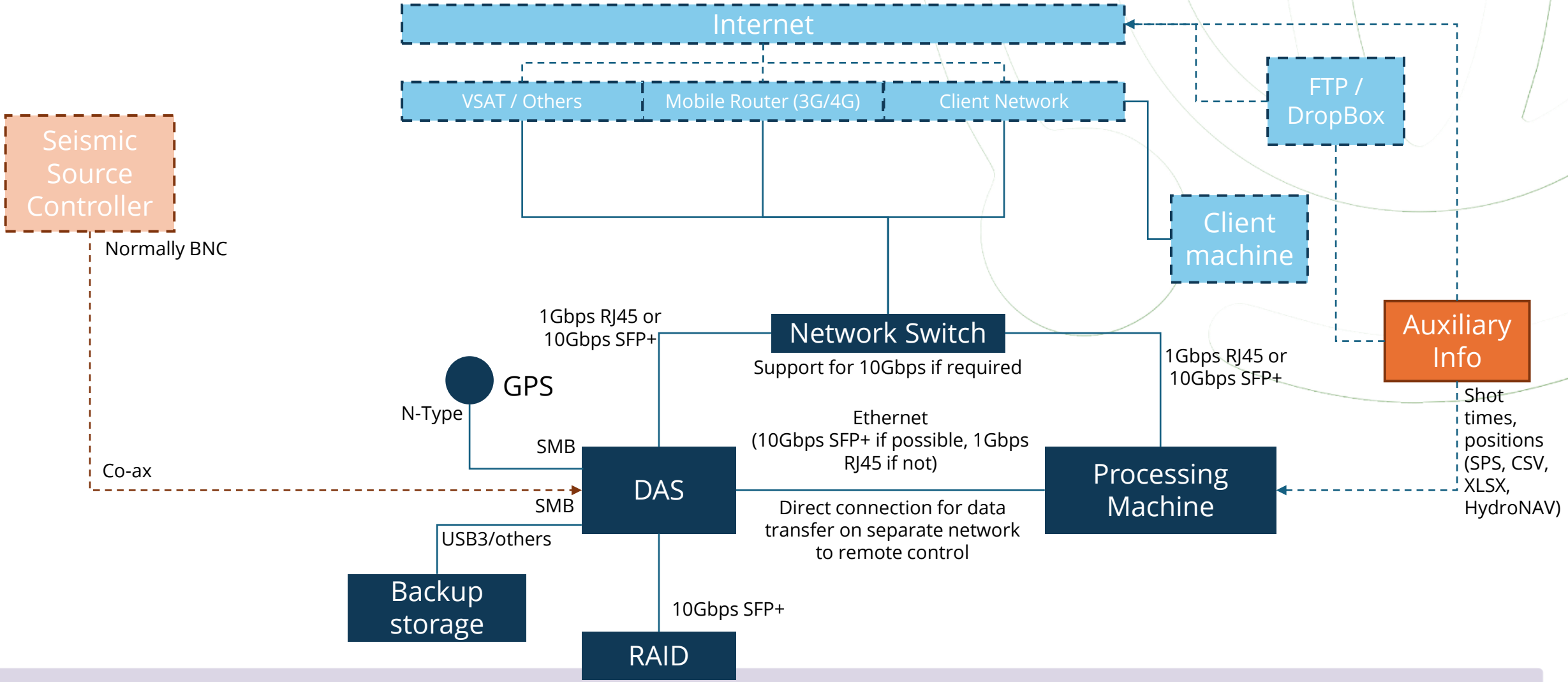
Make sure you have everything you need!

- DAS and fibre optic cables
  - Fibre cleaner
  - RAIDs (spare hard drives)
  - Keyboard/mouse/monitors and cables
  - Power cable
  - GPS kits (check connectors)

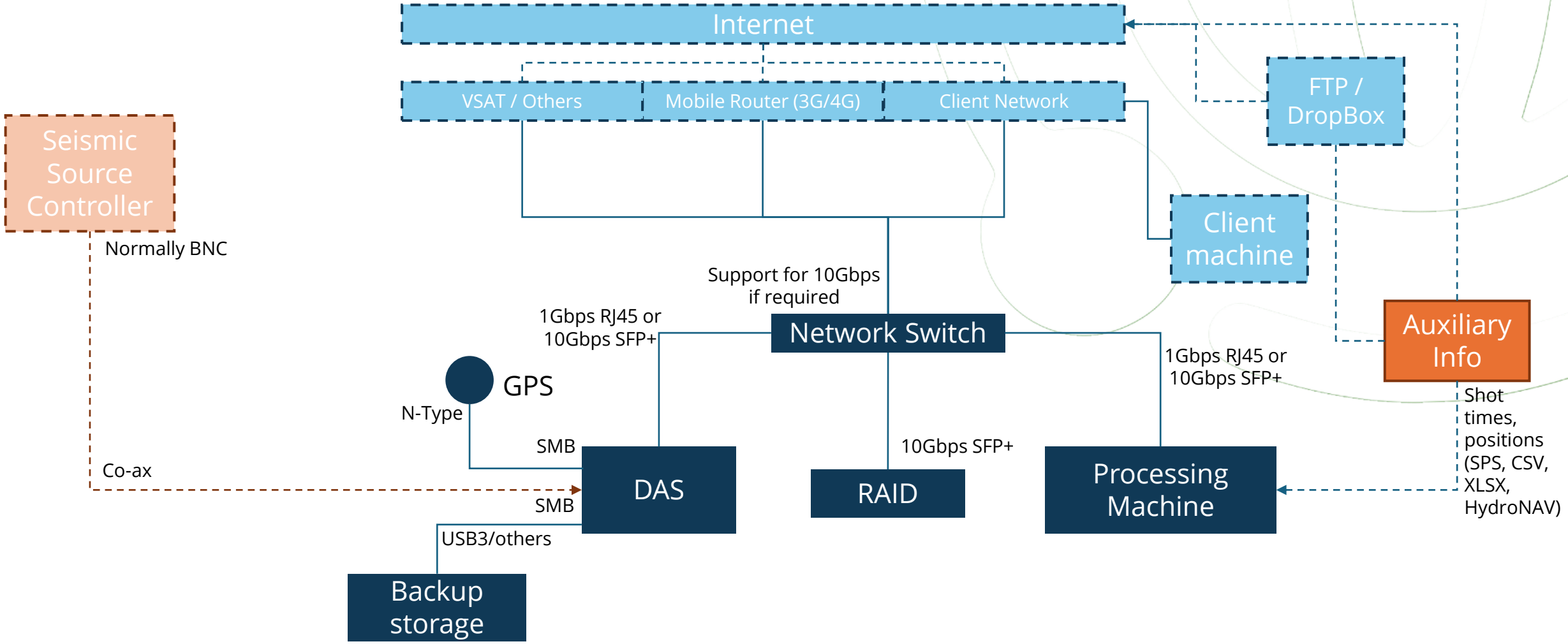
- Processing PC
  - Laptop/Server/Desktop PC
  - Keyboard/monitor/mouse
  - Network cables

- Misc.
  - Multiplug sockets (country adapters)
  - Back up hard drives and caddies (USB3?)
  - Hand tool kit
  - Network switch
  - Splicer, OTDR
  - Surface cables, patch cords, splice cassettes etc

Equipment Set Up
(Single iDAS, single processing machine)



Equipment Set Up
(Single iDAS, single processing machine)



The process of calculating the real-world position of the fibre receivers

Pre-requisites

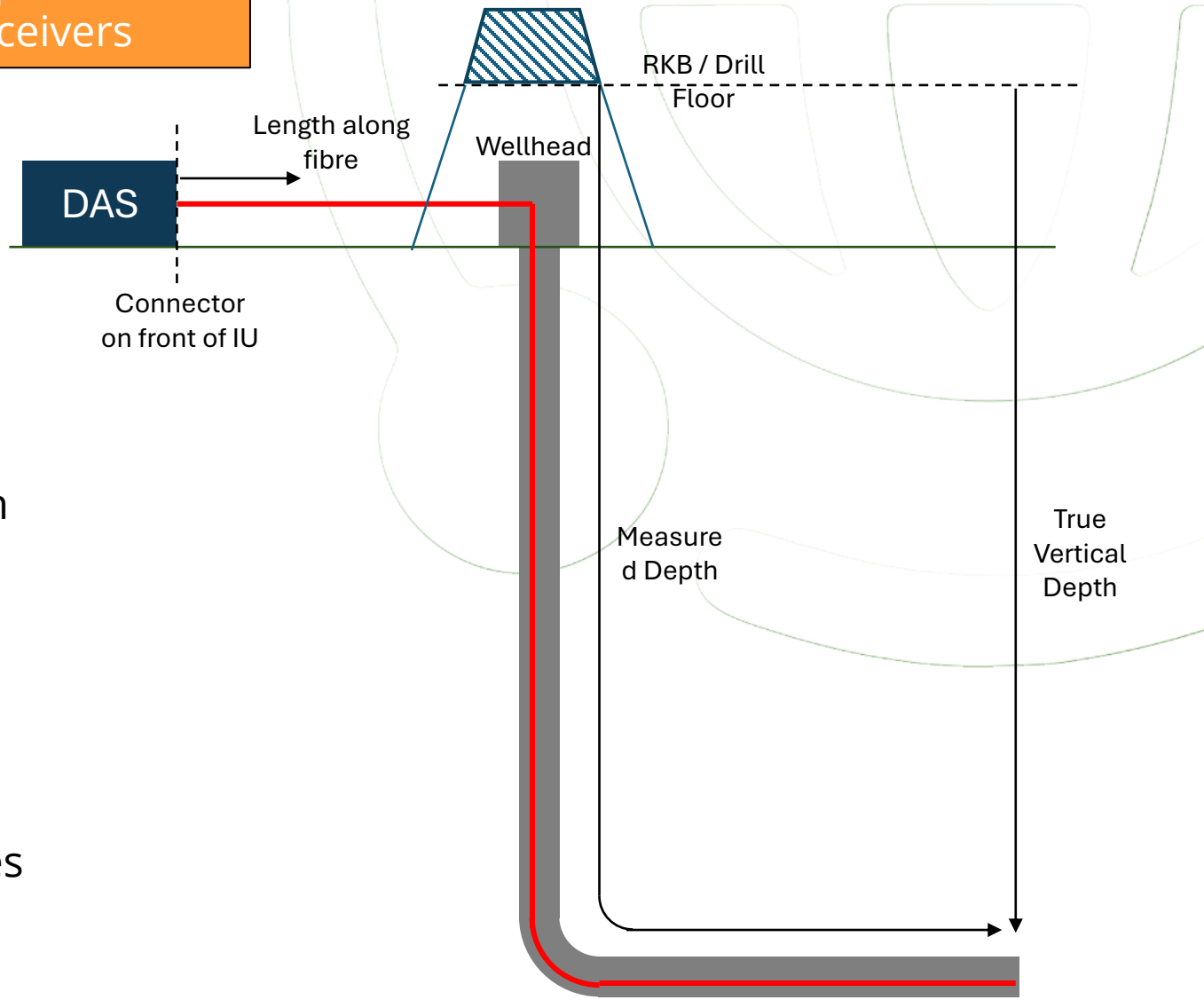
- Fibre path
  - Including any discontinuities in the fibre path

- Position information
  - Comes from client e.g. completion diagram
  - Depth of known points

Two-stage process

1. Map Fibre Distance to Measured Depth (or length along the “Facility”)
   - Tap test
   - Optical features e.g. reflections, splices
   - Acoustic features e.g. valves, changes in pipe diameter

2. Measured Depth/Facility Length to 3D coordinates
   - Deviation survey
   - Wellhead or trench vertex coordinates
   - Trench elevation profile



Depth Calibration

Common procedure (Permanent Fibre in-well)

- For each vertex in the fibre path
  - Wellhead/Tubing hanger
  - Valves/splices in fibre path
  - Bottom of well (end of fibre or fibre turnaround)

Goal: Collect the list of reference points.
- *Fibre distance from connector*
- *Measured Depth for each point*

1. *Tap test at wellhead*
   - See both out-going and return leg of double-ended
   - Correct wellhead tap test location for fibre wraps around tubing hanger (TH)
     - Tap is normally above the TH (e.g. on wellhead outlet)
     - Add approximate fibre length to location below TH
     - Find depth of point below TH from completion diagram

2. *Valves/splices in path at positions within the well*
   - Valves might make noise, use acoustic view
   - Splices show up in OTDR, compare OTDR distance with iDAS distance to find positions in iDAS
   - Components will likely have additional fibre wrapped above and/or below them. Reference point above and below is required

3. *End of fibre/Turnaround*
   - End reflection
   - Turnaround point in acoustics
   - Half-way point between tap test locations

Depth Calibration

Goal: Collect the list of reference points.
- *Fibre distance from connector*
- *Measured Depth for each point*

Common procedure (Intervention)
- For each vertex in the fibre path
  - Wellhead/Tubing hanger
  - No discontinuities
  - Bottom of well (end of fibre or fibre turnaround)

1. Tap test at surface
   - If tap test is not at wireline zero then measure distance between tap location and zero

2. End of fibre/Turnaround
   - End reflection
   - Turnaround point in acoustics
   - Half-way point between tap test locations
   - Need to know amount of fibre in the head
   - Need to know the difference between fibre end/turnaround and cable TD

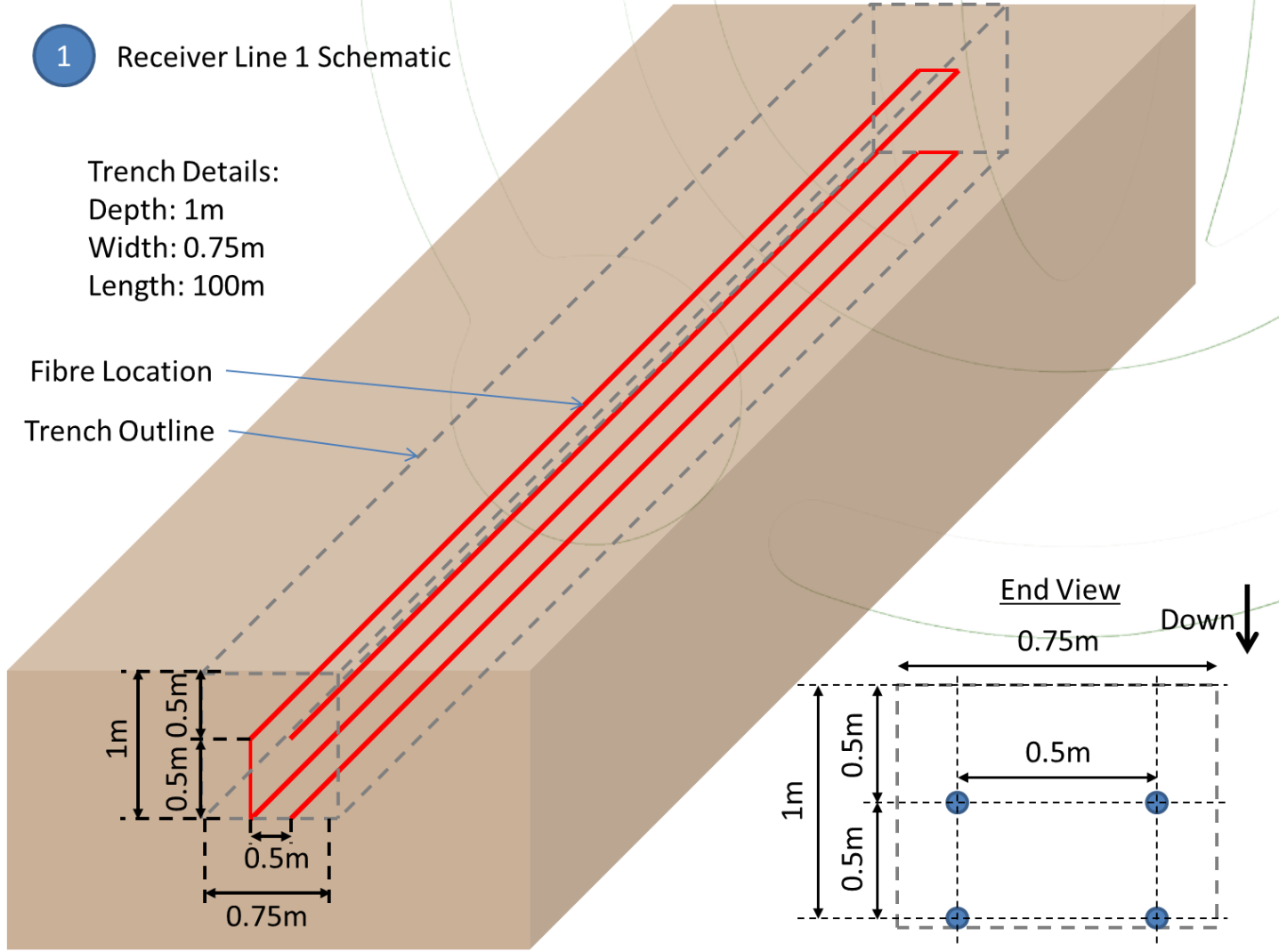
Depth Calibration

Common procedure (Trenched Fibre)

- For each vertex in the fibre path

1. Tap tests at every vertex
   - Look at acoustic data to find positions
   - Account for any additional fibre in junction boxes
   - Map out each fibre, if more than one connected in series

Goal: Collect the list of reference points.
- *Fibre distance from connector*
- *GPS coordinate (X,Y,Z) for each point*



Depth Calibration

Entry into SeiBer

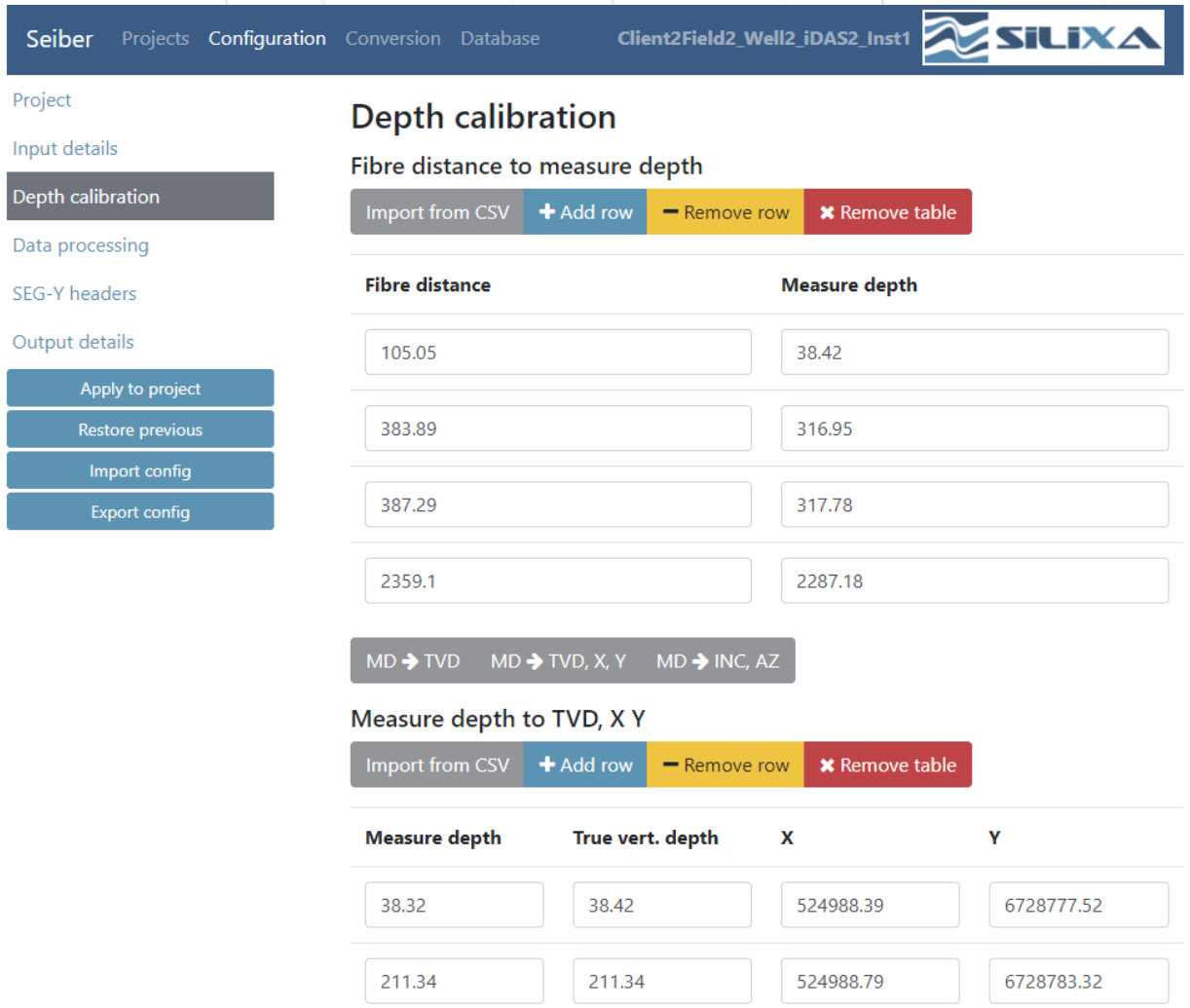
- Two-stage process

1. Map Fibre Distance to Measured Depth (or length along the “Facility”)
   - Fibre Distance to measure depth table

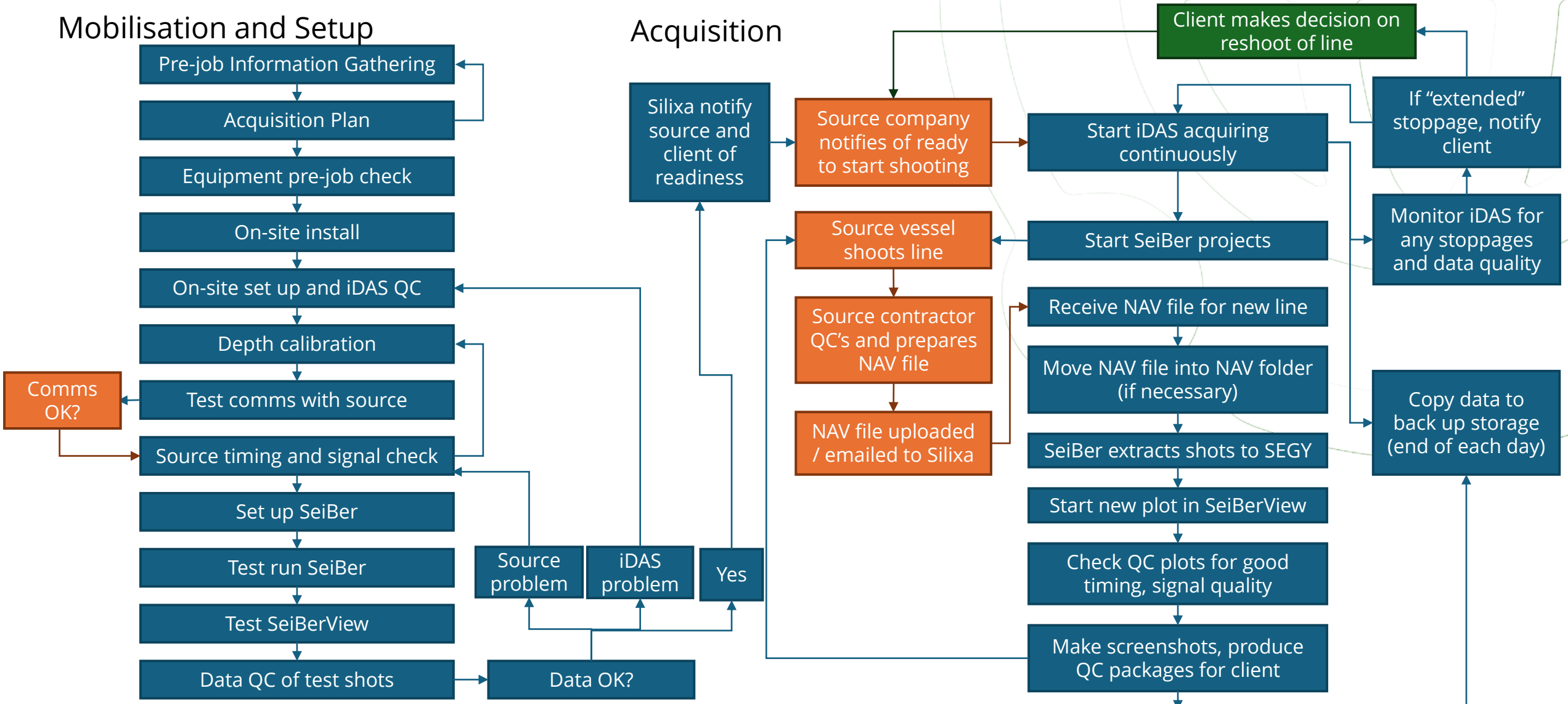
2. Measured Depth/Facility Length to 3D coordinates#
   - MD > TVD (, X, Y) or MD > Inc, Az

SeiBer performs linear interpolation to calculate the position of every receiver channel

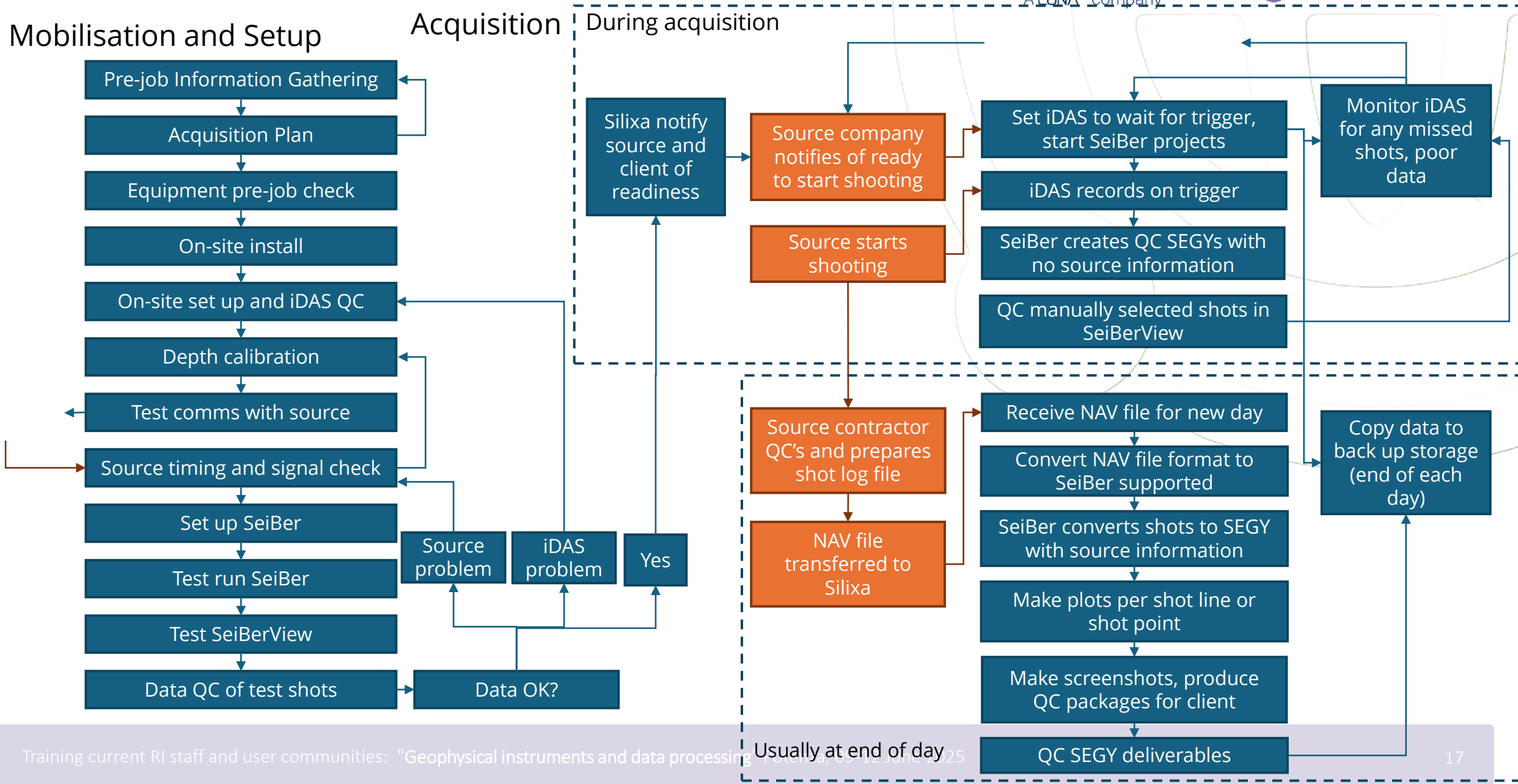
Goal: Enter the reference points into the software



Continuous Acquisition + Shot Extraction Survey Workflow, e.g. Marine



Triggered Survey Workflow, e.g. Land Seismic



DAS QC – Noise Floor

- There are two ways to check how the measured noise floor compares to the expected noise floor

- A dashed red line is shown on the Frequency Spectrum graph at the bottom of the Acoustic mode window

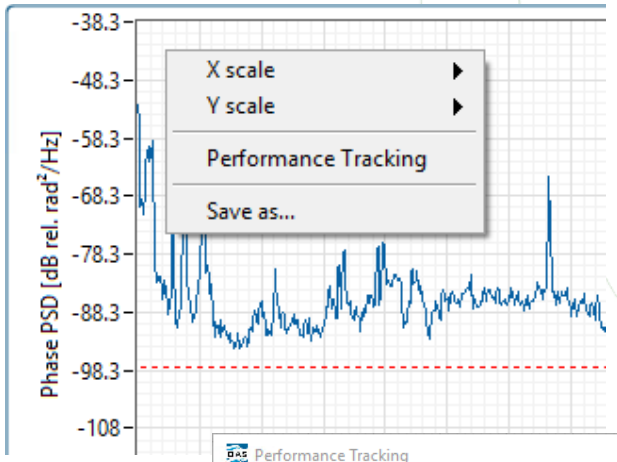
    1. Turn on Acoustic vs Time
    2. Turn on Integrate
    3. Select X Scale = Linear
    4. Select a distance to display using the red cursor on the top graph
    5. FFT graph at the bottom displays the

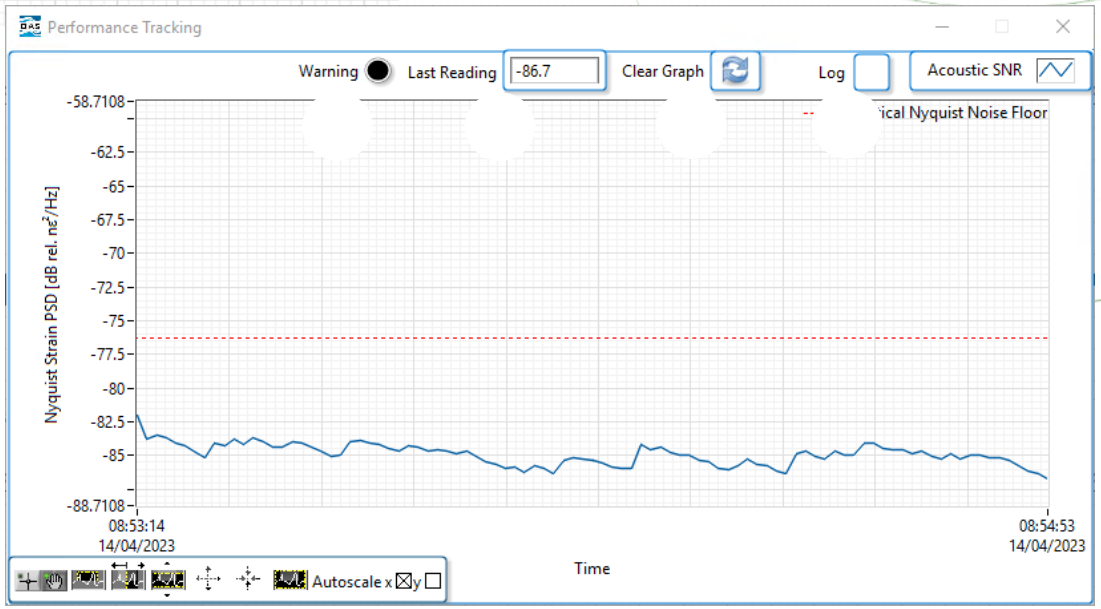
Ensure the noise floor is below the red dashed line at the Nyquist frequency

DAS QC – Noise Floor

- The pop out Performance Tracking tool will track the noise level over time

    1. With Acoustic vs Time and Integrate turned on
    2. Position the red cursor on the top graph in acoustic mode at a location you want to monitor (this can be changed at any time)
    3. Right click on one of the graphs in acoustic mode
    4. Select Performance Tracking
    5. The Performance Tracker will display the acoustic noise level over time and a dashed red line





Ensure noise floor is below the red dashed line

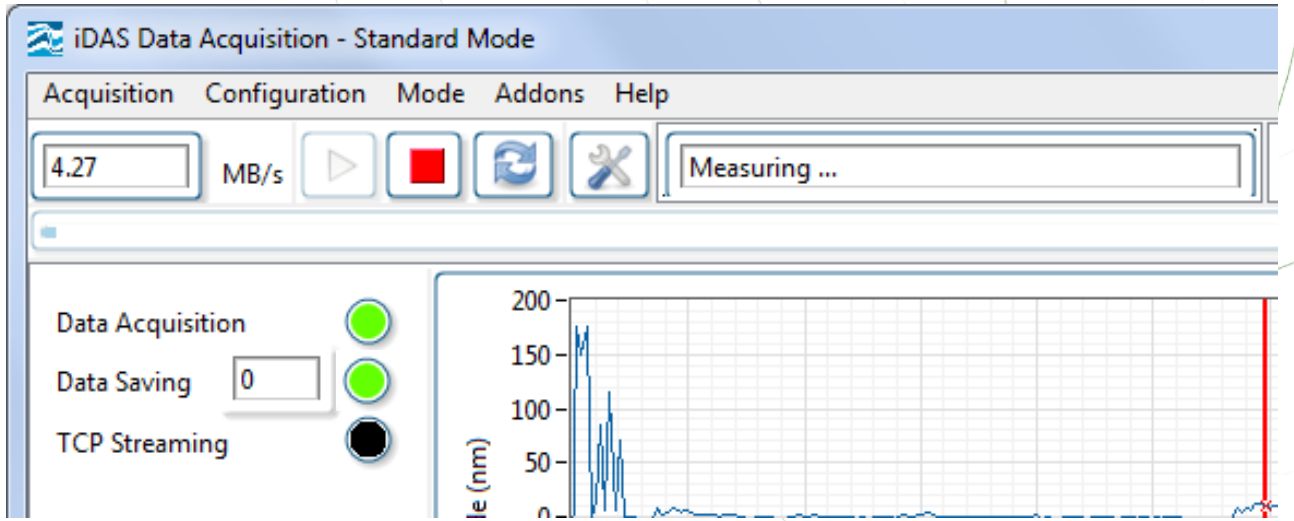
DAS QC

1. Ensure the DAS status message says “Measuring …” during acquisition

2. Ensure the Data Acquisition LED is Green.
   - If it flashes RED for a couple seconds this is OK
   - A constant red LED means the acquisition cannot be maintained and should be stopped and troubleshooted

3. Ensure the Data Saving LED is Green
   - If it flashes RED for a couple of seconds this is OK
   - A constant red LED means the data saving cannot be maintained and should be stopped and troubleshooted

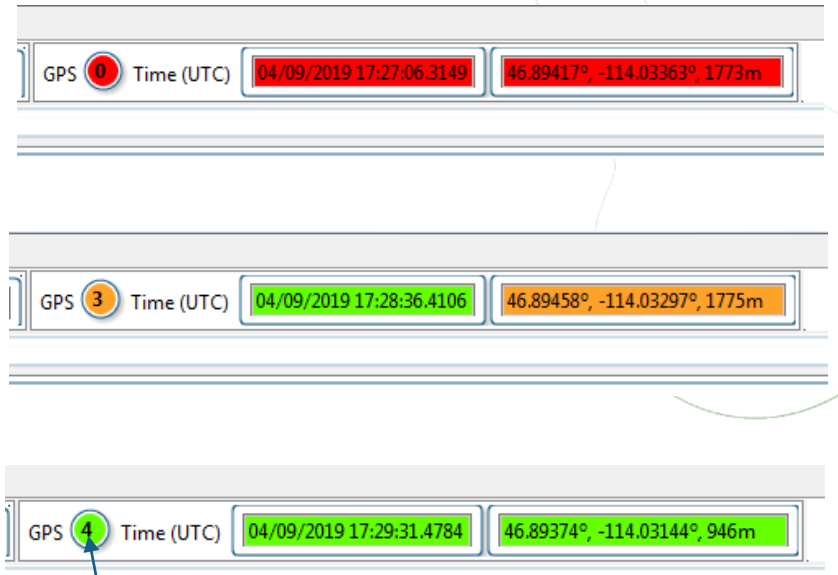
4. Ensure the saving rate of your measurements is below 250MB/s
   - If it is not, it is likely that the incorrect settings have been used



If the LED’s stay red, stop and check the acquisition settings and the status of the data storage device

DAS QC

- Monitor the GPS status panel to ensure timing synchronization is good
- GPS satellites should be:
  - Good = 3+
  - Minimum = 1+
- Panel LED's should be green to show a good cable connection



Number indicates how many satellites are connected

If any of these indicators aren't green the GPS cable connection should be checked

DAS QC – iDAS Saving

- Checking the file integrity and timestamps in saved data is another good way to QC if iDAS is saving data correctly

- If recording continuously, all files should be the same size and the timestamps should be separated by the same interval
  - If a GPS antenna is connected, the timestamps of the files should all have the exact same millisecond value

Name	Date modified	Type	Size
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202208.568.tdms	17/07/2019 21:22	TDMS File	401,744 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202240.434.tdms	17/07/2019 21:22	TDMS File	236,969 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202340.131.tdms	17/07/2019 21:24	TDMS File	585,031 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202410.130.tdms	17/07/2019 21:24	TDMS File	585,031 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202440.130.tdms	17/07/2019 21:25	TDMS File	585,031 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202510.130.tdms	17/07/2019 21:25	TDMS File	585,031 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202540.130.tdms	17/07/2019 21:26	TDMS File	585,031 KB
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DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202640.130.tdms	17/07/2019 21:27	TDMS File	585,031 KB
DOE_BM101A_FOWL5_SMF_2mGL_P10_UTC_20190717_202710.130.tdms	17/07/2019 21:27	TDMS File	585,031 KB

Millisecond value

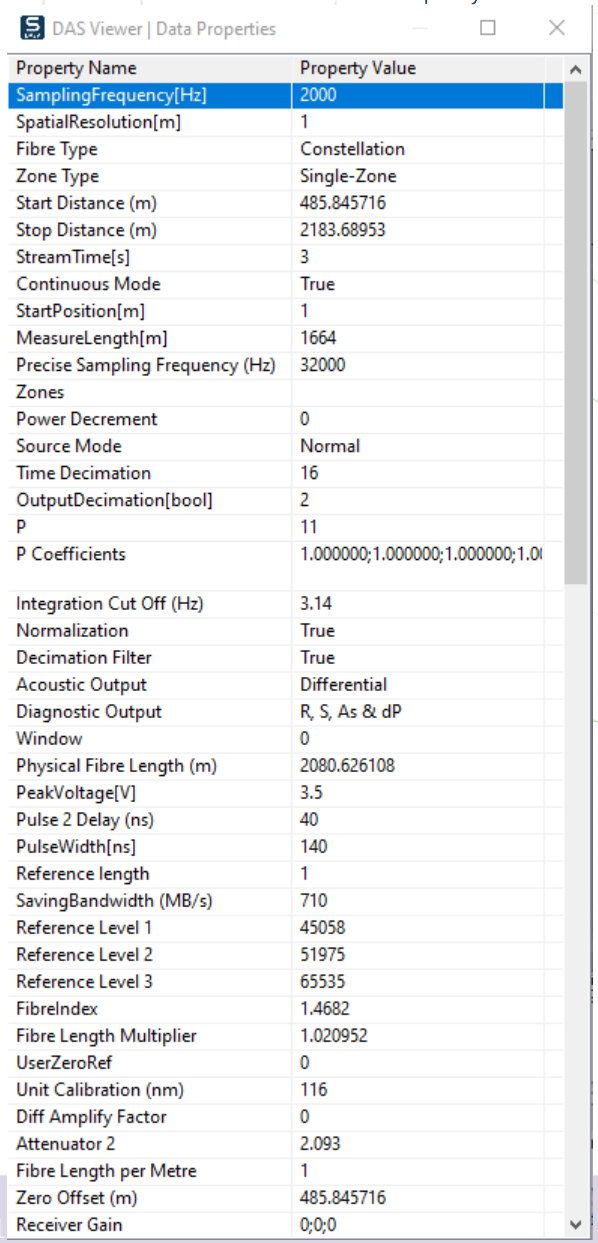
Different file sizes and gaps between timestamps indicate saving stopped and restarted

Later files all the same size and have exact same millisecond value

DAS QC – File Headers

- Open a file in DAS Viewer (available on the DAS)
- Go to Tools > Properties to view the file headers

Check to ensure the values displayed are the same as those set in the software

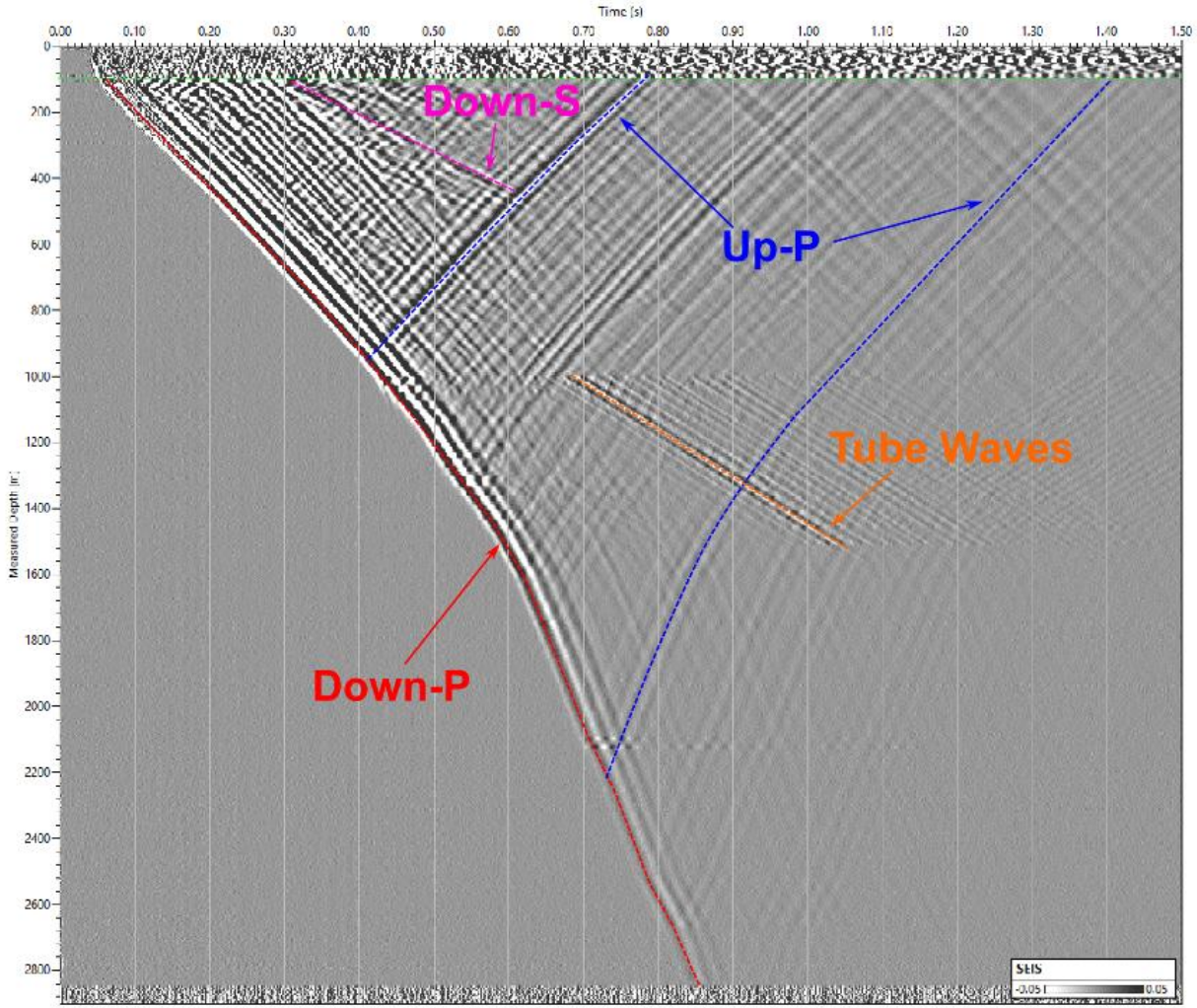


Property Name	Property Value
SamplingFrequency[Hz]	2000
SpatialResolution[m]	1
Fibre Type	Constellation
Zone Type	Single-Zone
Start Distance (m)	485.845716
Stop Distance (m)	2183.68953
StreamTime[s]	3
Continuous Mode	True
StartPosition[m]	1
MeasureLength[m]	1664
Precise Sampling Frequency (Hz)	32000
Zones	
Power Decrement	0
Source Mode	Normal
Time Decimation	16
OutputDecimation[bool]	2
P	11
P Coefficients	1.000000;1.000000;1.000000;1.0(
Integration Cut Off (Hz)	3.14
Normalization	True
Decimation Filter	True
Acoustic Output	Differential
Diagnostic Output	R, S, As & dP
Window	0
Physical Fibre Length (m)	2080.626108
PeakVoltage[V]	3.5
Pulse 2 Delay (ns)	40
PulseWidth[ns]	140
Reference length	1
SavingBandwidth (MB/s)	710
Reference Level 1	45058
Reference Level 2	51975
Reference Level 3	65535
FibreIndex	1.4682
Fibre Length Multiplier	1.020952
UserZeroRef	0
Unit Calibration (nm)	116
Diff Amplify Factor	0
Attenuator 2	2.093
Fibre Length per Metre	1
Zero Offset (m)	485.845716
Receiver Gain	0;0;0

Data QC

Signal QC

- Good data contains different wave propagation modes
- P-waves are faster than S-waves (slope of arrival tells you the speed)
  - General rule is Vs = Vp x sqrt(3)
- P-wave will be the first arrival at the fibre, S-waves behind
- Due to changes in speed at different rock layers and deviation in the fibre trajectory a seismic arrival is very rarely straight
- Tube waves follow the same path as the fibre and are therefore normally straight
  - Their speed is due to the speed of sound in the fluid they are moving in e.g. water or oil
  - Normally slower than P-waves but can be similar to S-waves
  - Tube waves are noise for seismic, signal for production!
- Also check the noise before the signal. Is it quiet? Are there artefacts?



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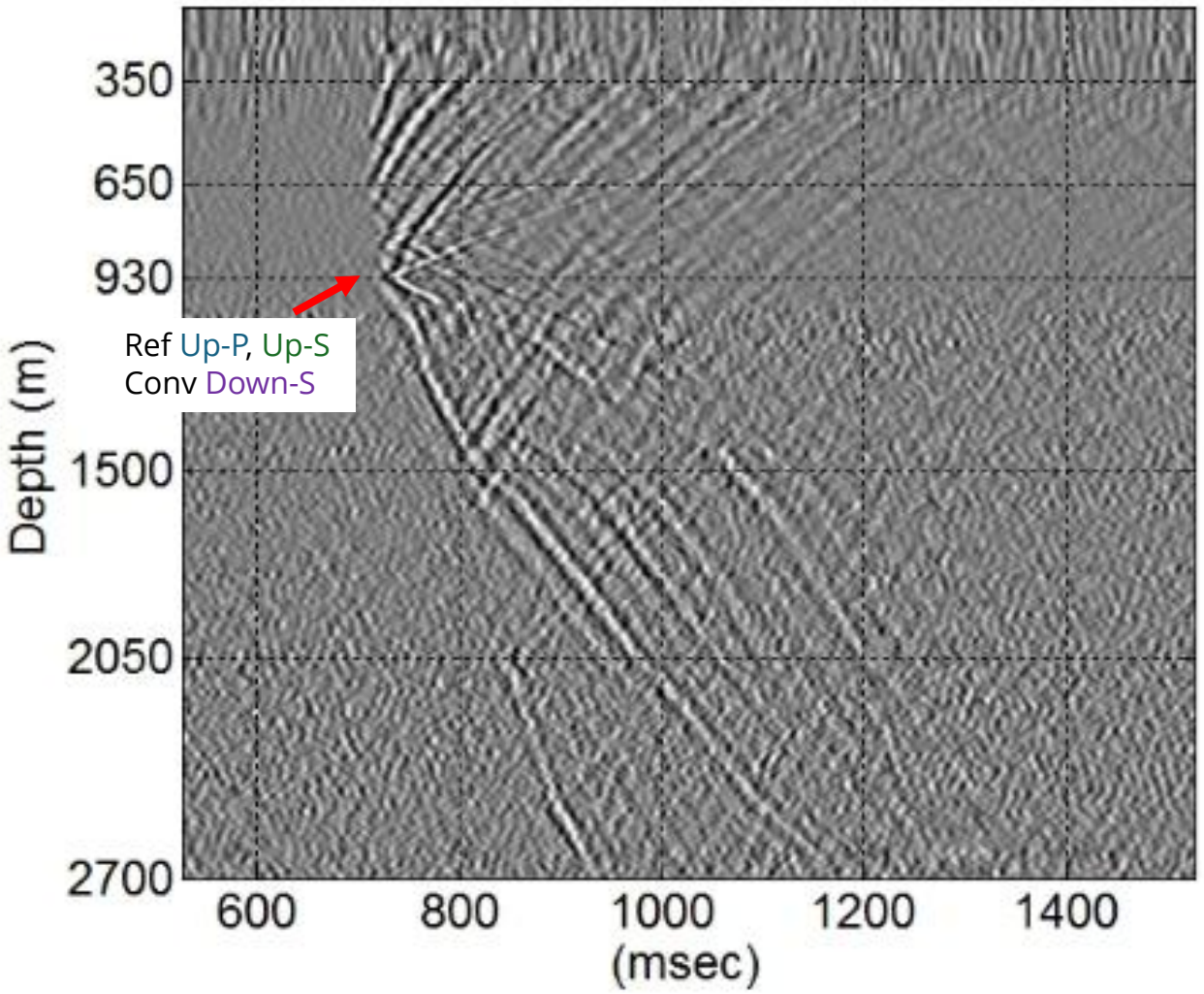
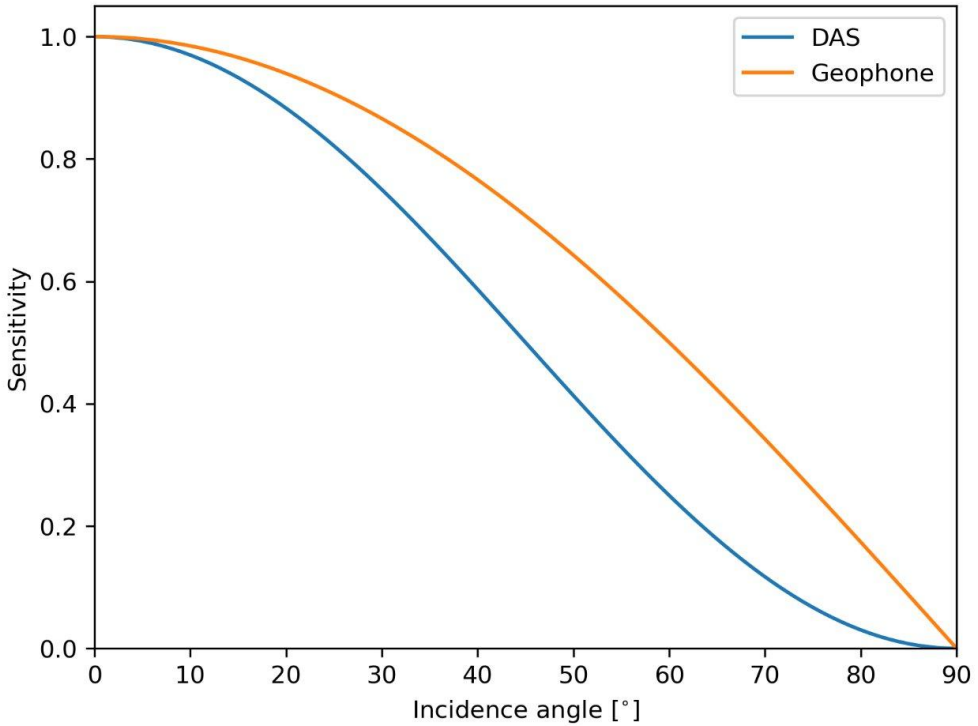


Data QC - Directivity

- P-wave
- DAS = $\cos^2\Theta$
- Geophone = $\cos(\Theta)$

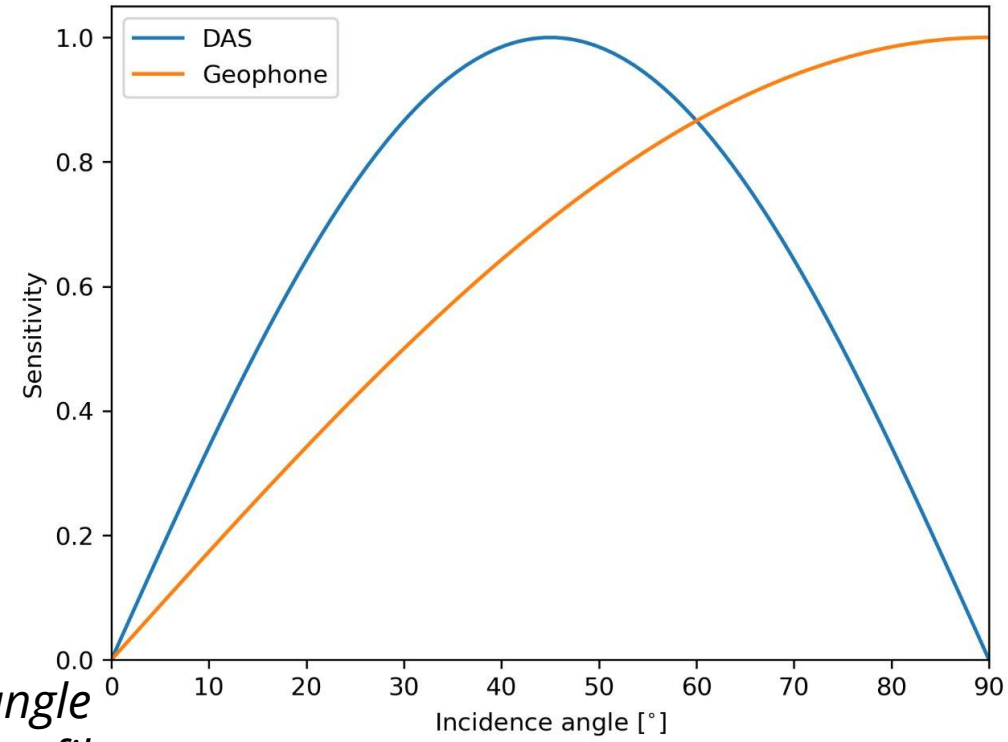


S-wave

(vertical fibre = S_v, horizontal fibre = S_h)

DAS = $\sin(2\Theta)$

Geophone = $\sin(\Theta)$



Θ = incidence angle

0° = in-line with the fibre

90° = perpendicular to the fibre

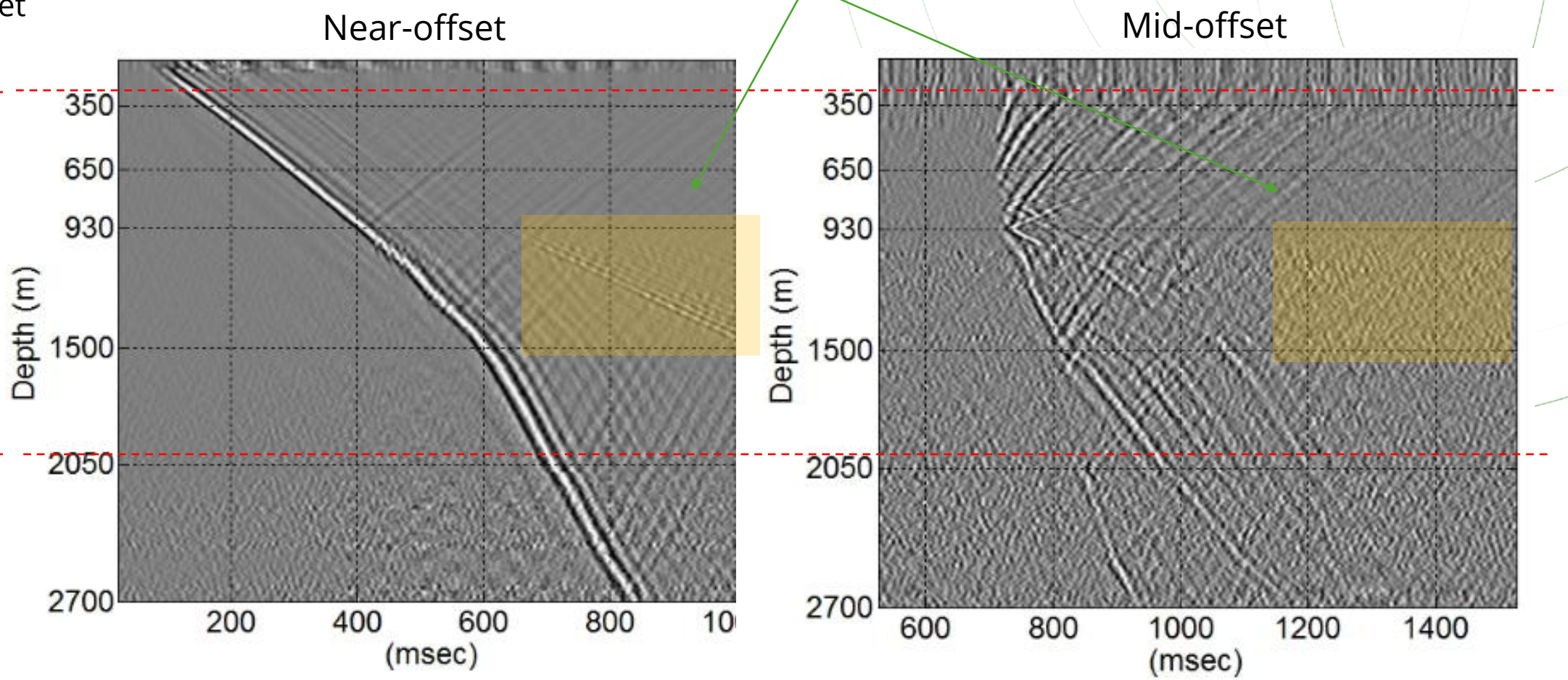
Data QC

Signal QC

- Effect of offset

Tube waves
Near offset: Tube waves generated
Mid-offset: Tube waves not generated

P-wave Angle of incidence
Near offset = ~0°
Mid-offset = ~90°



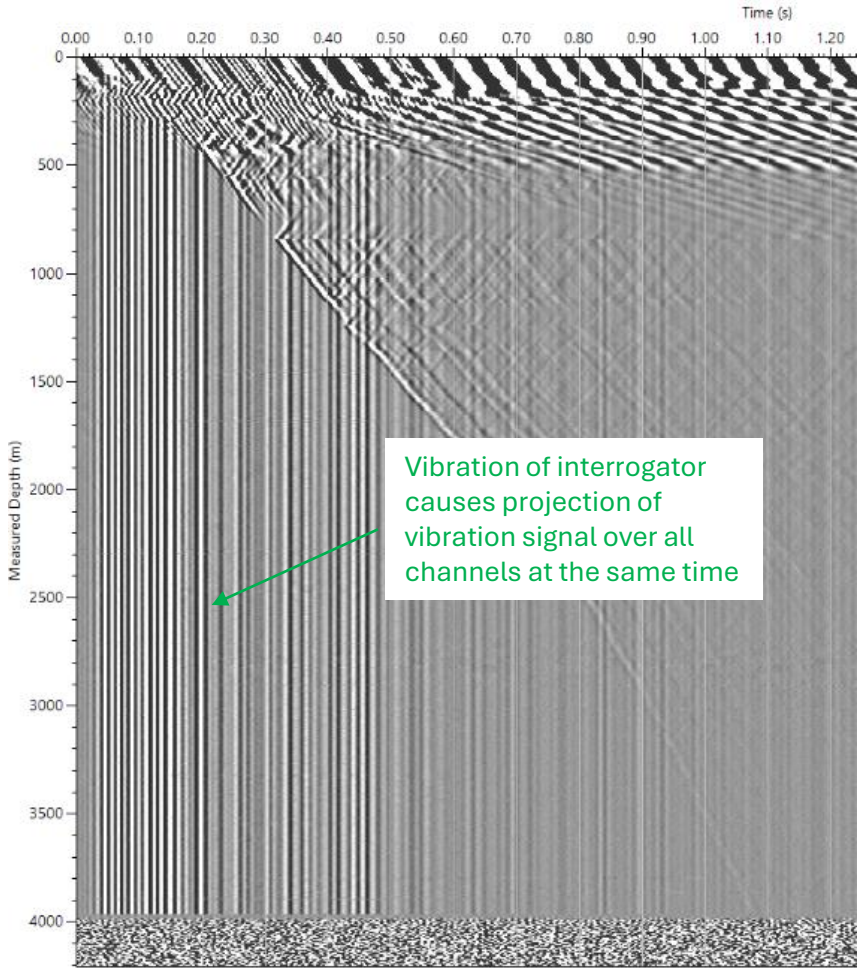
Common Issues

Signal QC

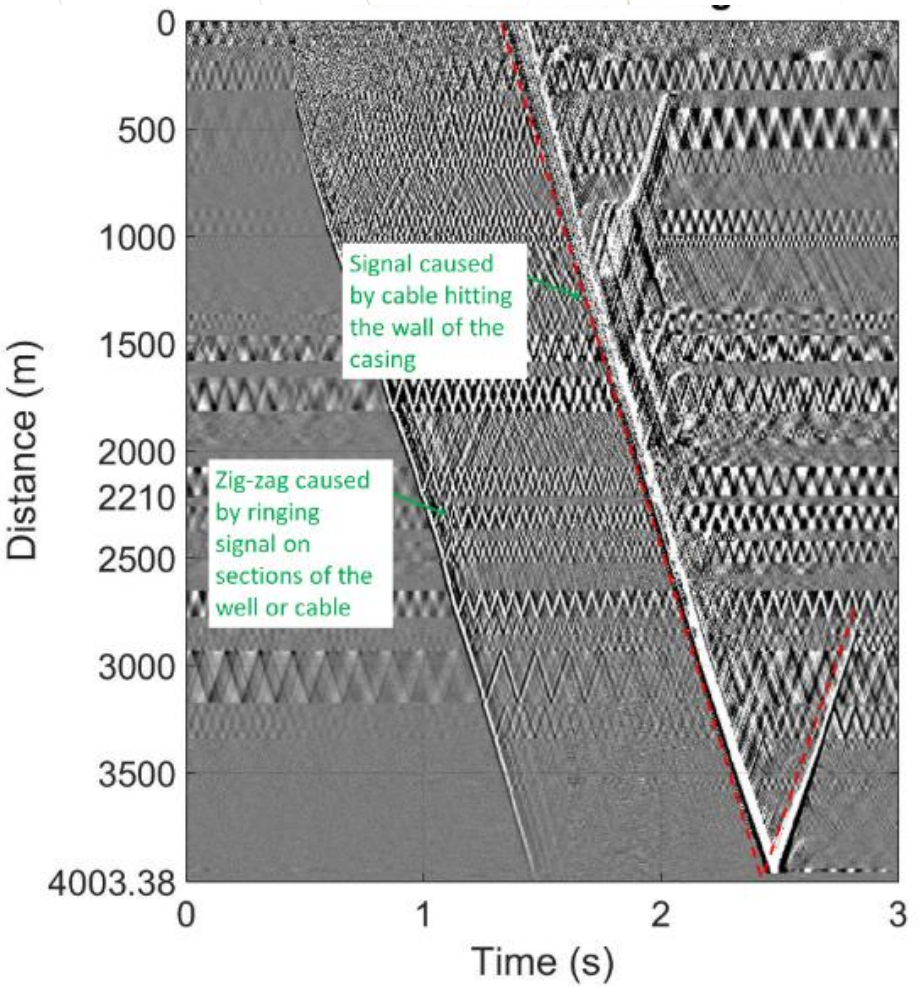
Common mode noise
- Caused by vibration of the DAS unit
- Seen as stripes at same time over all depths
- Vertical stripes if depth is on Y-axis

Intervention cable “ringing”
- Poor coupling between cable and wellbore means the cable acts like guitar string
- Ringing is zig-zag pattern seen in data

Common-Mode Noise



Intervention cable “ringing”

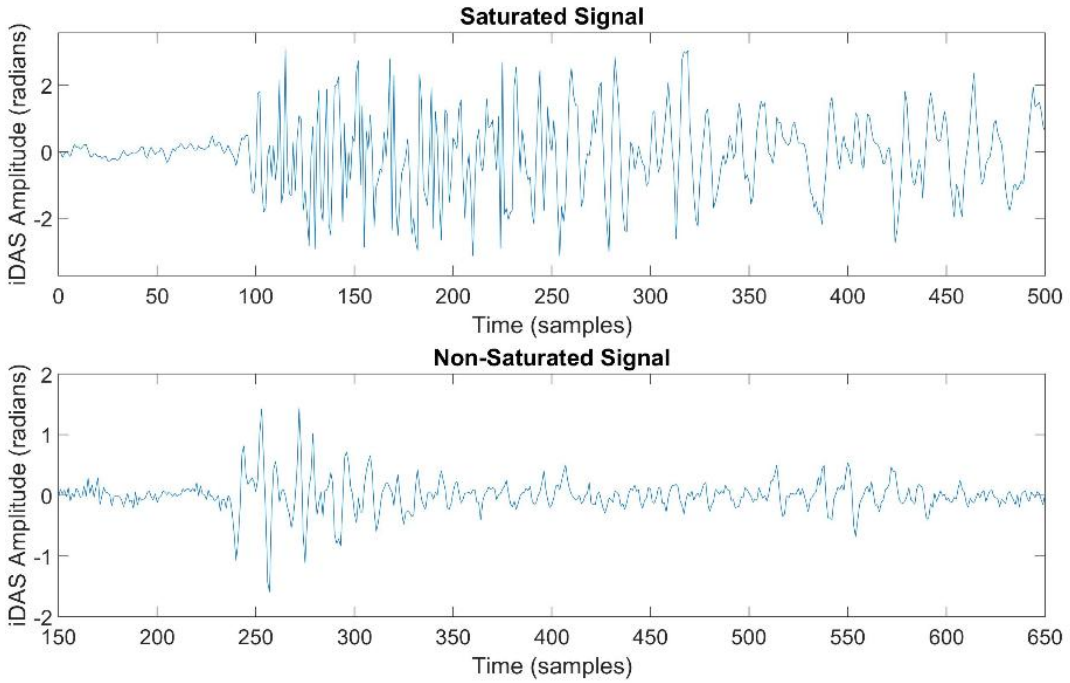


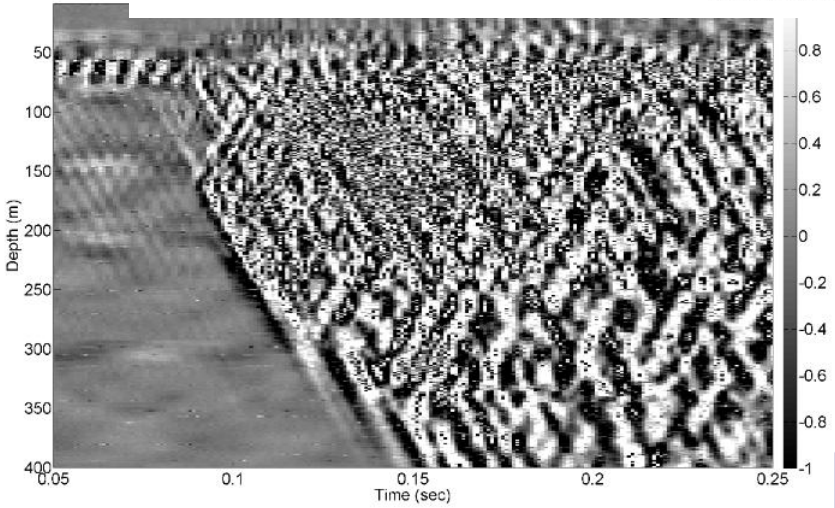
Common Issues

Signal QC

Saturated signal e.g. too loud

- It is possible in rare cases to exceed the maximum signal amplitude that DAS can record
- Seen in waterfall-style plot as “mottled” data rather than clearly defined propagating waves
- Signal saturates in optical domain so does NOT look like “clipping” i.e. signal reaching a maximum value and being limited
- Saturation in optical domain causes signal to “wrap around” which, in acoustic data, looks like many discontinuities (much spikier)

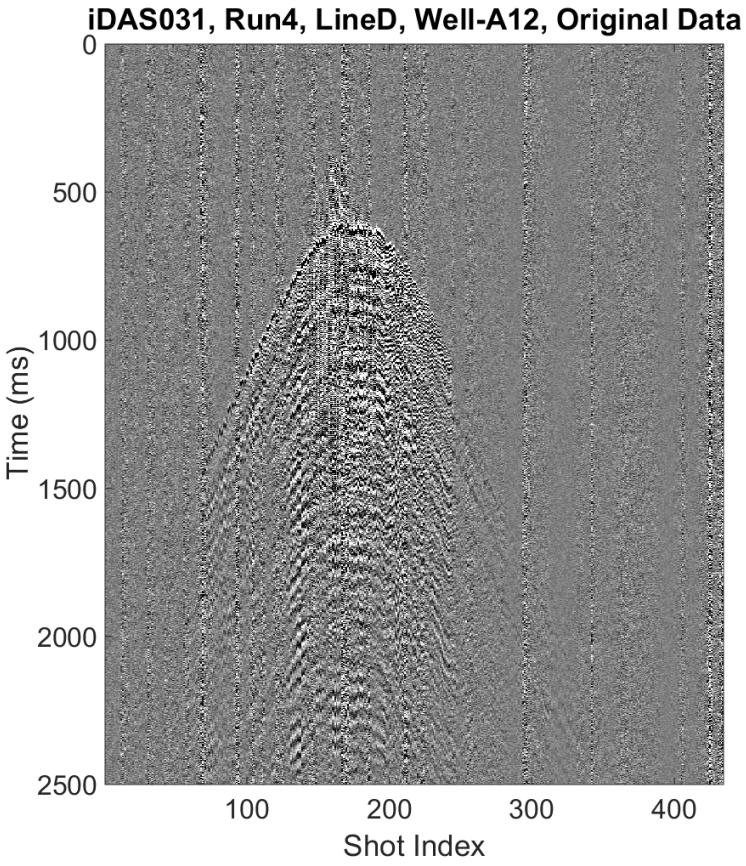


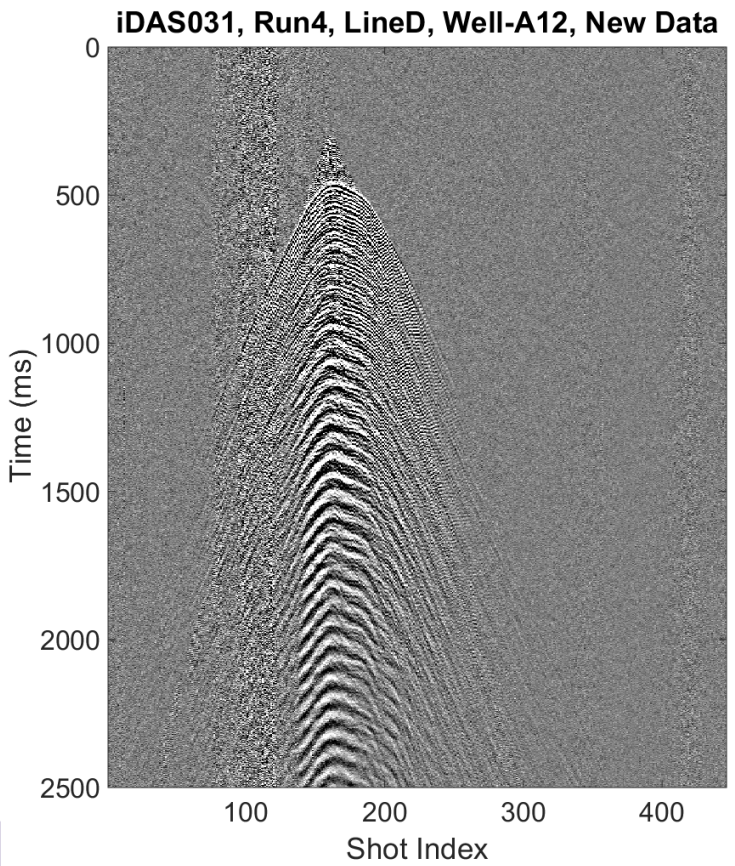


Common Issues

Timing problems

UTC vs GPS Timing
(or bad DAS timing sync with GPS)

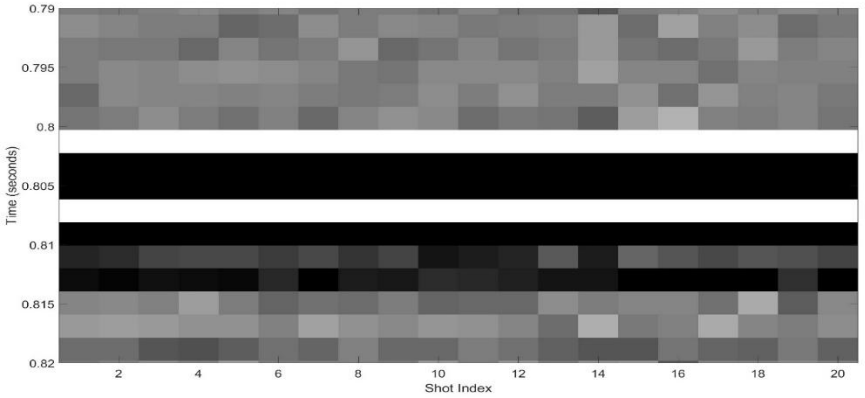




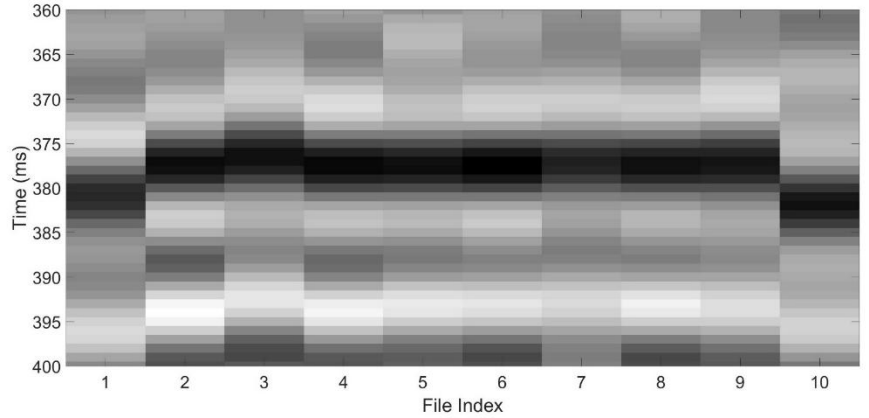
Triggering Issue

Receiver gather, single shot point, triggered

Good



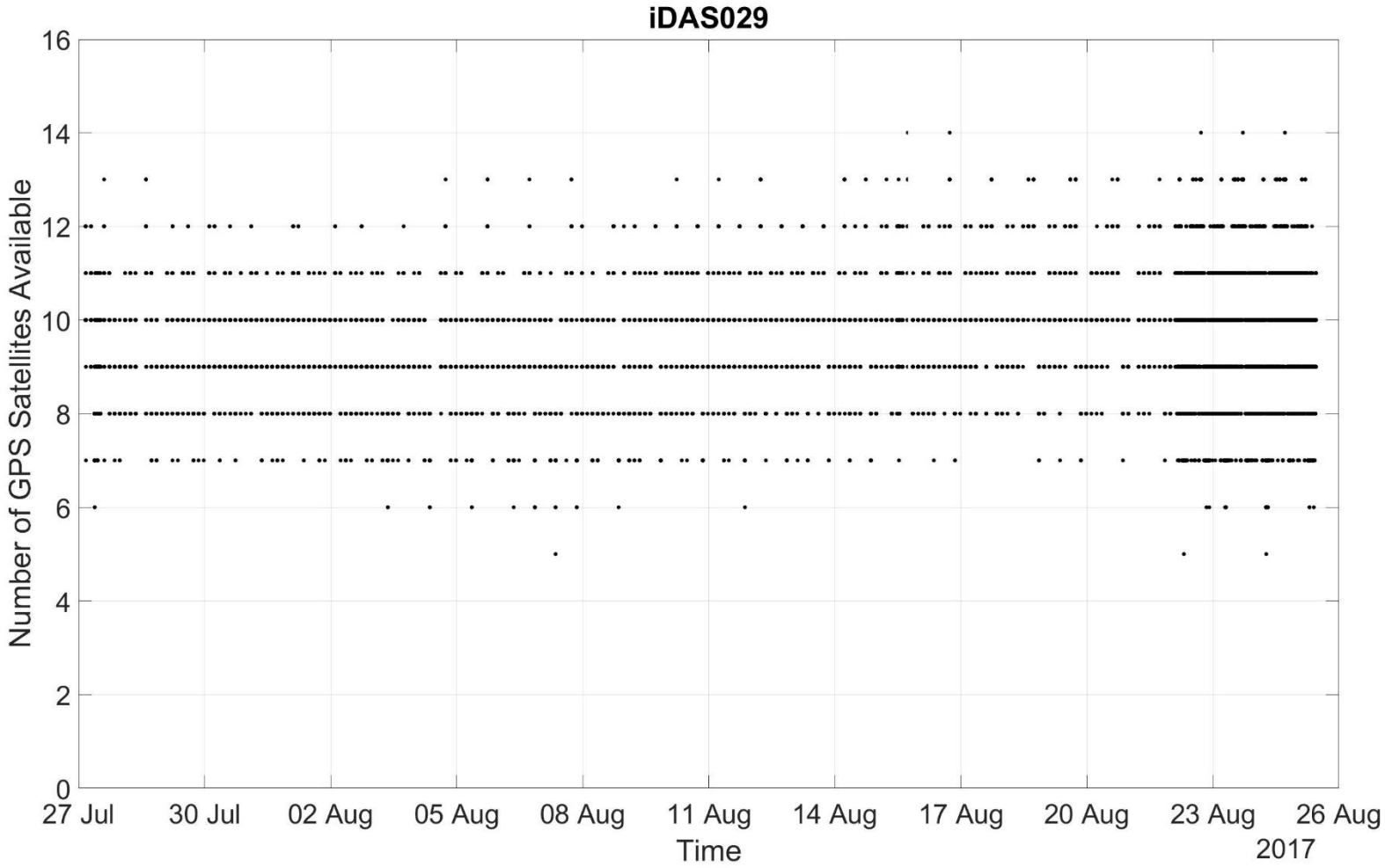
Bad



Common Issues

GPS Satellite Drop-Out

- This is a very rare issue but worth pointing out
- Plot Number of GPS satellites vs time (values stored in TDMS or PRODML headers)



Remote Limitations

Real-time Data visualisation bandwidth
- Waterfall heatmaps plot a lot of data and can often be too resource intensive to use over a slow internet connection
- Waterfall heatmaps are extremely useful in seismic for real-time QC so best practice is to monitor performance on a case-by-case basis
- If it is causing problems switch to a mode that doesn't use a waterfall heatmap and use static data viewers to intermittently check data quality

Comms with source
- It is vital to know what the source is doing at any given time to allow for good QC of the data
- This is harder to achieve on a land job as the source movements can be more random, i.e. not following straight lines
- Radio comms are normally used on site. However, if performing remotely the source company should periodically update source movements by email (or better, a messenger application such as Teams or WhatsApp etc)
- Concentrate on DAS QC and ensuring good data quality when comms is patchy

Observer Notes
- Normal practice is to ensure detailed notes about events throughout the day are recorded. Specifically noting any bad shots or abnormal noise in the area.
- This is impossible when no one is there in person. So important that the source company or a client rep on-site make notes

Remote Limitations

Losing remote access
- If internet or network access drops out it can be impossible to connect to perform any QC. This can throw up a few issues
- No knowledge if DAS is still recording
- No knowledge that the source is still shooting or that data quality is OK
- Notify the client and attempt to regain access as quickly as possible
- Have a plan in place for someone on-site to be able to assist in troubleshooting and restarting machines if necessary

Hardware shut down restart
- Turn it off and turn it back on again is a widely known fix for all problems
- Having someone on site who is aware they may be called on to restart machines (and supplying them with documentation on who to do this safely) is important
    - Note that this person may be busy with other duties so there may be a delay in them doing this. Make the client aware of this in the pre-job meetings
- Having equipment on a managed Power Distribution Unit can allow the power to be cycled remotely

Power failures
- Lots of sites have unreliable power supplies
- Once again, having a plan for how to turn on equipment in the event of a power failure is important
    - It is possible to make the interrogators and some processing machines turn on automatically. Set up and test this in pre-job
    - DAS can auto-restart the CTRL SW after a power failure in some circumstances

THANKS!

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

Geophysical instruments and data processing

Fibre optical cables (FOC) & installation types

- Frantisek Stanek

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

Outline

- Fibre types
- Connectors
- Cable types
- Cable installations & downhole components
- System architecture

Optical Fiber Handling Safety

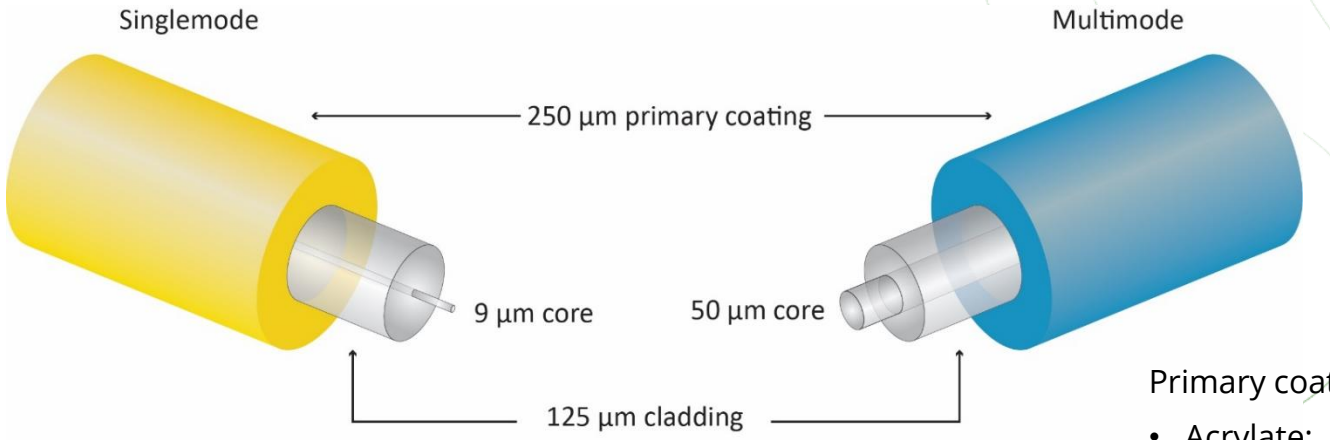
Hazards:

- ⚠ Optical fiber off-cuts can get embedded in the skin.
- ⚠ Optical fiber is brittle and breaks easily into small pieces.
- ⚠ Optical fiber is transparent which makes it difficult to spot.

Recommended best practices:

- ⚠ Account for all fiber off-cuts during splicing or termination process.
- ⚠ Use tweezers or tape to pick up fiber strands.
- ⚠ Sweep the entire fiber preparation area with tape to pick up any stray off-cuts before and after any splicing or termination work.
- ⚠ Dispose fiber off-cuts in appropriate sharps containers.
- ⚠ Keep food and drinks away from fiber preparation area.
- ⚠ Minimize skin contact with cleaning solvent, for example Isopropyl-alcohol (IPA), and be aware of any chemical safety requirements.

Optical Fibre: SMF vs MMF



Primary coating ambient temperature range

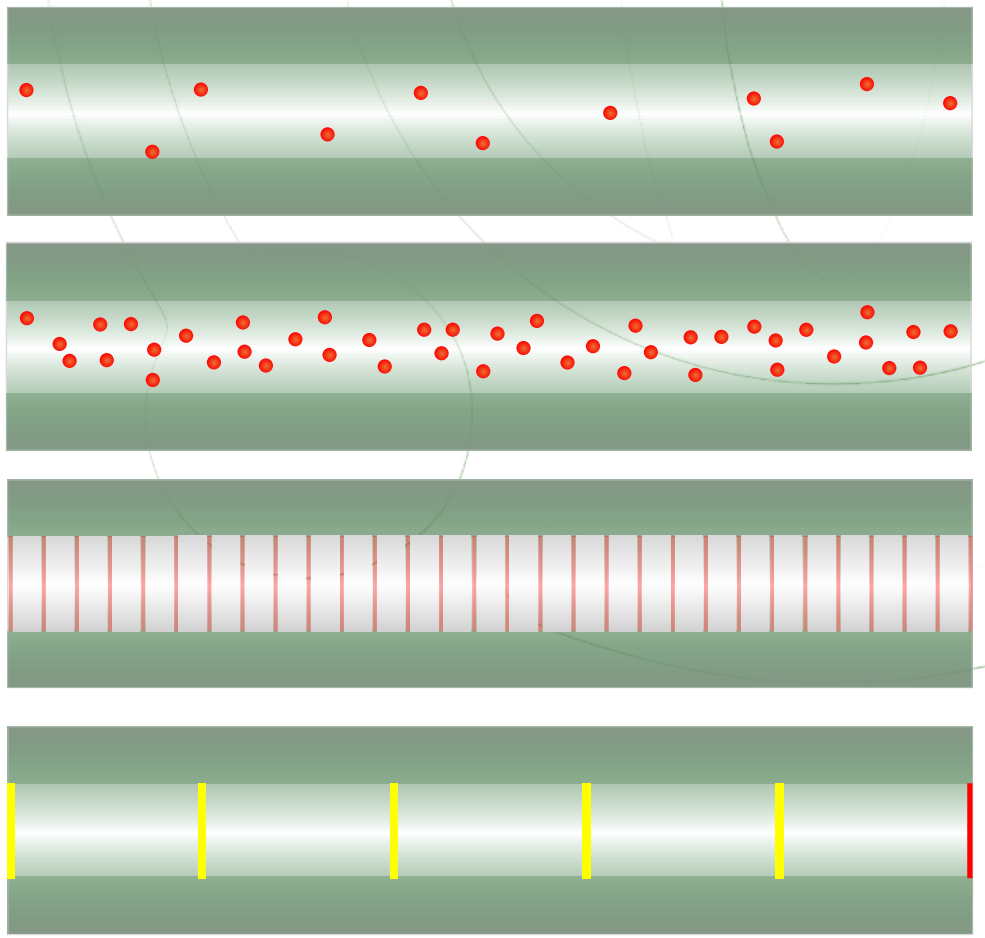
- Acrylate: -40°C to +85°C
- HT Acrylate: -40°C to +180°C
- Silicone PFA: -40°C to +200°C
- Polyimide: -180°C to +300°C
- Metal: -180°C to +650°C

Multimode typically used for DTS

- better system signal-to-noise ratio -> better temperature resolution.
- fibre connector losses are typically smaller.

Optical Fibre: Engineered

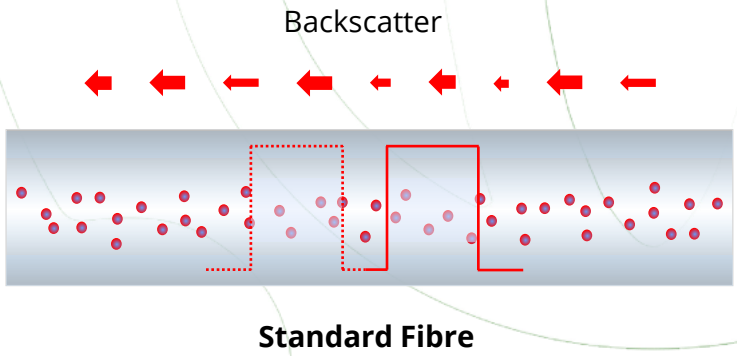
- **Standard fiber** – worst for signal, best for loss; uncontrolled phase relationship causes SNR variation (fading), which is an issue in some interrogator architectures
- **Highly doped fiber** – higher signal, but significantly higher loss increase
- **Continuous enhanced fiber** – much higher signal; reasonable losses but still uncontrolled phase relationship from multiple scatterers means there is a limit how the extra light can be effectively used
- **Engineered fiber** – much higher signal, reasonable losses and distinct scattering locations give control of the optical signal amplitude and phase: with the right interrogator, the extra light can be used to reduce the noise floor



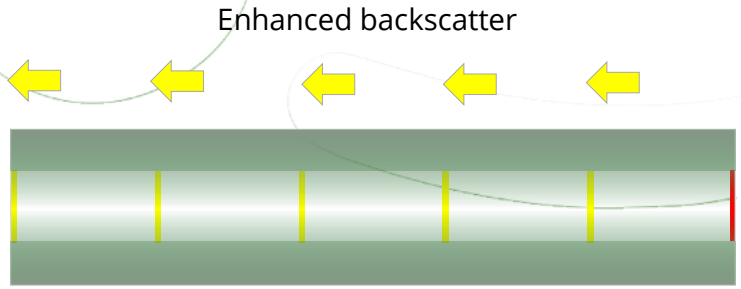
US Patent No. US 10,883,861 B2
EP Patent No. 3265757

Engineered Constellation Fibre

- 20 dB (100x) improvement in SNR when paired with Carina system
- Specifications can be tailored to the installation:
  - Engineered all along length, or just in region of interest
  - Increasing reflectivity to counteract losses
- Able to operate with multiple gauge lengths:
  - 2 m gauge length and above standard
  - 25 cm gauge length for specialist flow metering applications
- Multiple coating and core types:
  - Acrylate, silicone and polyimide coatings; carbon coating on the way
  - Germanium doped and pure silica cores
- Successfully tested for hydrogen resistance above 150°C



Standard Fibre



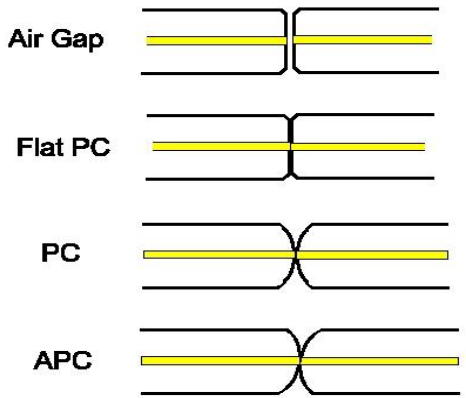
Engineered Fibre

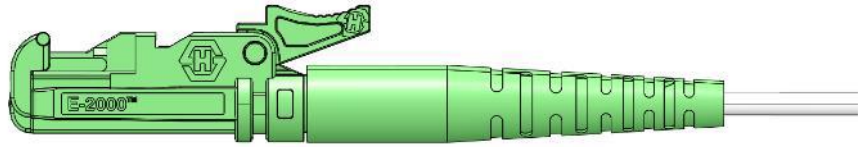
US Patent No. US 10,883,861 B2
EP Patent No. 3265757

Provides a **20 dB (100x) higher signal to noise ratio** than can be achieved on standard singlemode fibers.

E2000 Connector

Fiber optic cabling comes with several connectors and can have several different ferrule shapes or finishes.





Fibre Connection

Clean connectors every time.

1. Use the fiber optic cleaner to clean the connector attached to the measurement cable.

With the cleaner inserted in the connector, push cleaner in until it clicks and releases.

2. Remove the dust protection cap and use the fiber optic cleaner to clean the connector on the XT-DTS front panel.

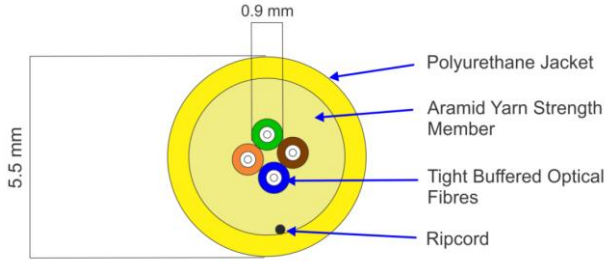
3. Plug the measurement cable into the XT-DTS front panel.

Cable types

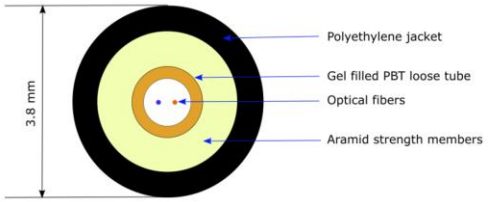
Durability

Low-temp → **High-temp**

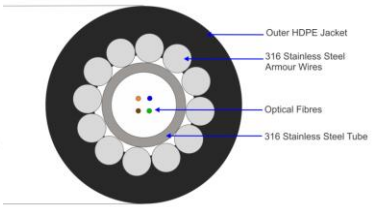
Tactical



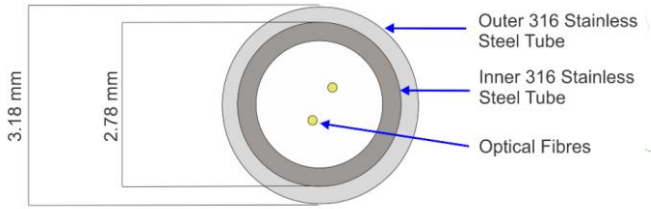
Loose Tube



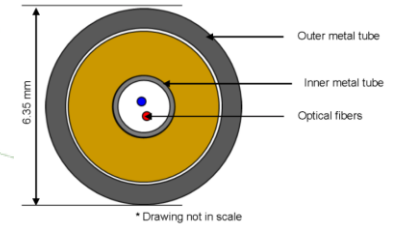
Armored FIMT



1/8” or 4mm Double-Tube



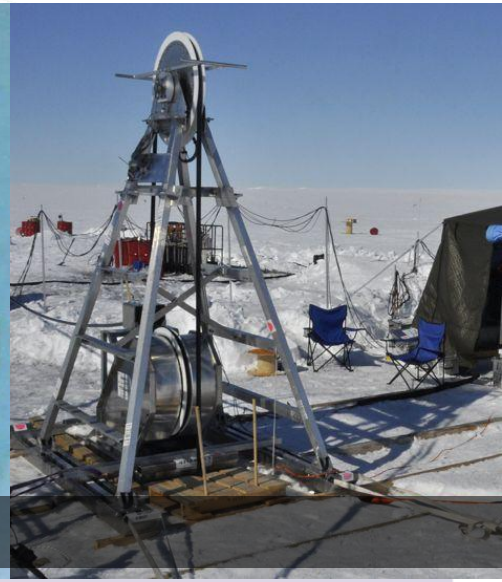
1/4” Downhole



....Or just use dark fibres in telecom networks

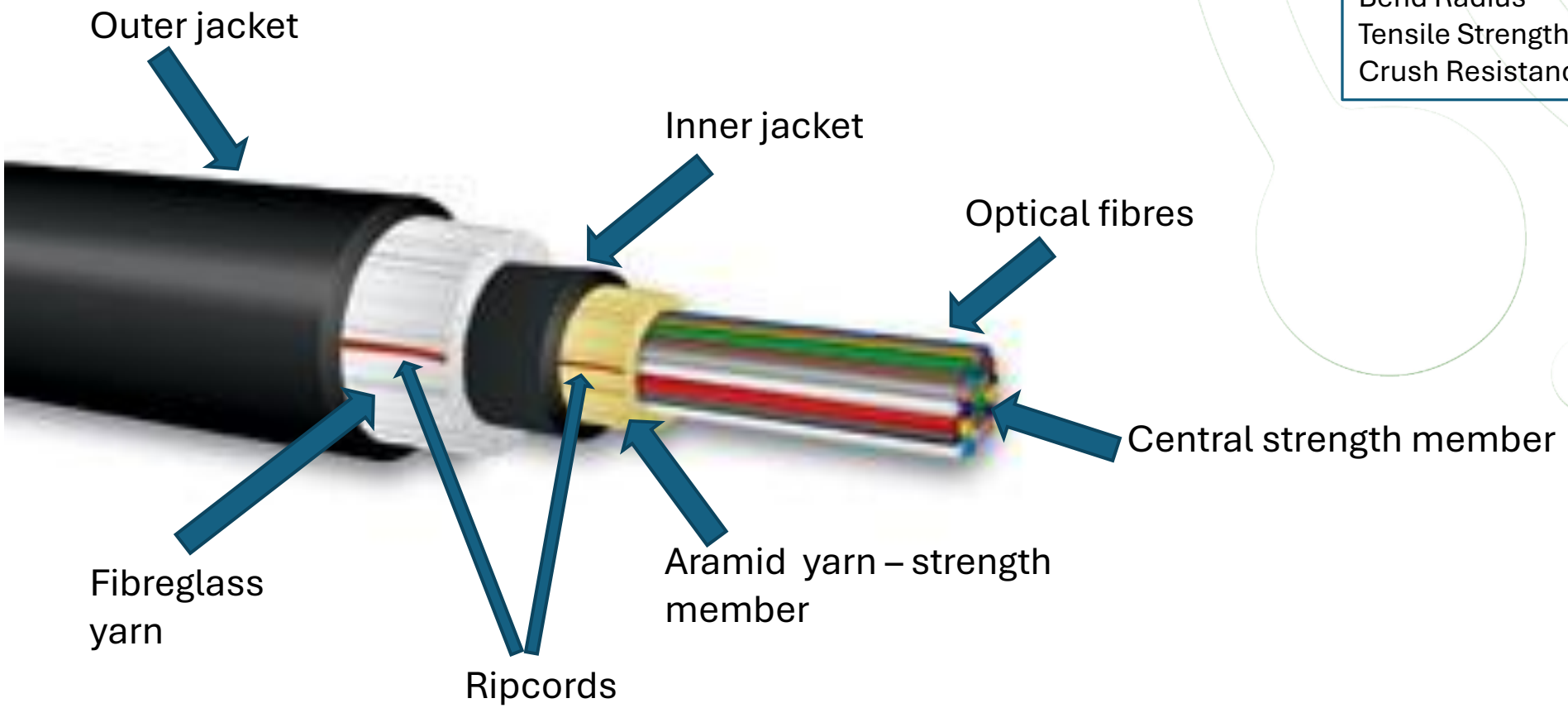
Surface

Downhole



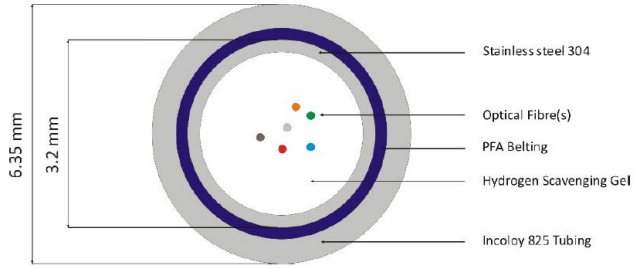
Fibre Optic Cable – Tight Buffered

Typical properties	
OD:	11mm
Bend Radius	11 cm
Tensile Strength	2,100N
Crush Resistance	1,800 N/cm



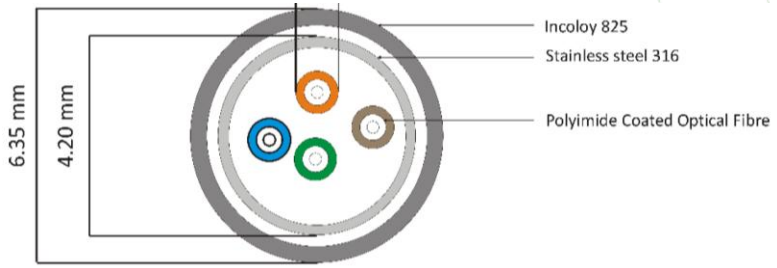
Downhole cables

High-temp – 260º C



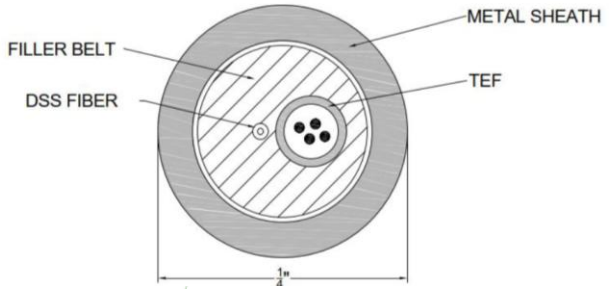
	ENTIRE ARMOURED CABLE
Nominal overall Diameter	6.35 mm
Approximate Weight	156.0 kg/km
Tensile Strength	10,904 N
Yield Strength	8,481 N
Strain at Yield	0.320%
Coefficient of thermal expansion	1.44E-05 m/m°C
Hydrostatic Pressure	121.1 MPa
Working Pressure	104.1 MPa
Dynamic Bend Radius	635 mm
Static Bend Radius	159 mm
Temperature rating	-40°C to +260°C
	METAL TUBING
Material	Stainless steel 304
Thickness tubing	0.2 mm
OD	3.2 mm
Material	Incoloy 825
Thickness tubing	0.89 mm
OD	6.35 mm

High-temp – 300º C



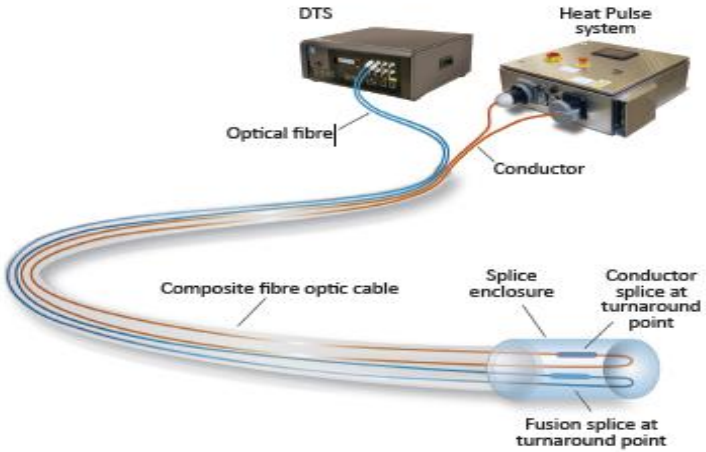
	ENTIRE ARMOURED CABLE
Nominal overall Diameter	6.35 mm
Approximate Weight	144.7 kg/km
Tensile Strength	10,904 N
Yield Strength	8,481 N
Strain at Yield	0.320%
Coefficient of thermal expansion	1.45E-05 m/m°C
Hydrostatic Pressure	121.1 MPa
Working Pressure	104.1 MPa
Dynamic Bend Radius	635 mm
Static Bend Radius	159 mm
Temperature rating	-40°C to +300°C
	METAL TUBING
Material	Stainless steel 316
Thickness tubing	0.2 mm
OD	4.2 mm
Material	Incoloy 825
Thickness tubing	0.89 mm
OD	6.35 mm

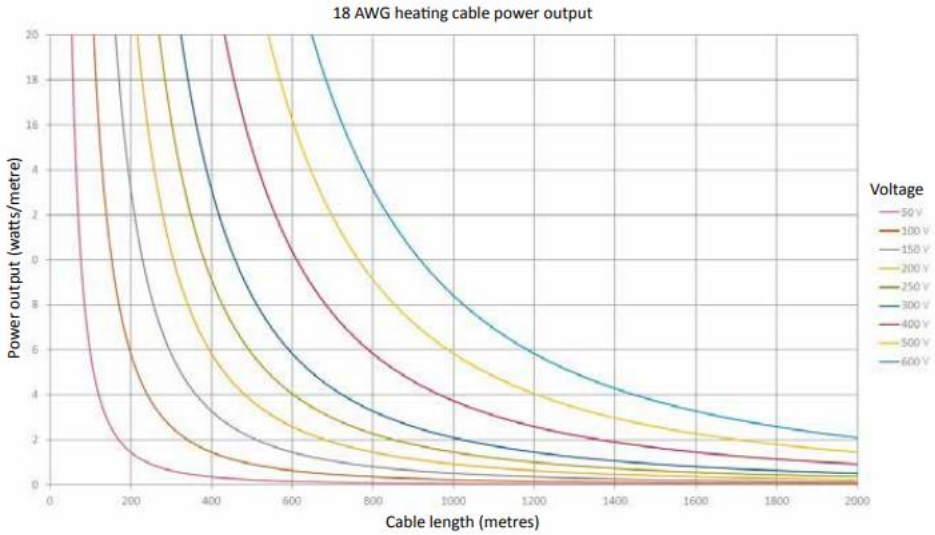
Special construction including DSS – 260º C



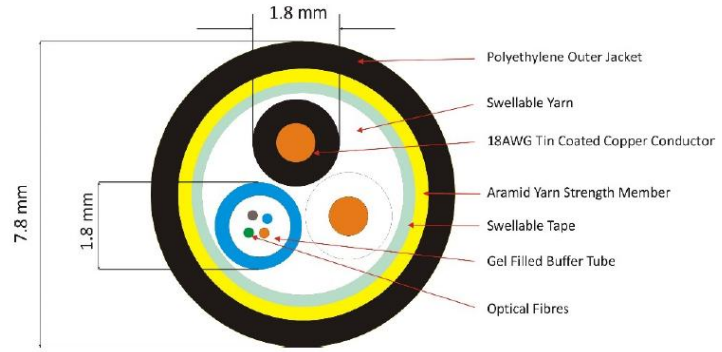
External Collapse Pressure	40,000 psi		
Temperature Rating	260 °C		
Fiber Type	Singlemode Carbon Polyimide		Silixa Constellation™ Pure Silica Core Polyimide
Fiber Count	4		1
Core Diameter	9 µm		9 µm
Cladding Diameter	125 µm		125 µm
Wavelength	1310 nm	1550 nm	NA
Maximum Attenuation	<1.0 dB/Km	<1.0 dB/Km	NA
Inner tube material	SS 316L		
Belting material	PP		
Outer tube material	SS 316L		
Nominal Diameter	6.4 mm (0.250")		

Composite Cables





Typical values:
1-2 W/m for atmospheric measurements such as wind speed
0-20 W/m for geothermal wells and shallow soil monitoring



Typical characteristics

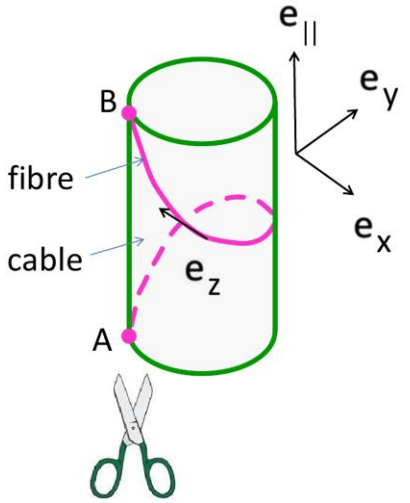
Fibre Code/Type	Multimode/OM3		Singlemode / ITU-T G.652.A2	
Fibre Count	2		2	
Core Diameter	50 µm		9 µm	
Cladding Diameter	125 µm		125 µm	
Wavelength	850 nm	1300 nm	1310 nm	1550 nm
Maximum Attenuation	3.5 dB/km	1.5 dB/km	0.5 dB/km	0.5 dB/mm

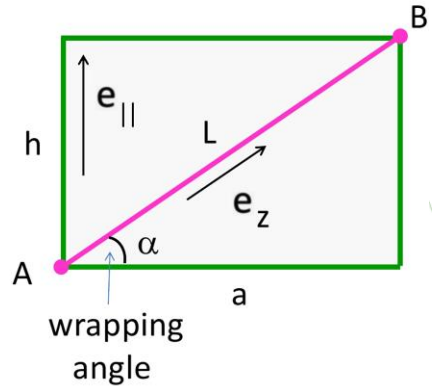
Mechanical Properties

Cable Diameter	7.8 mm
Total Cable Weight	60 kg/km
Installation:	
Max. Tensile Load	1,780 N
Min. Bend Radius	15.6 cm
Operating:	
Max Tensile Load	400 N
Min Bend Radius	2.8 cm
DC Resistance at 20°C	23.3 ohms/km
Voltage Rating	500 volts d.c
Operating Temperature	-40°C to +80°C
Storage Temperature	-40°C to +80°C

Power output cable with 2x18 AWG (American Wire Gauge)
Electrical resistance of 21.4 Ohms/ km for different voltages as a function of cable length.

Helically wound cables



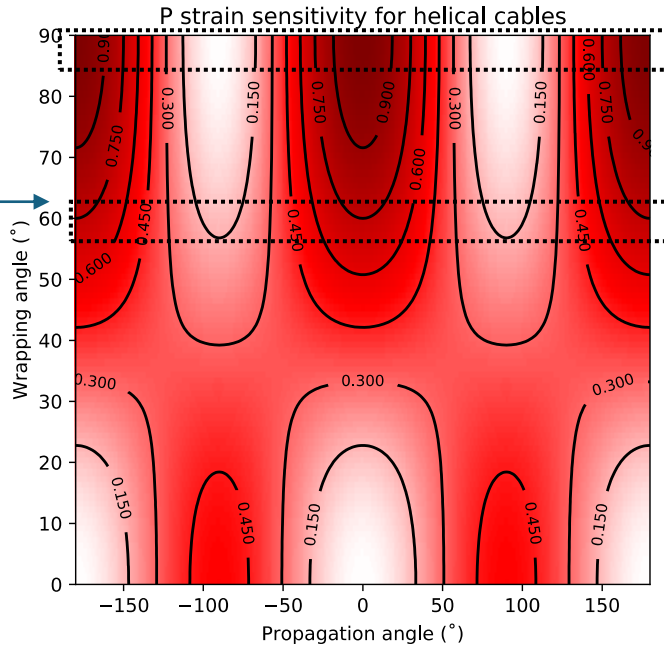


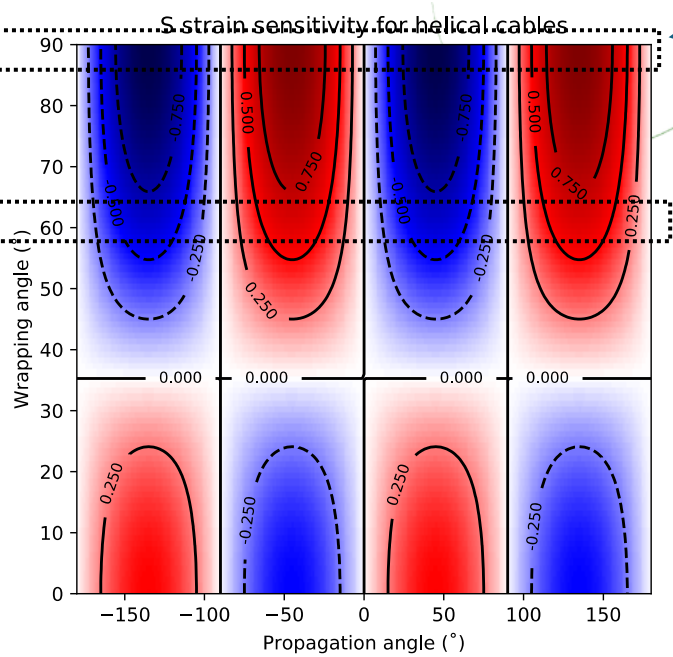
Linear fibre

HWC

S-wave
Lower response than linear

P-wave
More even response



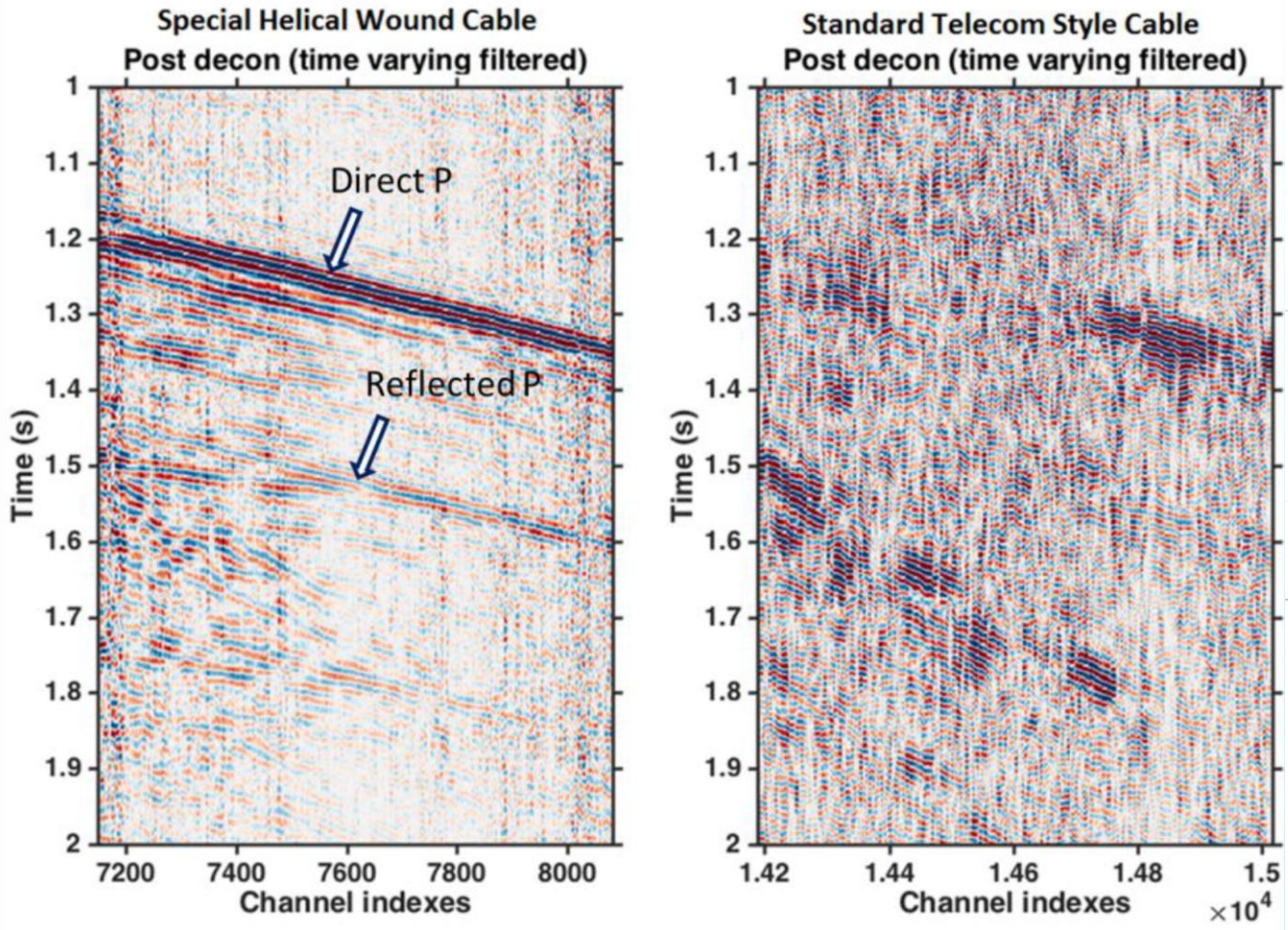


Baird, 2020

HWC case study: Archer Daniels Midland CCS (USA)

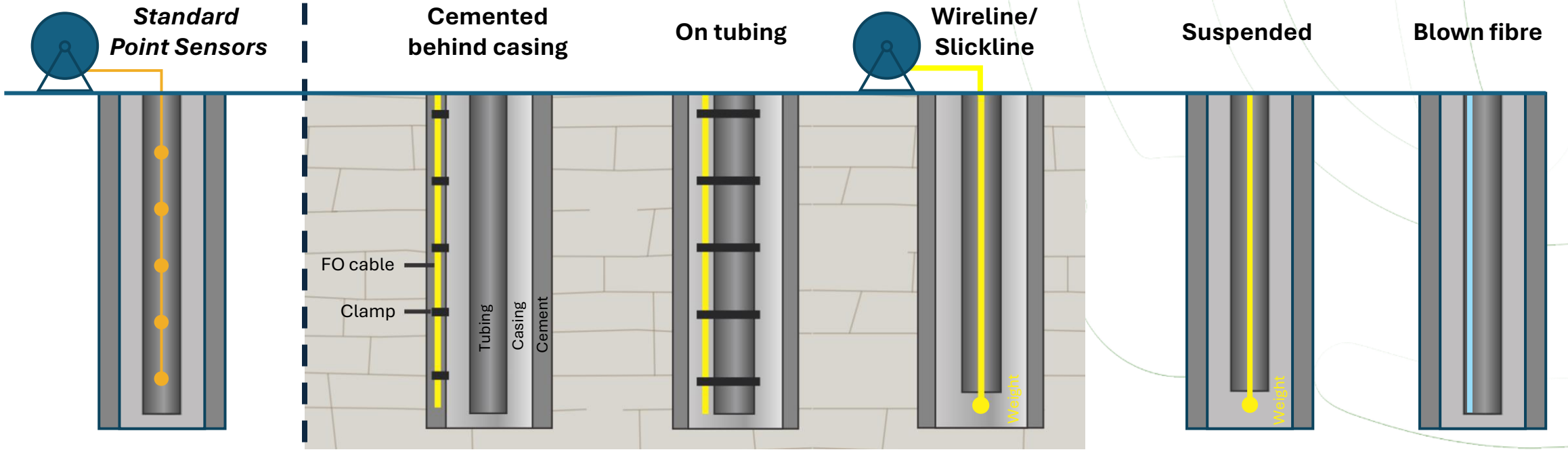
SOV – Surface Orbital Vibrator

Broadside sensitive cable



McDonald (2017), US Dept. of Energy data repository.

Downhole installation options



- Low coverage/ density
- High cost for higher temp
- High failure rate
- Need service

→ DFOS

- Permanent
- Good Coupling

- Semi-permanent
- Brown field development

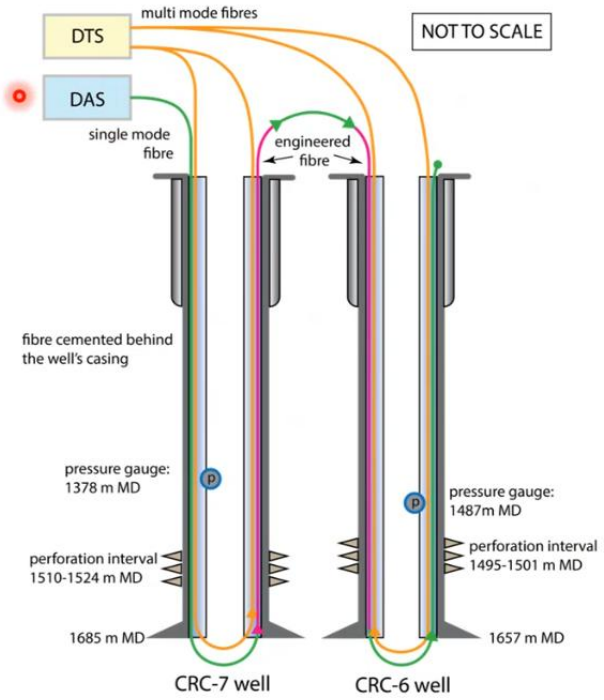
- Intervention
- Time-lapse surveys

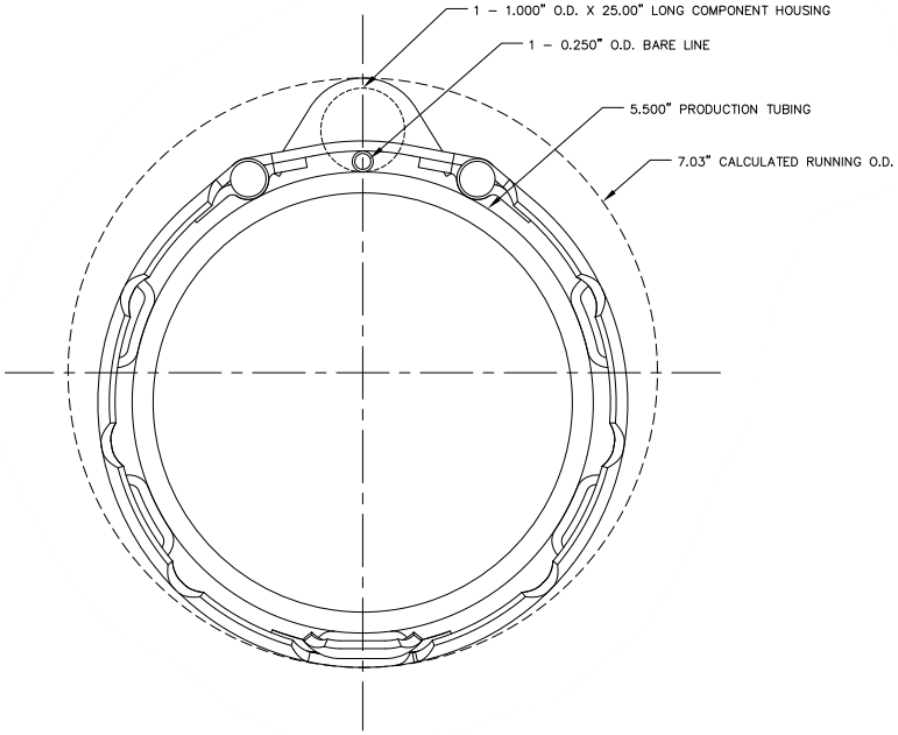
- Semi-permanent
- Time Lapse Surveys

- Corrosive & H_2-rich environments
- Fibre can be replaced

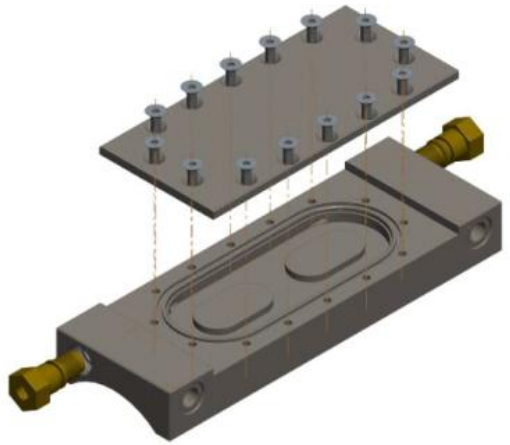
Downhole components

High Pressure Bottom Hole Assembly





High Pressure Downhole Splice Housing

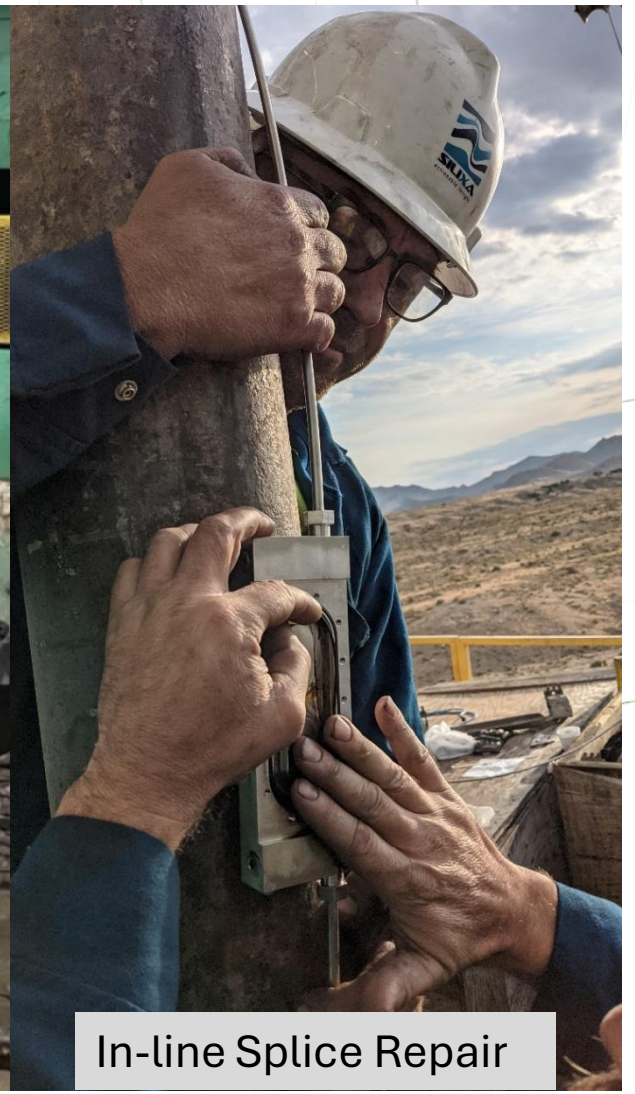


Cable Installation

Cable Installation

Bottom Hole Assembly Clamp

Welded Bar Centralizers and FOC

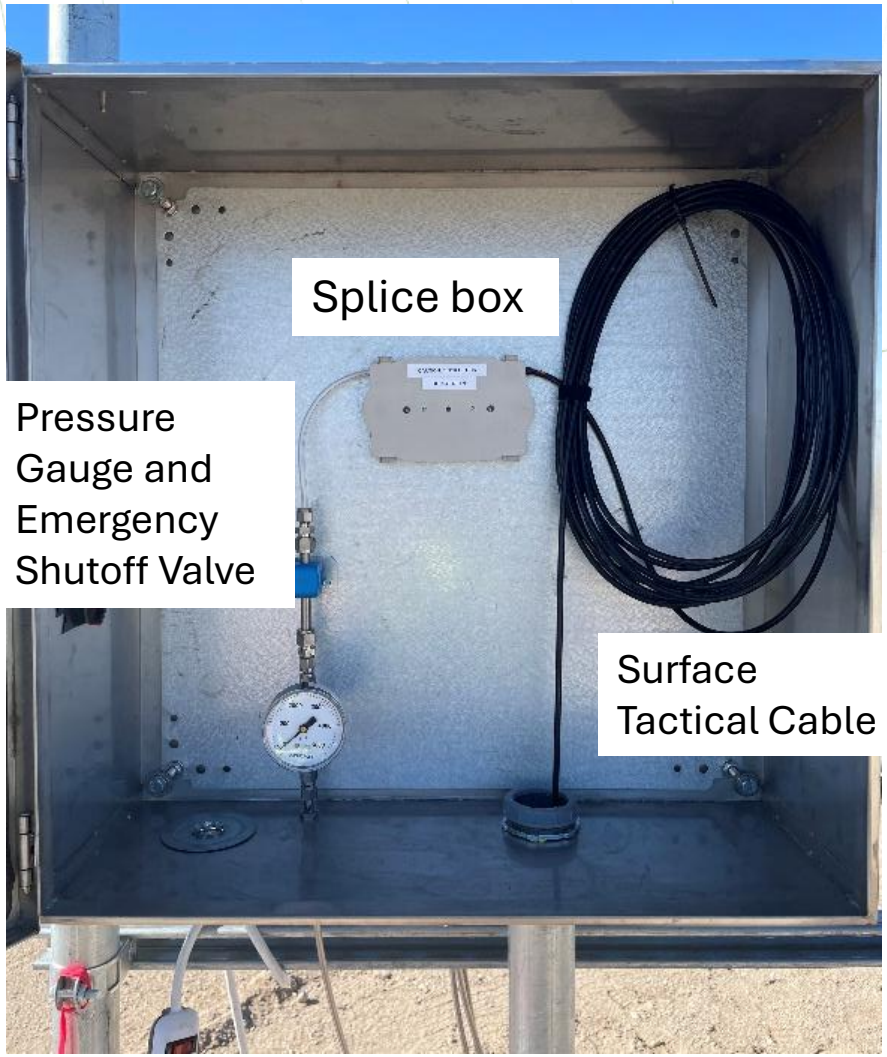


In-line Splice Repair

Example Fiber Optic Cable Surface Enclosure

Example Cable Trenching from Wellhead to Surface Enclosure

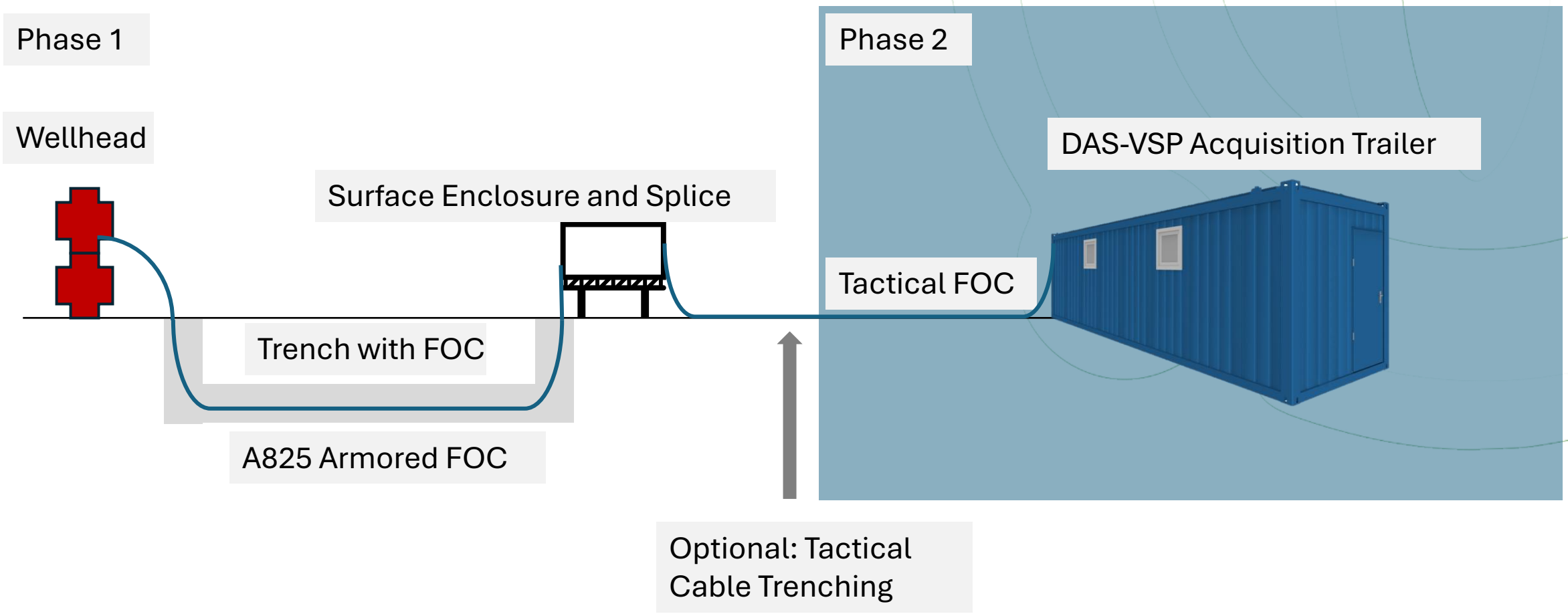
Example Cable Termination in Surface Enclosure with Spare Surface Cable



Example Completed Surface Enclosure

Silixa Surface Enclosure and Instrumentation

Example Completed Surface Enclosure



DAS-VSP Data Collection

Edge Monitoring Platform: System Architecture

Assembled

Instrumentation Cabinet

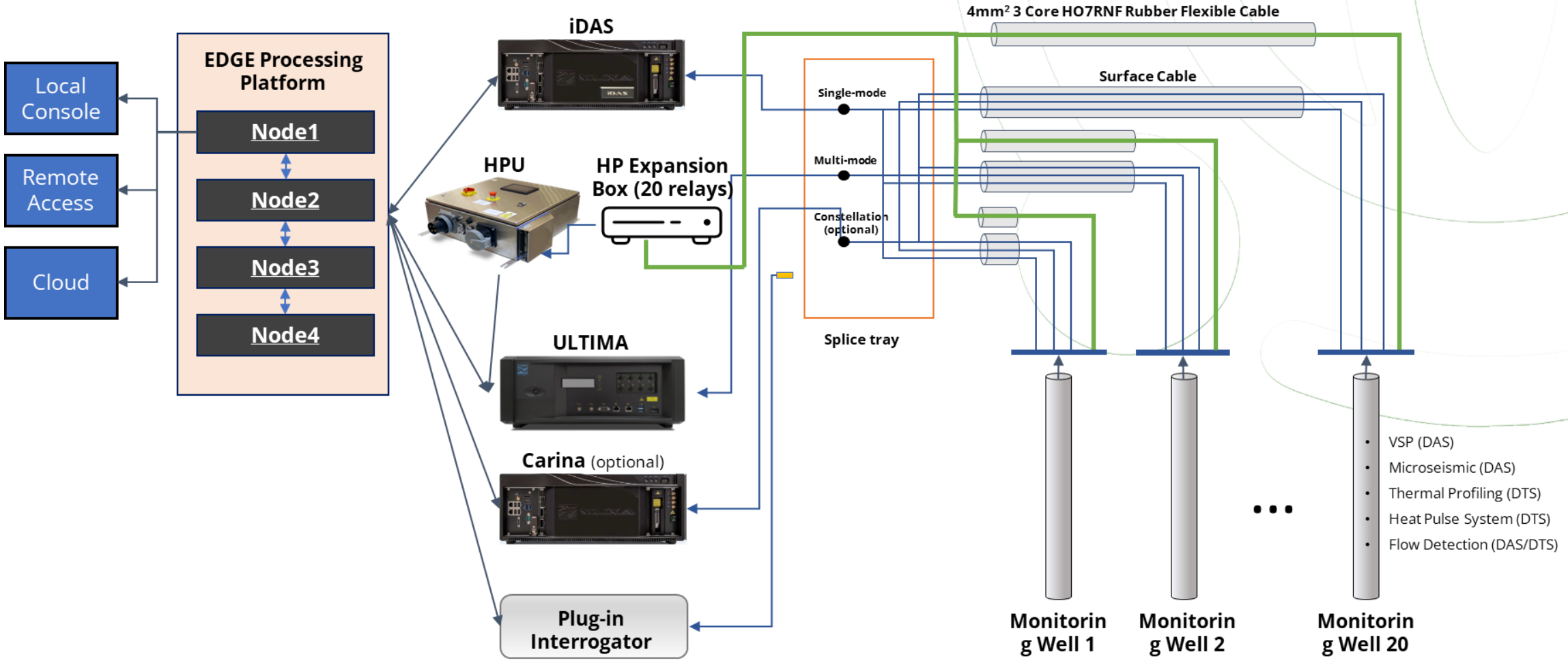
Processing Cabinet

On-Site Example

Front of Cabinet

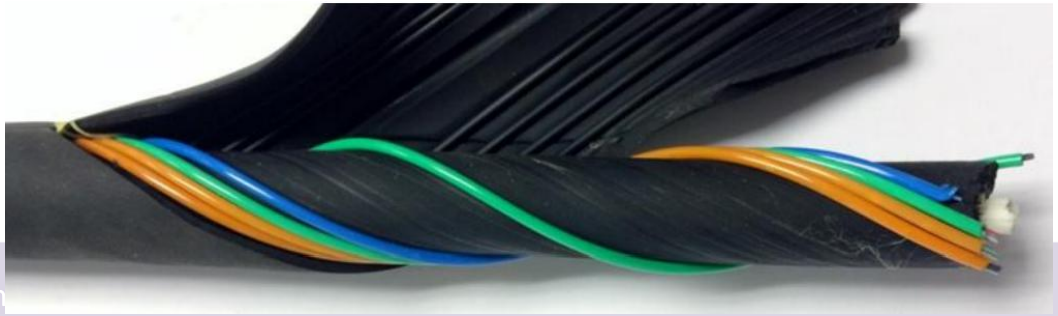
Cable Routing

System design & test



Surface Installations

(HWC) – Improve broadside P-wave sensitivity

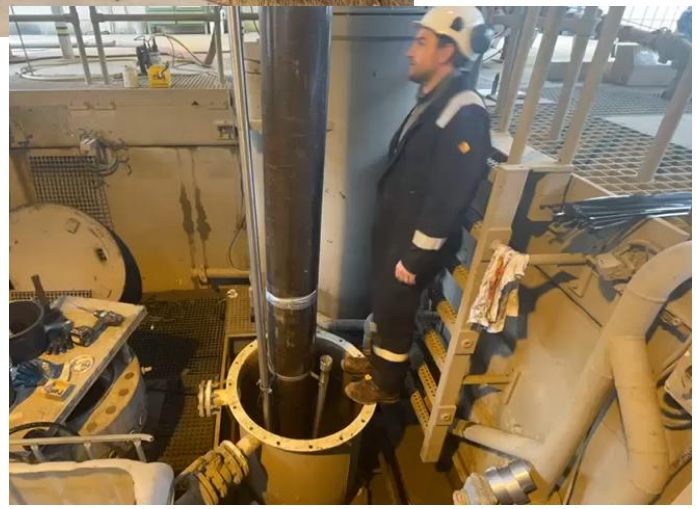


Surface Installations

Installation during Construction

Retrofit - Trenching

More Installation Types



THANKS!

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Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Geophysical instruments and data processing

DAS data curation and acoustic measurements

- Frantisek Stanek

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Introduction

1. DAS acoustic data uses
2. Data curation: ways of reducing data volume or preparing it for further analysis
3. Real-time display of curated data

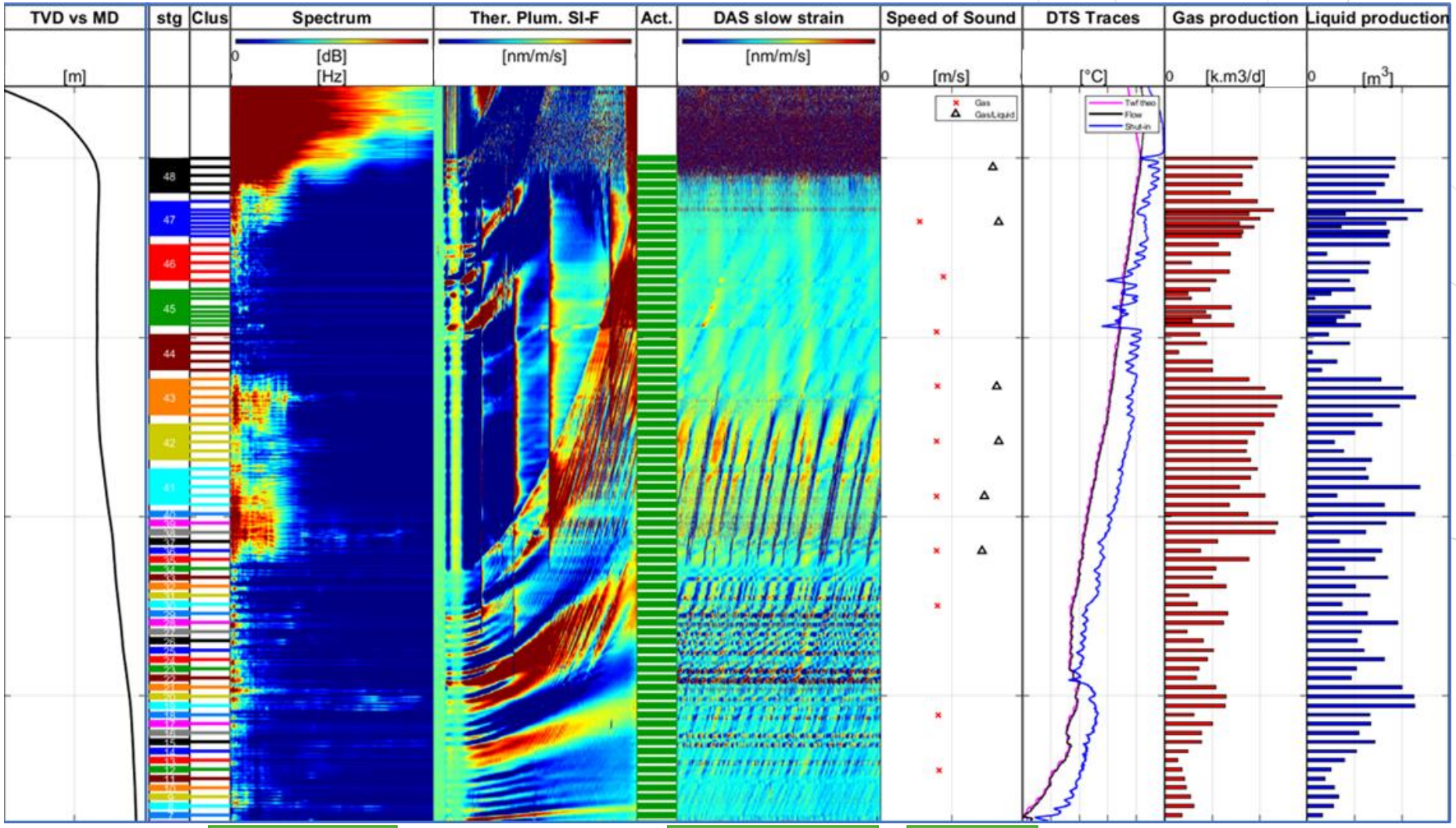
In-well Use Cases

Monitoring Objective	Measurements	DFOS	Benefits
Reservoir Characterisation	Continuous Temperature Profiling Time-lapse 2D & 3D VSP (seismic)	DAS, DTS	High SNR, coverage, spatial and temporal resolution Real-time, continuous data Easy access & high repeatability
Injection Optimisation	Flow allocation Hydraulic properties Well interconnectivity	DAS, DTS	Injection performance monitoring Regulation compliance
Well Integrity	Leak detection Cementation monitoring	DAS, DTS	Operational safety Regulation compliance
Microseismic Monitoring	Microseismic event detection Fracture evolution monitoring	DAS	Operational safety Regulation compliance Public acceptance
Deformation Monitoring	Pressure development Reservoir deformation (uplift / subsidence)	DAS, DSS	Operational safety Regulation compliance Public acceptance

Other Use Cases

Earthquake Monitoring
Structure monitoring
Ground water monitoring

DAS Acoustic Data



Frequency vs Distance

Low Frequency DAS

Speed of Sound

Data curation

- Units
- Filtering
    - Common Mode Noise removal
    - Basic filtering
- Basic Data reduction techniques
    - Cropping + Decimation
- Calculating metrics
    - Low Frequency DAS
    - RMS frequency bands
- Frequency domain
    - Frequency
    - Speed of Sound

Examples of ways to work with DAS data

What are the units of amplitude?

- iDAS directly measures a change in phase of the backscattered light

- For a single channel (receiver position) the native iDAS measurement gives:
  - The total **phase change** over a gauge length
    - Longer gauge length systems will report a higher amplitude
  - At the rate of change over one time sample
    - Higher sampling frequencies will report a lower amplitude

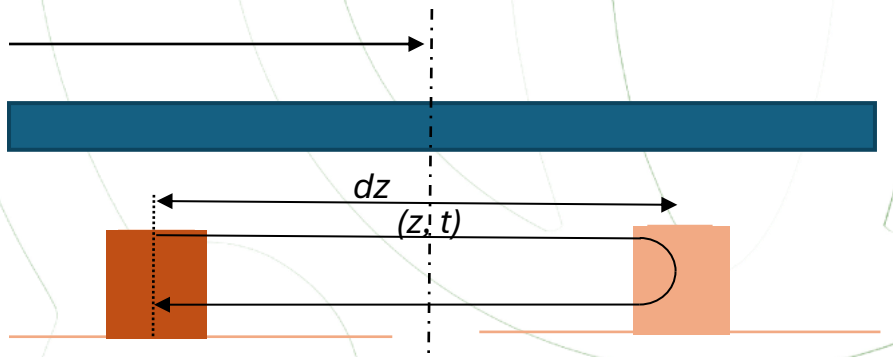
- The optical to acoustic conversion must be very fast so is done in a hardware FPGA module on-board the iDAS. These work best on integer arithmetic

- Also, **integers** are much smaller to store in a file than floating point (decimal) numbers

- To work in integers without losing precision the iDAS values are scaled up by a factor

- These scaled values are the values that are saved in TDMS and PRODML files

- Engineers want the amplitude of iDAS data to tell them what the physical extension of the fibre is and express that extension in standard units



What are the units of amplitude?

- For accurate comparison of data, or in order to provide data in engineering units, the data must be scaled

- There are two steps to this process

1. **Remove the scale factor** applied to turn the data to integers. This converts the values to a strainrate value that is phase change per gauge length, per time sample

    - Scale factor = $\frac{1}{8192}$

    - The scale factor is a multiplier. The data should be multiplied by this factor after loading to convert to the required units

What are the units of amplitude?

- For accurate comparison of data, or in order to provide data in engineering units, the data must be scaled

- There are two steps to this process

2. **Convert to engineering units**. The standard units are nm/m/s. nm/m is sometimes called nanostrain.

    - Instead of total strainrate over a gauge length, we want to normalise this to total strainrate per metre
        - To do this, divide by the gauge length

    - Instead of total strainrate in a time sample, we want to normalise this to total strainrate per second
        - To do this, multiply by the sampling frequency

    - Instead of a phase change in the backscattered light, we want the elongation of the fibre
        - The standard value that relates 1 radians of phase change to 1nm of fibre elongation = 116

    - Therefore, the overall equation for iDAS values that have had the previous scale factor applied

$$strainrate\left(\frac{\frac{nm}{m}}{s}\right) = 116\ x\ iDAS\ values\ x\ \frac{sampling\ freq\ (Hz)}{gauge\ length\ (m)}$$

Data Reduction Techniques: Cropping and Decimation

Original Data

Lots of DAS data is oversampled, especially in distance e.g. 1m sampling with 10m gauge length

It is common to record parts of the fibre that are not interesting

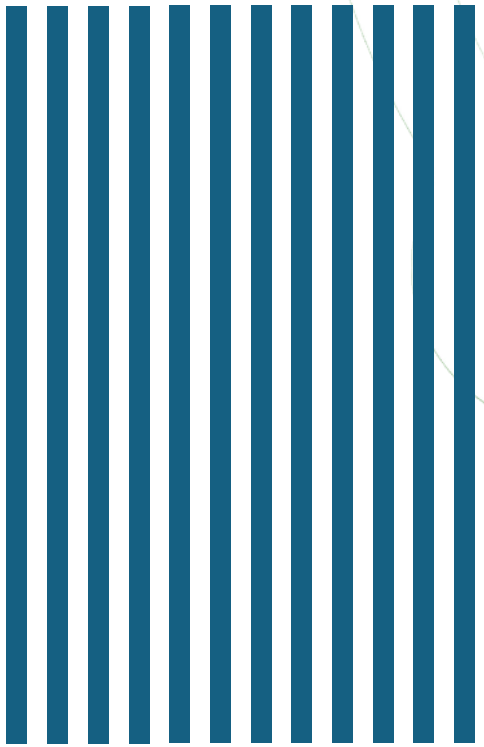
d

t

Cropping (distance)

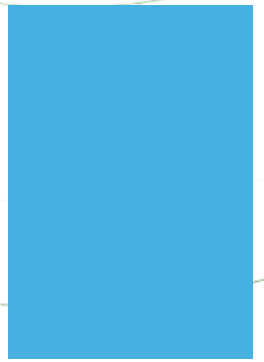
Cut off the unnecessary parts of the fibre

Decimation (time)



Decimation (distance)

Final smaller data

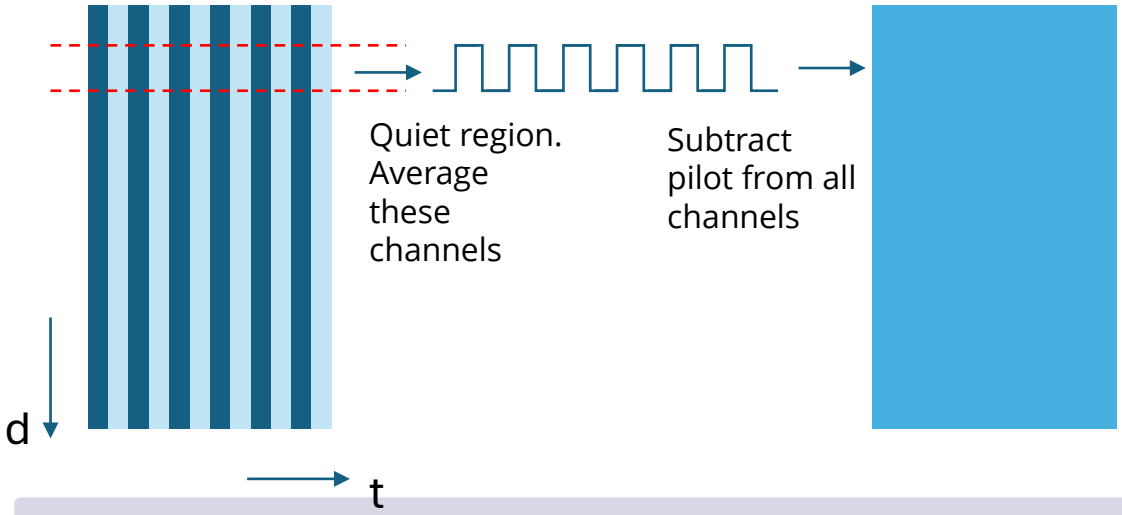


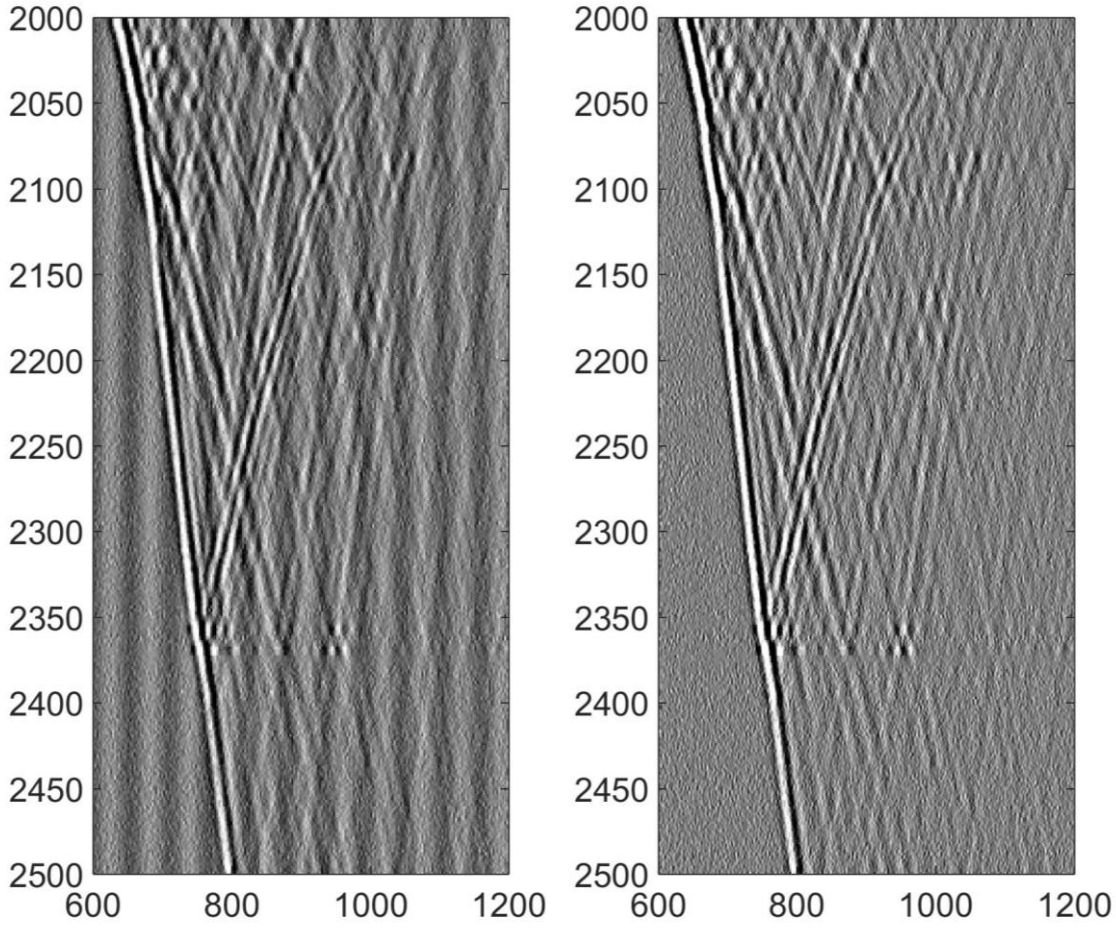
If oversampled, decimation (with or without averaging) can be used to reduce data size

Use anti-aliasing filters if possible, to avoid aliasing effects

Filtering: Common mode noise removal

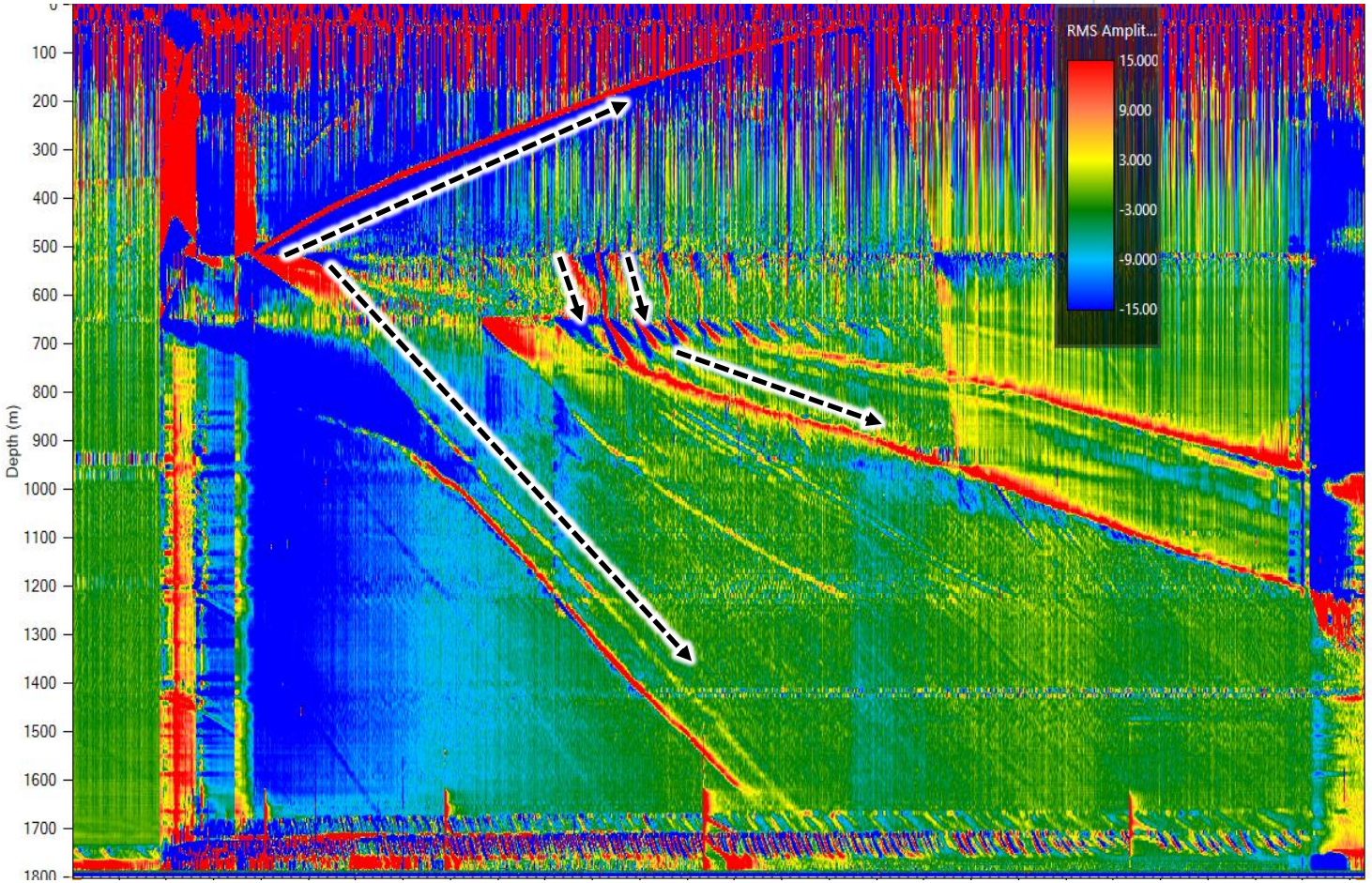
- Common mode noise is caused by vibration of the interrogator box
- The effect is a pattern of stripes in the data where the vibration signal is seen at the same time on all other fibre receiver channels
- Can be easily removed by creating an estimate of the vibration signal (normally by averaging a few channels in a quiet region of the fibre), and then subtracting that signal from every channel





Data Reduction Techniques: Low Frequency DAS

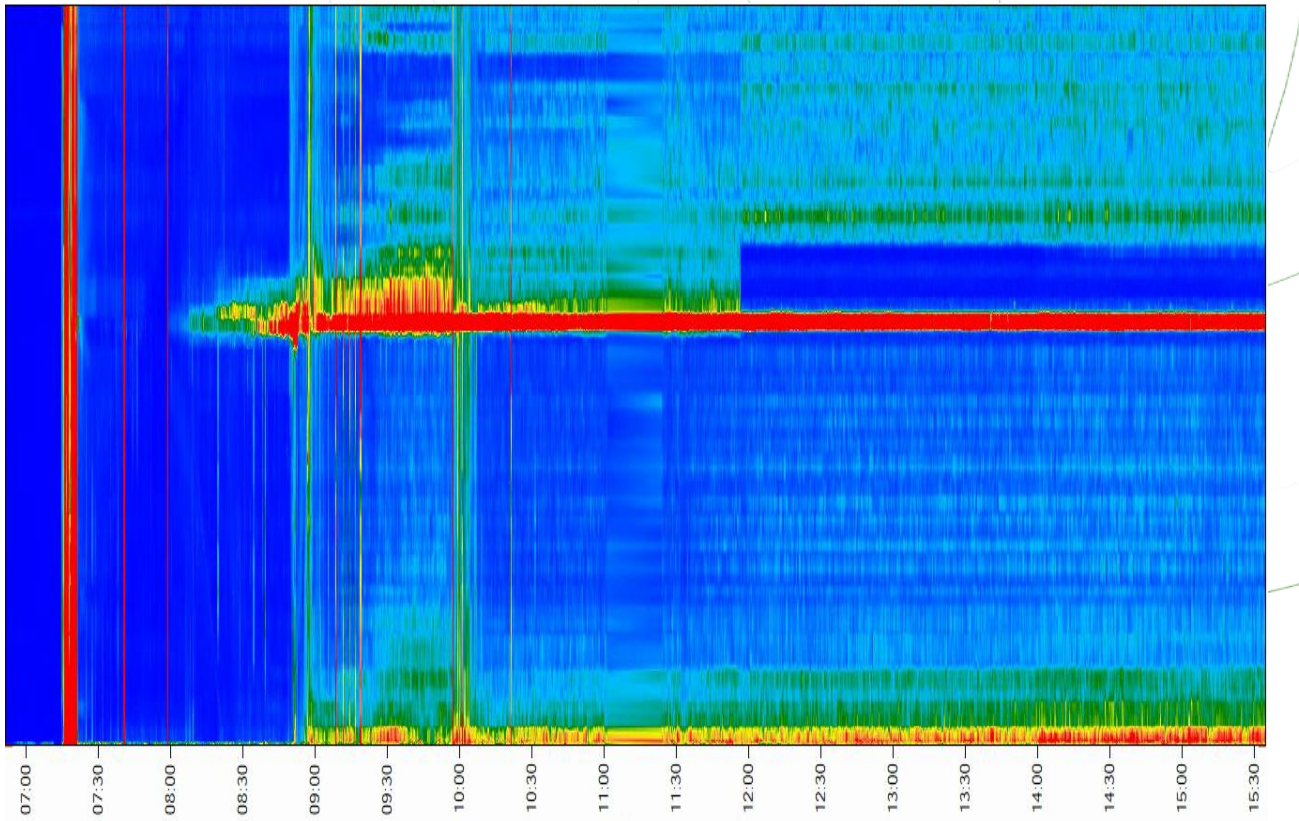
- Low pass filter and average
- Sub-Hz frequencies are visible
- Can track very low frequency strain changes caused by thermal or pressure effects
- Others have used the sea tides as a seismic source



RMS Frequency Bands

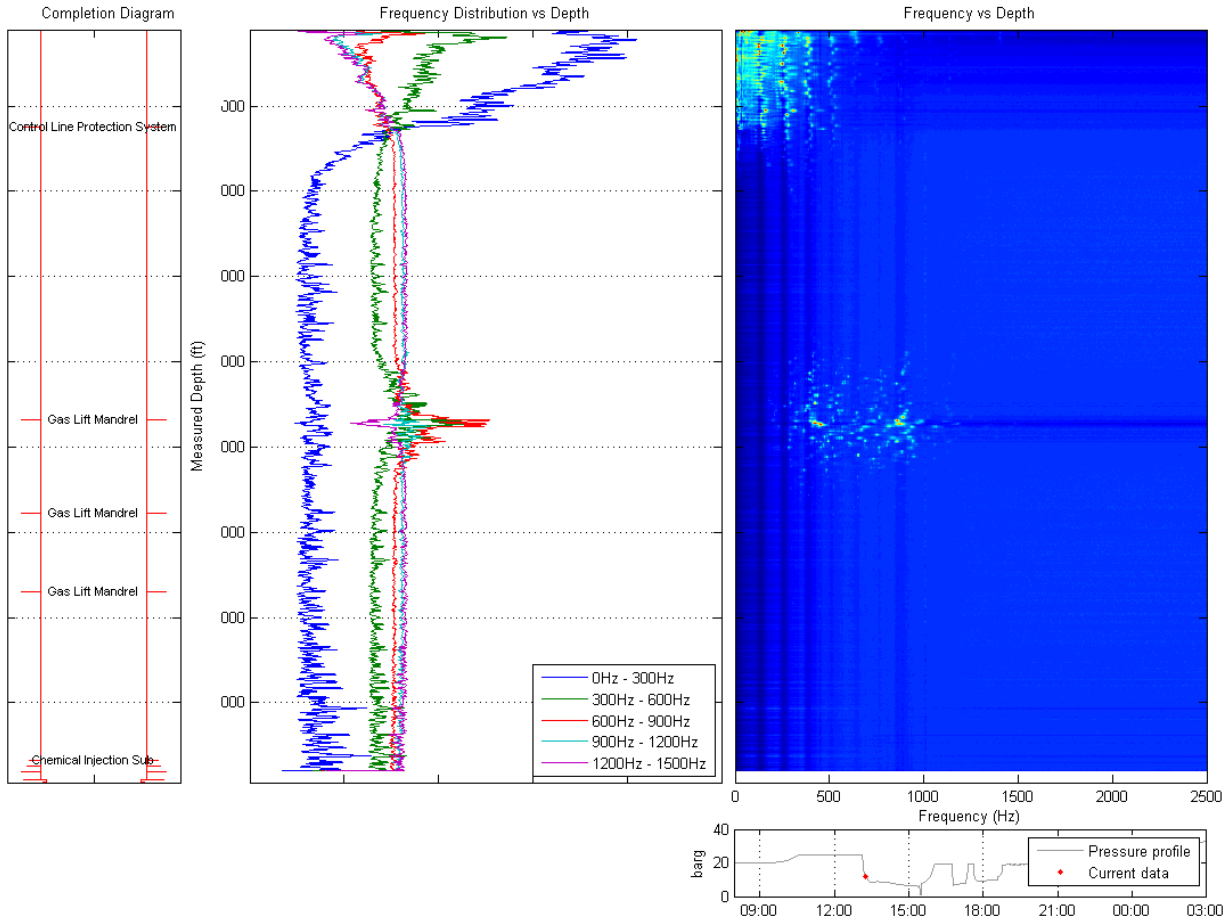
- Take the FFT of the data over a chosen time window (e.g. 1 sec) for every channel
- Do this for every 1 second window in the acquisition
- Divide the FFT into frequency bands e.g.
  - 0-1Hz
  - 1-10Hz
  - 10-100Hz
  - 100-1000Hz
- Within each frequency band calculate the RMS value
- Much smaller data that still contains frequency content information
- Caution! RMS saves the amplitude only, phase information is lost
- Be careful with amplitude units

0-100Hz band energy



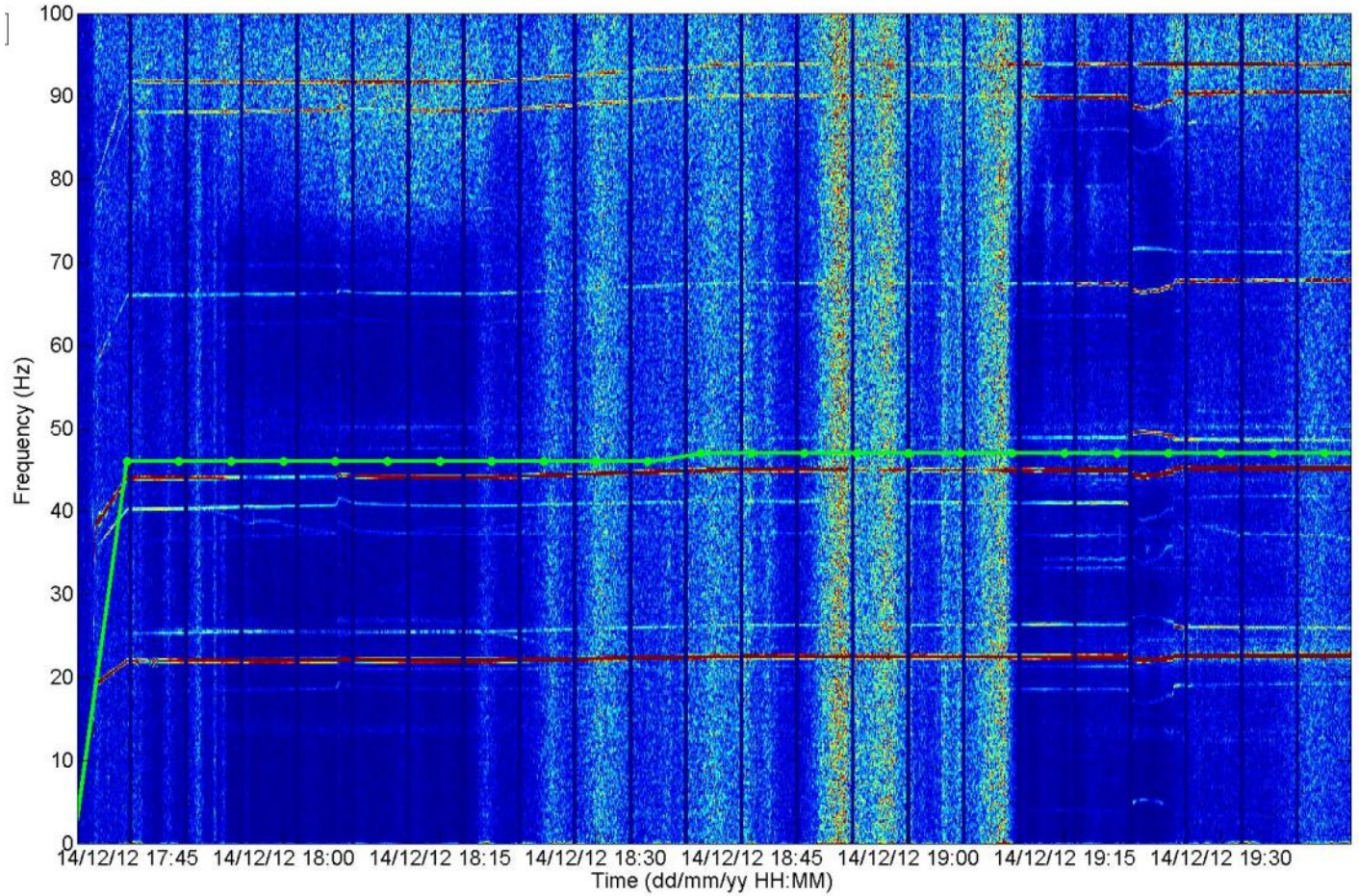
Frequency Domain: 1D-FFT vs depth

- Looking at the full frequency spectrum is very useful
- Small signals masked by higher amplitudes in other frequencies can be found
- Take the FFT vs all depth channels
- Plot as a 2D heatmap image
- Better for snapshots in time, because the 2D data is still quite large



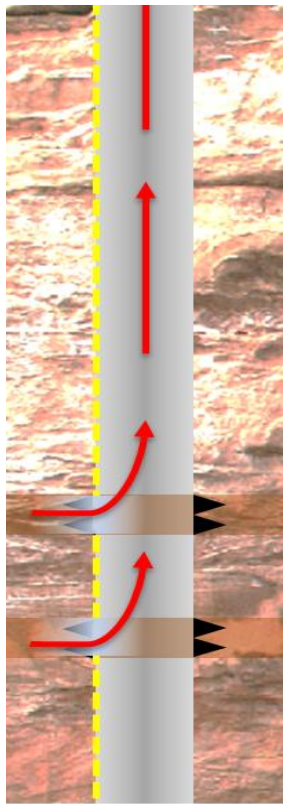
Frequency Domain: Spectrogram

- Frequency vs time
- Take a single receiver channel divide into small time windows
- Calculate the short time FFT
- Plot these next to each other to create a time history of the frequency content at that location
- Useful for monitoring changes over time in a single location
- E.g. downhole gauges, valves or pumps

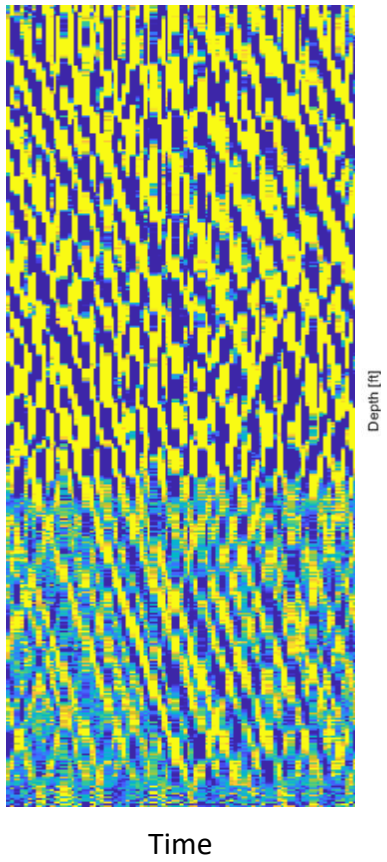


Methodology – Speed of Sound analysis

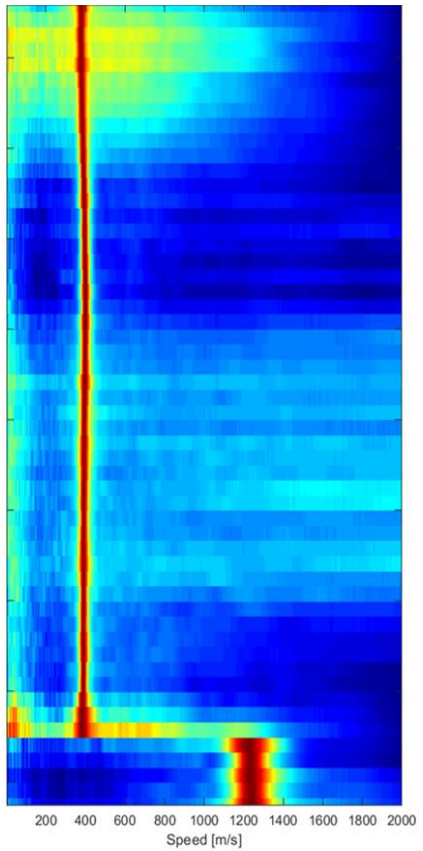
Well schematic

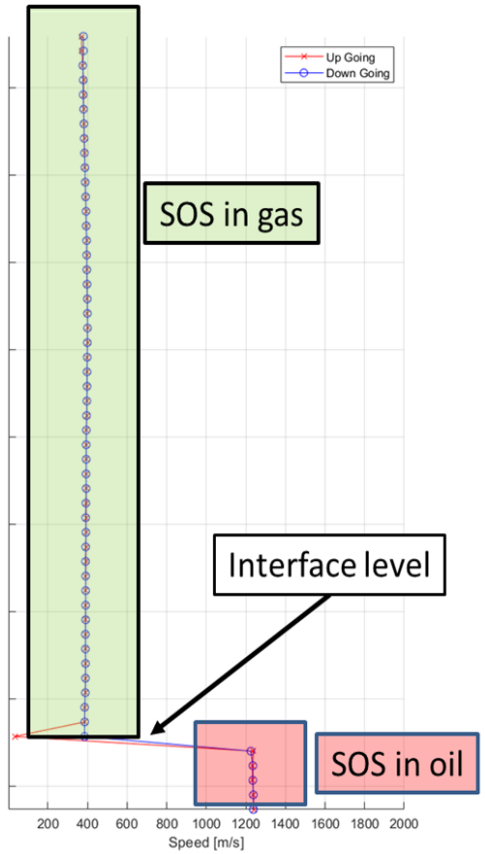


Acoustic waterfall

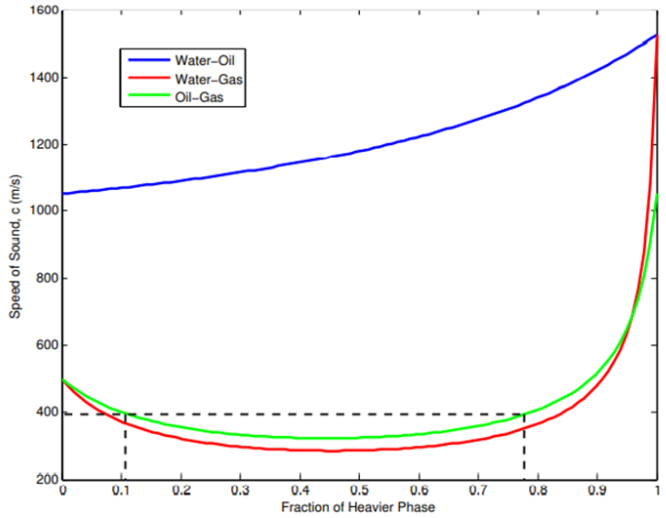


Speed of Sound



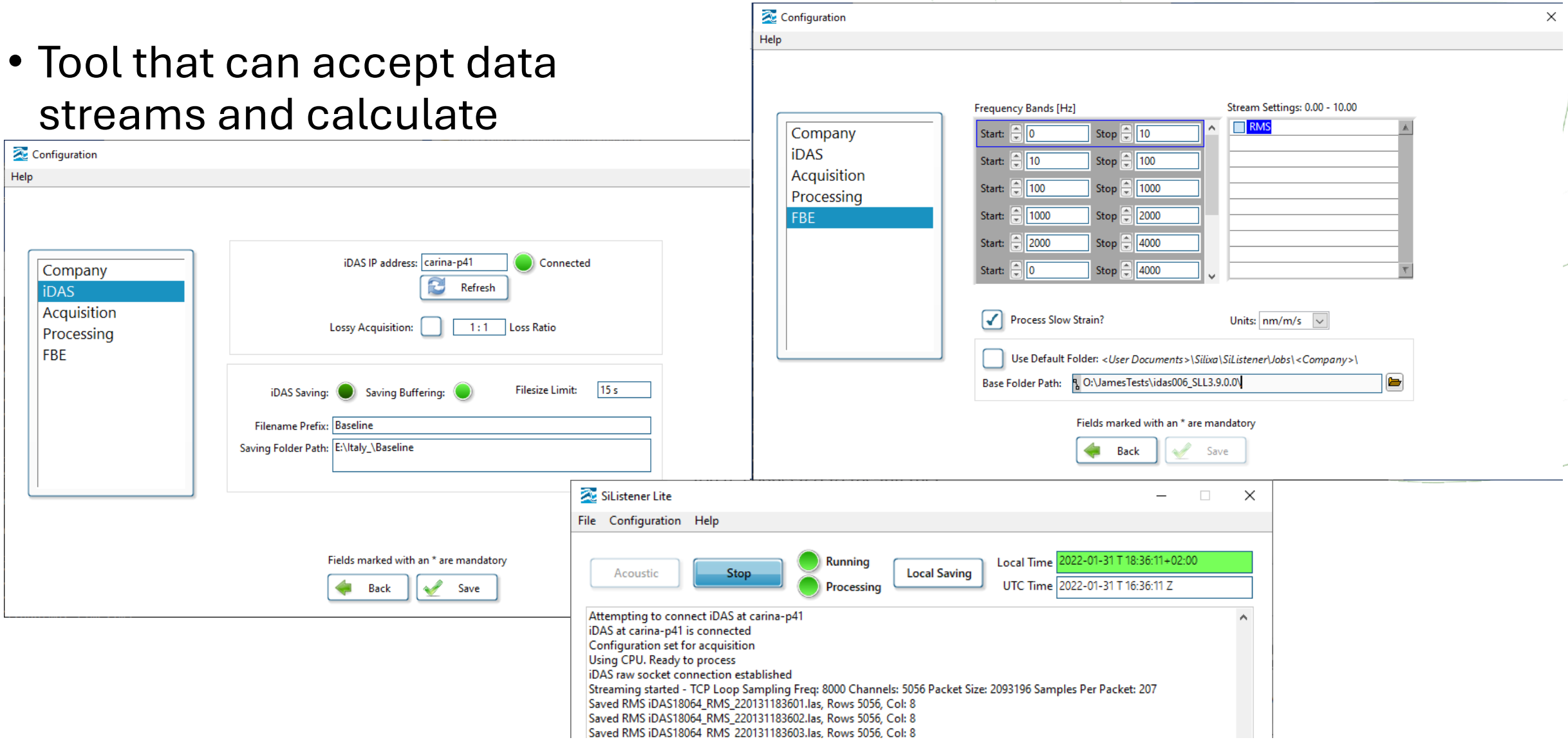


- Fluid composition and profiling
- Interface level detection



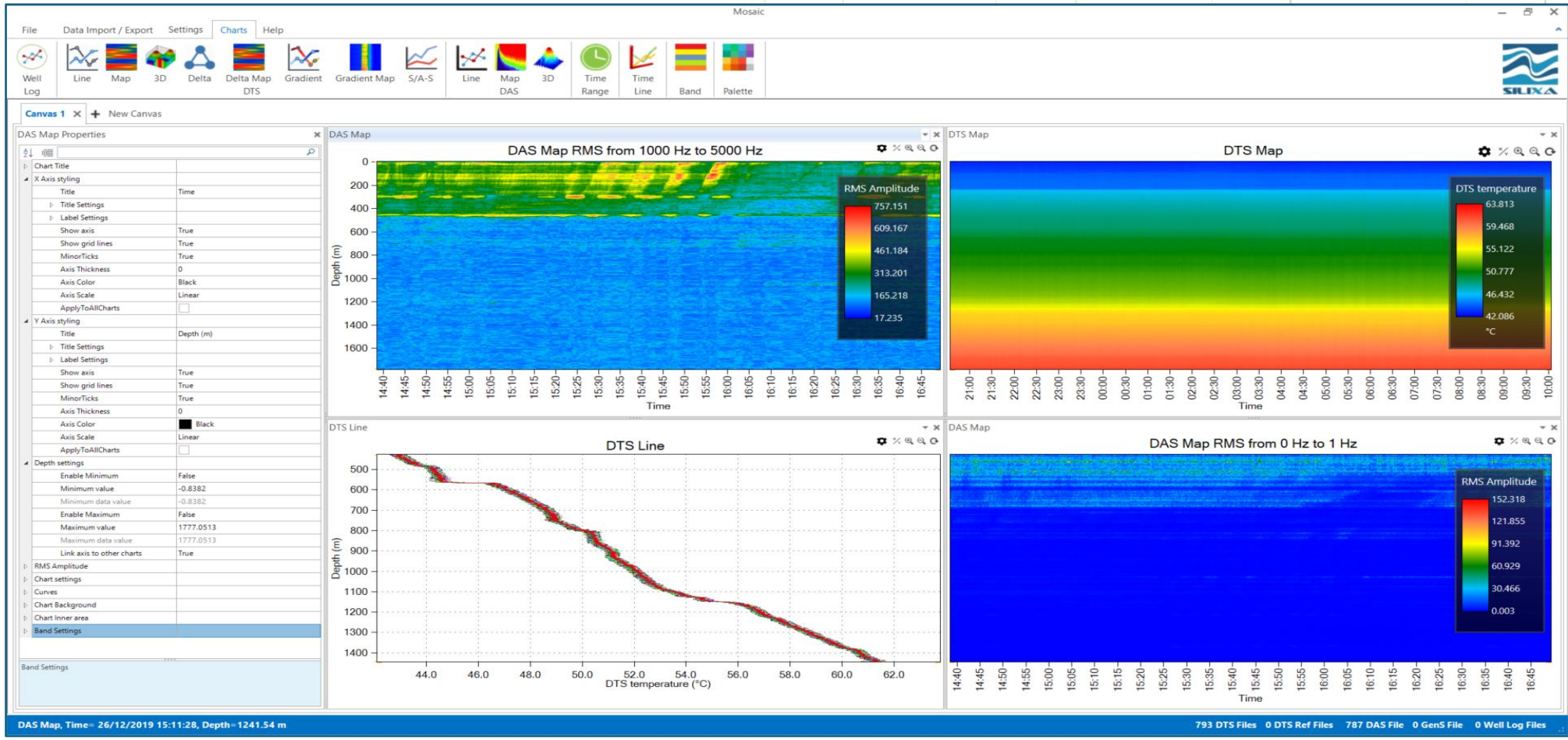
Real-time calculation of data derivatives

- Tool that can accept data streams and calculate



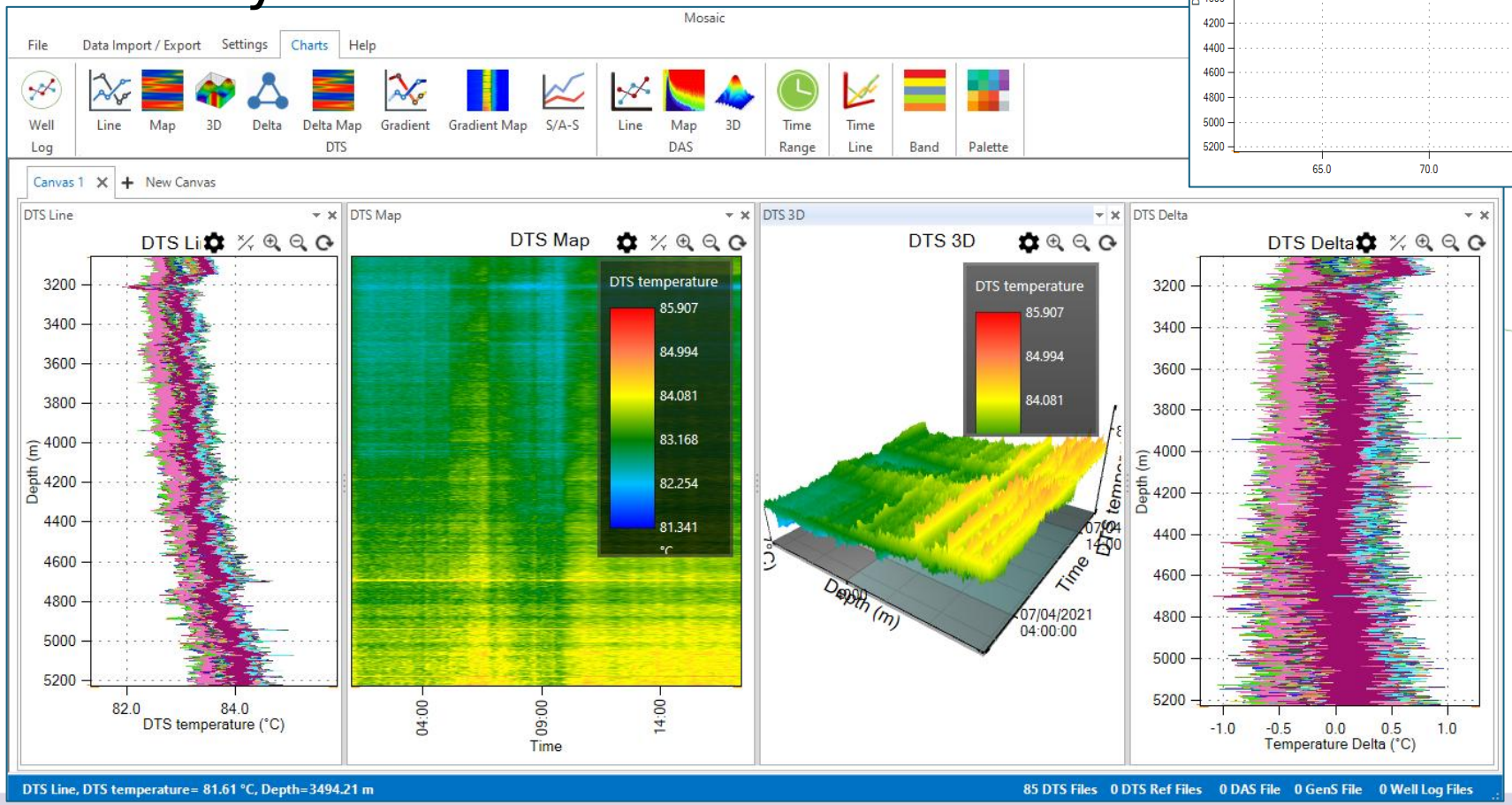
Real-time display of multiple datasets

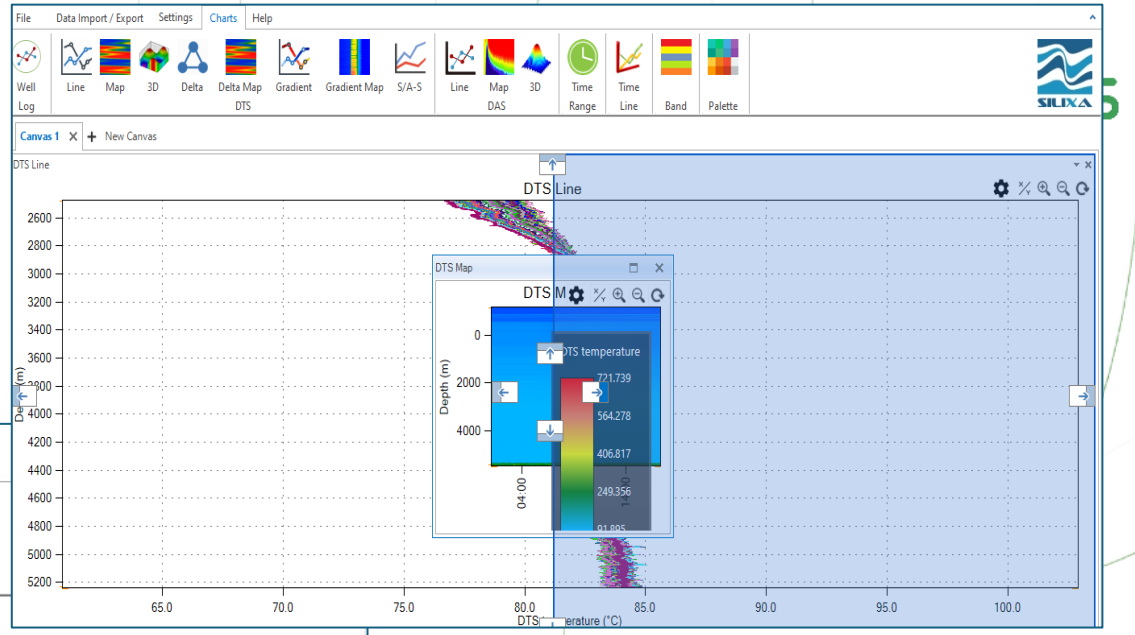
- Mosaic
- Real-time or offline visualisation
- DAS, DTS and DSS data
- Customisable displays



Real-time display of multiple datasets

- Mosaic
- Place different plot types where you want them





THANKS!

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