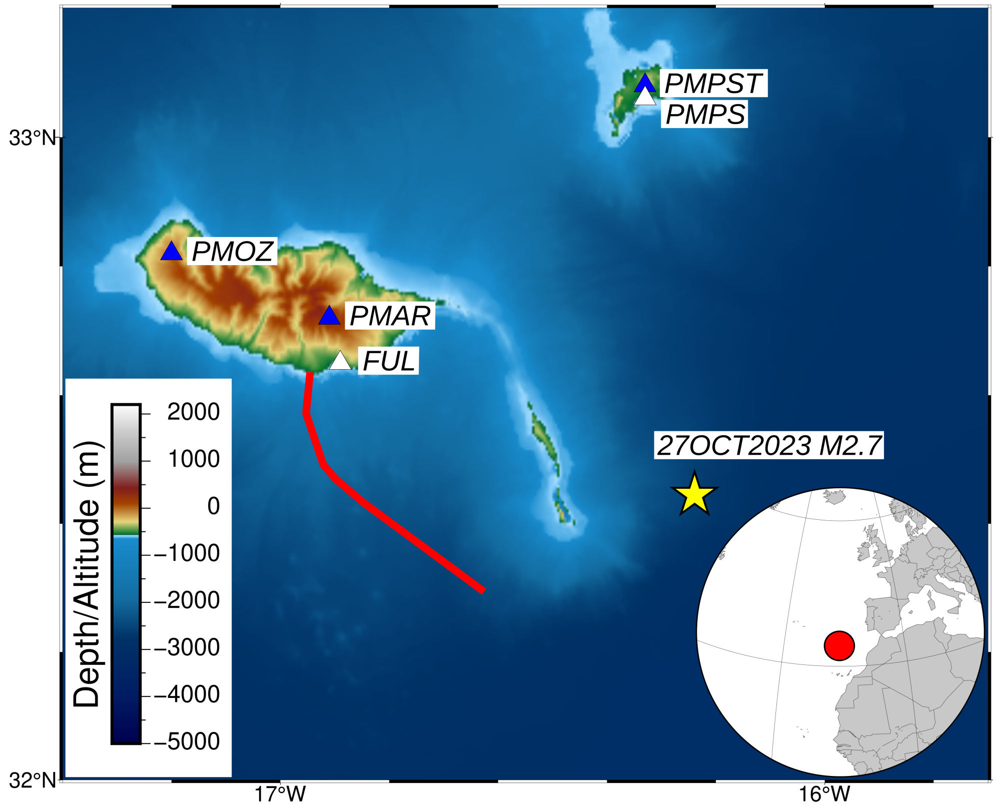
The GeoLab fibre

GeoLab is a ~57 km dark fibre exclusively used for research in seismology, oceanography, and biology

Has land, island slope and deep basin segments

ARDITI installed an OptoDAS interrogator in 2023

Complements the observational capabilities of OOM



Loureiro et al (submitted to Seismica)

The GeoLab fibre

INSTITUTO DOM LUIZ

arditi
agência regional para o desenvolvimento da investigação tecnologia e inovação

Observatório Oceânico da Madeira

Geo-INQUIRE

EllaLink

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Grupo EEM

FCCN serviços digitais fct

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Fundação para a Ciência e a Tecnologia

GÉANT

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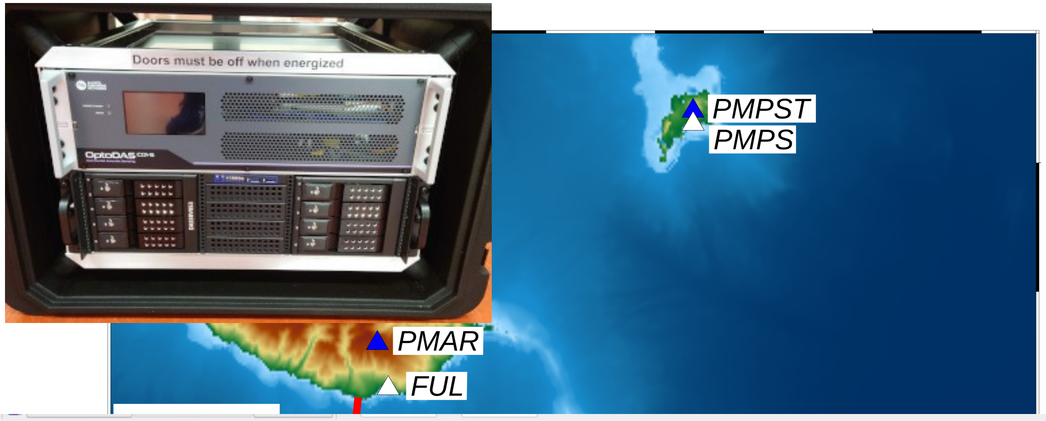
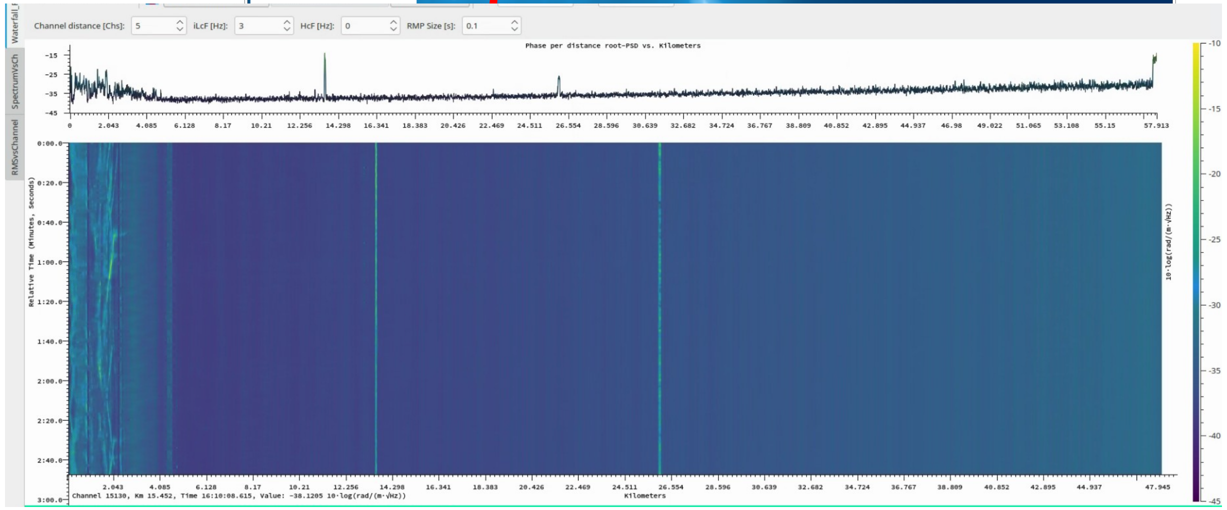


GeoLab has provided the first DAS dataset to be archived permanently at GEOFON

Dataset publicly available in 2026

The facility is open for collaborative research

Is part of the Geo-INQUIRE testbed facilities for transnational access (free of charge)



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What is Distributed Acoustic Sensing, after all?

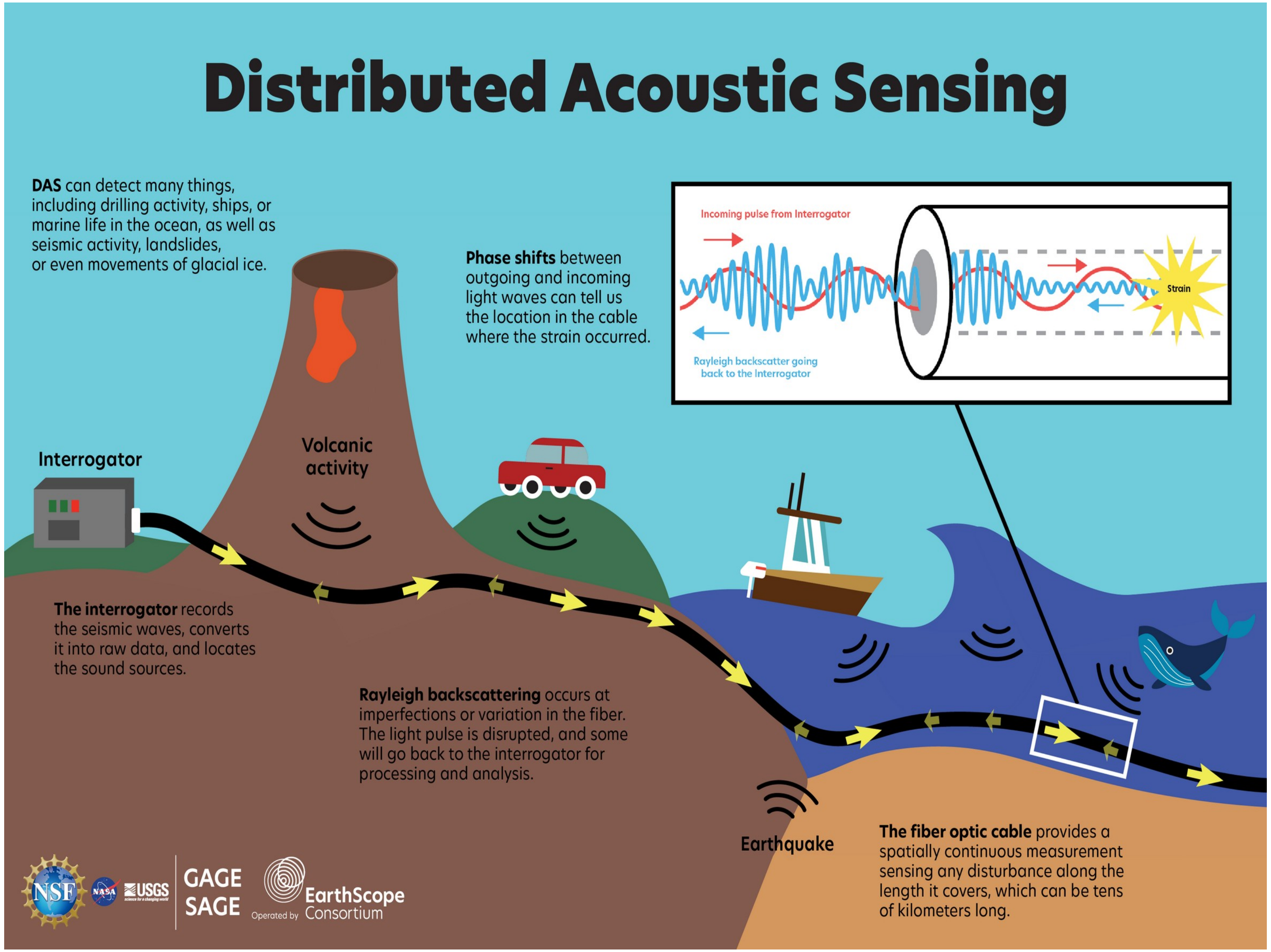
What is Distributed Acoustic Sensing?

DAS is the sampling of the acoustic field (vibrations) using a linear sensing element.

Measurements are taken along the entire sensor

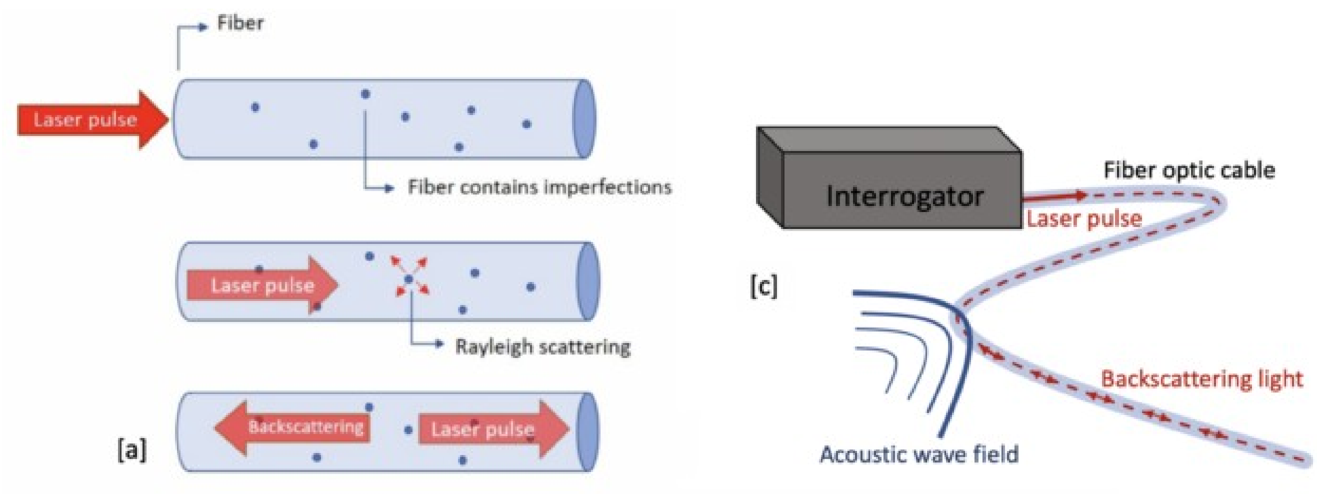
It should have been called Distributed Vibration Sensing (DVS) or Distributed Dynamic Strain Sensing (DDSS), but it’s too late to change the name now

DAS is easier to pronounce



What is Distributed Acoustic Sensing?

For data transmission, light pulses travelling along the fibre suffer attenuation that limits range, and small imperfections cause backscattering and lower the SNR.



Nap (2024)

Rayleigh backscattering patterns are affected by changes in the relative position of the fibre imperfections

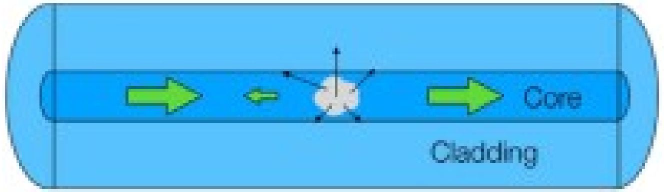
i.e.

We can detect when the fibre is deformed from phase shifts of the backscattered light

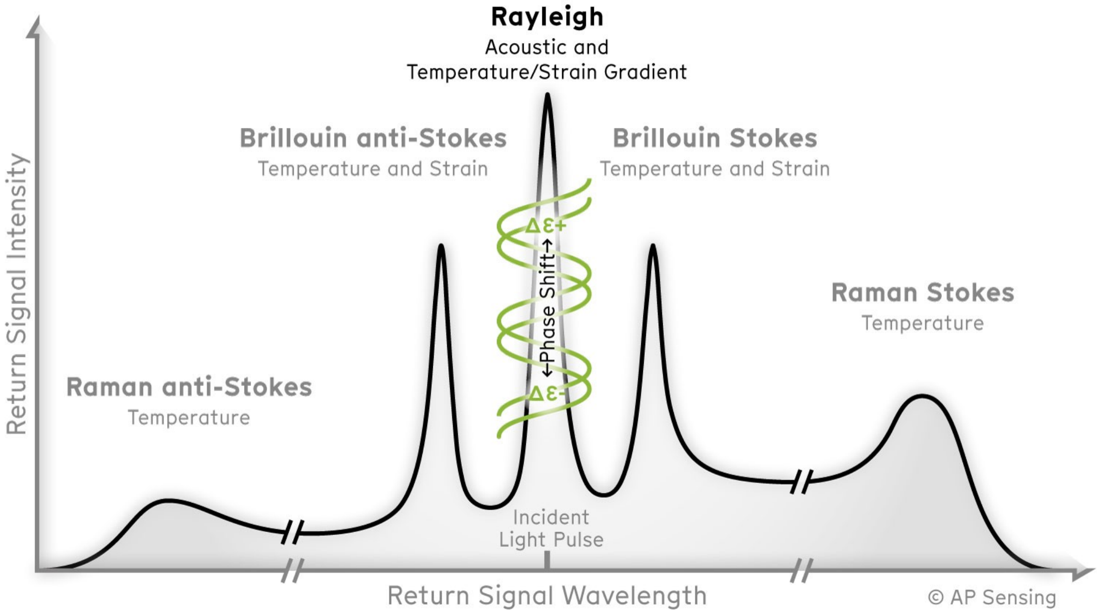
This is the basics of Rayleigh-based Distributed Acoustic Sensing systems (ϕ-OTDR)

What is Distributed Acoustic Sensing?

Scattering occurs in different modes



Blanc et al (2022)

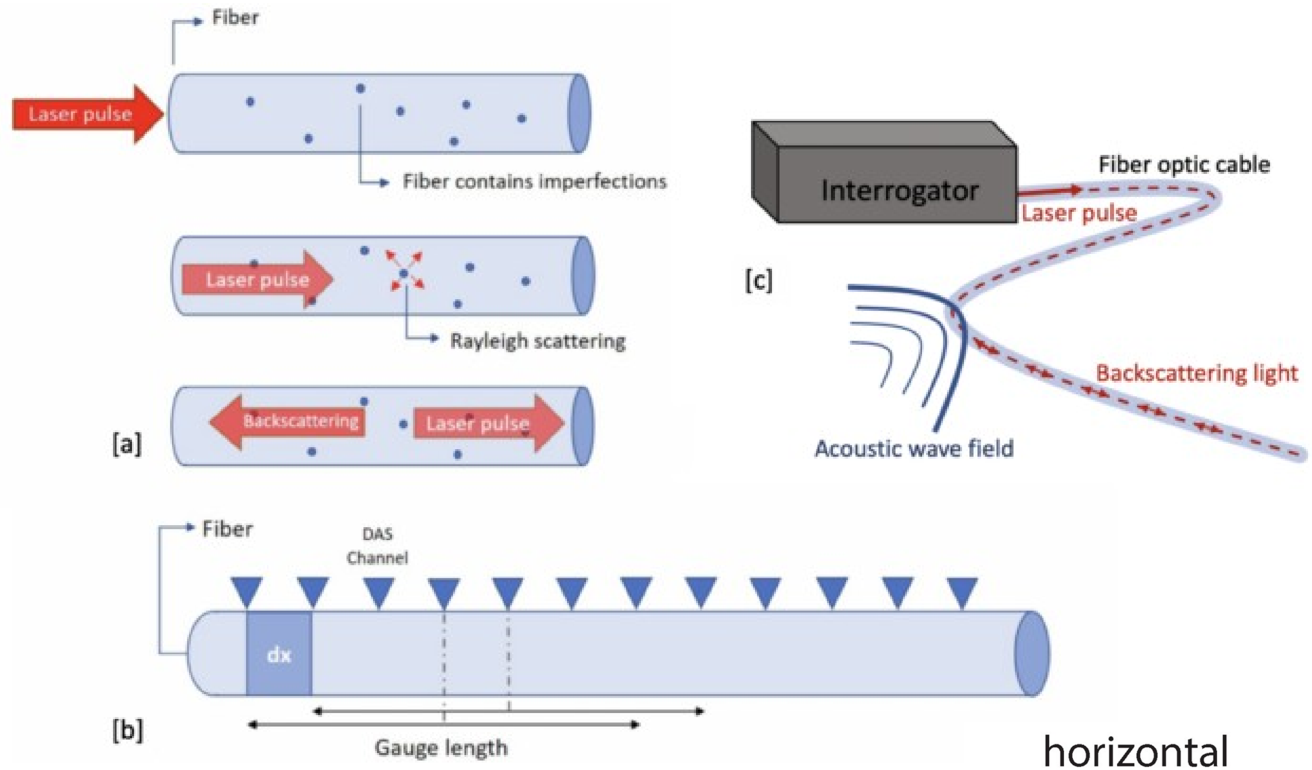


Fibre imperfections → Rayleigh scattering (elastic, no wavelength shift, strongest)

Optical properties changes → Raman and Brillouin scattering (inelastic, wavelength shift, allow to separate temperature and strain components)

What is Distributed Acoustic Sensing?

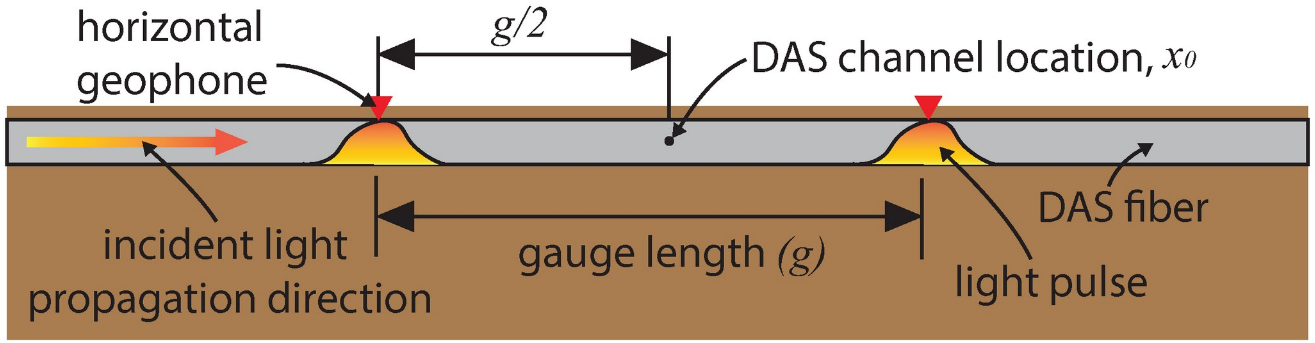
With time-gating, we can even pin-point where the deformation occurs



Nap (2024)

But, because the fibre's imperfections are randomly distributed, we have to integrate measurements over sections of the fibre, or channels

To improve the SNR, multiple channels are combined into gauge lengths



Hubbard et al (2022)

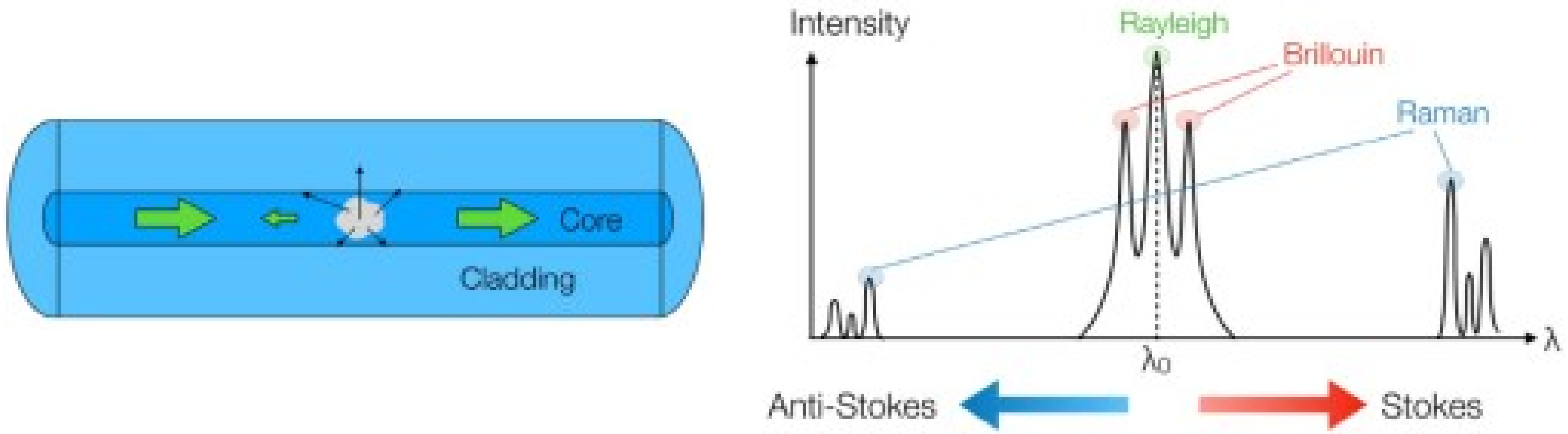
Let’s go back a step

So far, we’ve assumed that strain and apparent strain are about the same:

$$\varepsilon_{ap} \approx k \cdot \varepsilon$$

WARNING!

Spherical cow sighted



Let’s go back a step

But the fibre’s optical properties change with the acoustic, pressure, and temperature fields

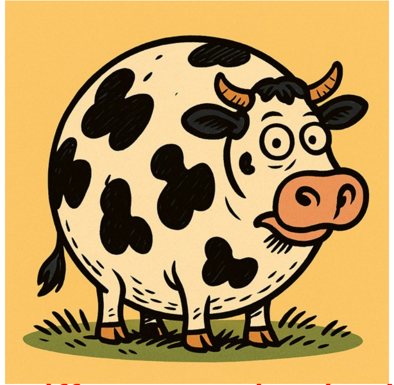
Apparent strain (in Rayleigh DAS) is cross-sensitive to more than just strain:

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}} + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} + \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

This cross-sensitivity is difficult to solve without external calibration

It is a limitation of Rayleigh-based systems

WARNING!



Different spherical cow sighted

How does the fibre respond to strain?

The response of of the fibre to strain is not as simple as other sensors

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}}$$

Measured strain* depends on:

How does the fibre respond to strain?

The response of of the fibre to strain is not as simple as other sensors

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}}$$

Measured strain* depends on:

1) The deformation (obviously)

How does the fibre respond to strain?

The response of of the fibre to strain is not as simple as other sensors

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}}$$

Measured strain* depends on:

1) The deformation (obviously)
2) The coupling of the fibre to the ground

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$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}}$$

Measured strain* depends on:

1) The deformation (obviously)
2) The coupling of the fibre to the ground
3) The age of the fibre

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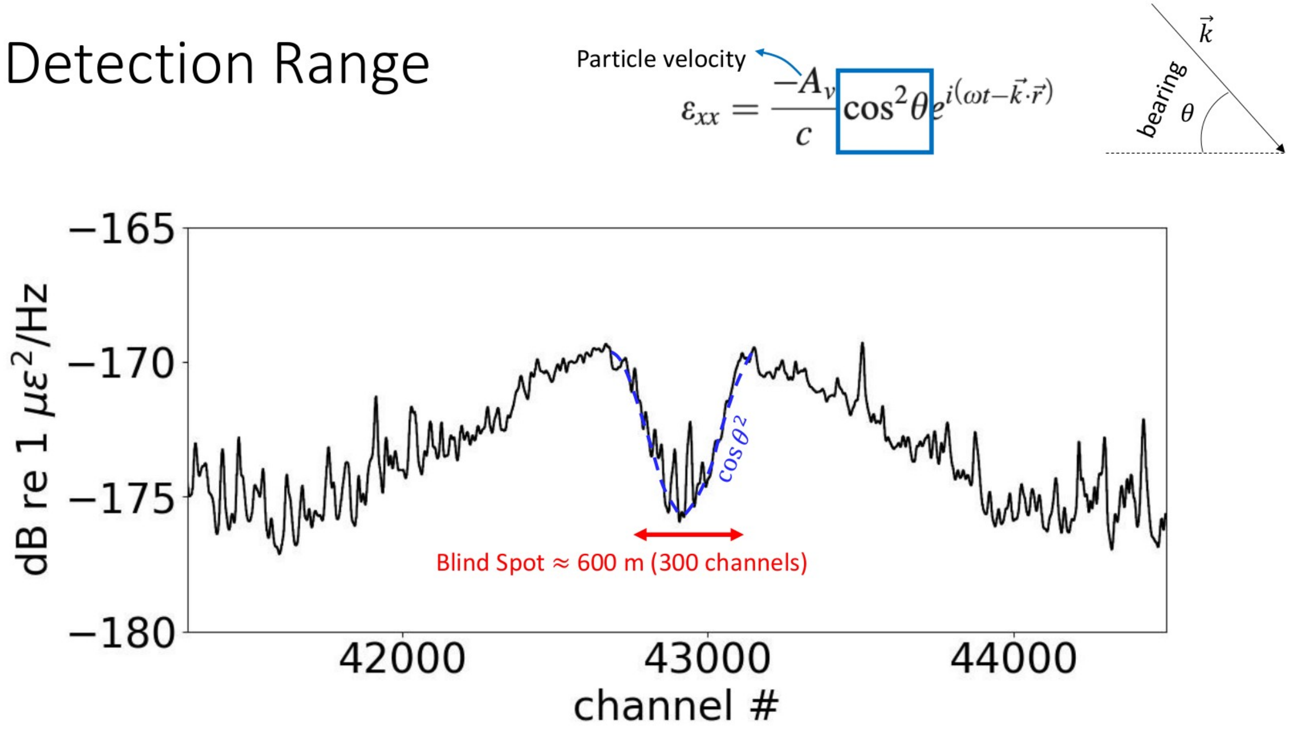

Abadi et al (2023)

Measured strain* depends on:

1) The deformation (obviously)
2) The coupling of the fibre to the ground
3) The age of the fibre
4) The azimuth of the signal

How does the fibre respond to strain?

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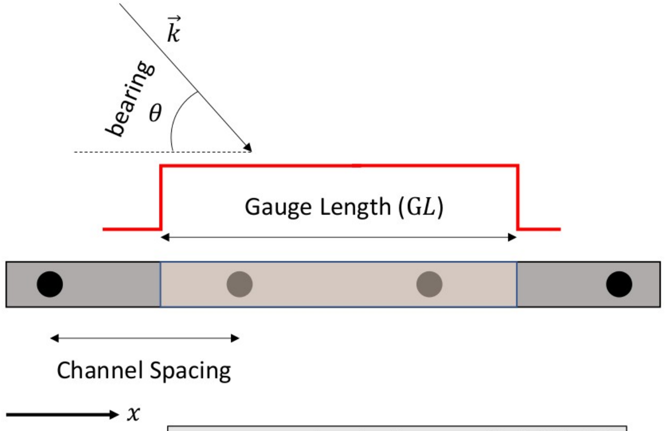
$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}}$$

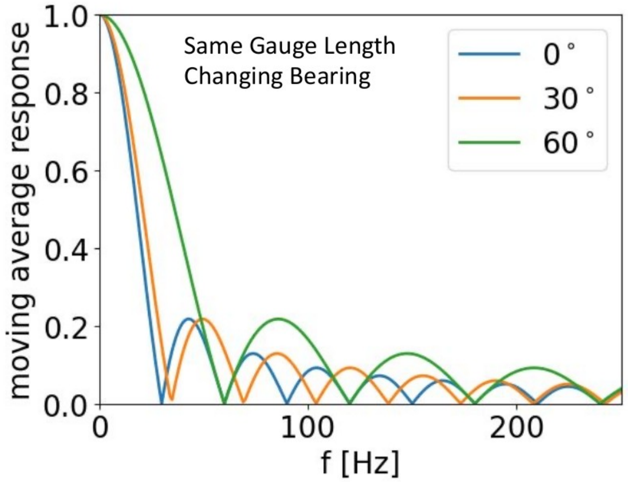
Measured strain* depends on:

1) The deformation (obviously)
2) The coupling of the fibre to the ground
3) The age of the fibre
4) The azimuth of the signal
5) The gauge length

Moving Average in Space → a Lowpass Filter



$$H(f) = \frac{1}{GL}\frac{\sin(\pi\cos\theta\, f GL/c)}{\sin(\pi\cos\theta\, f/c)}$$



Abadi et al (2023)

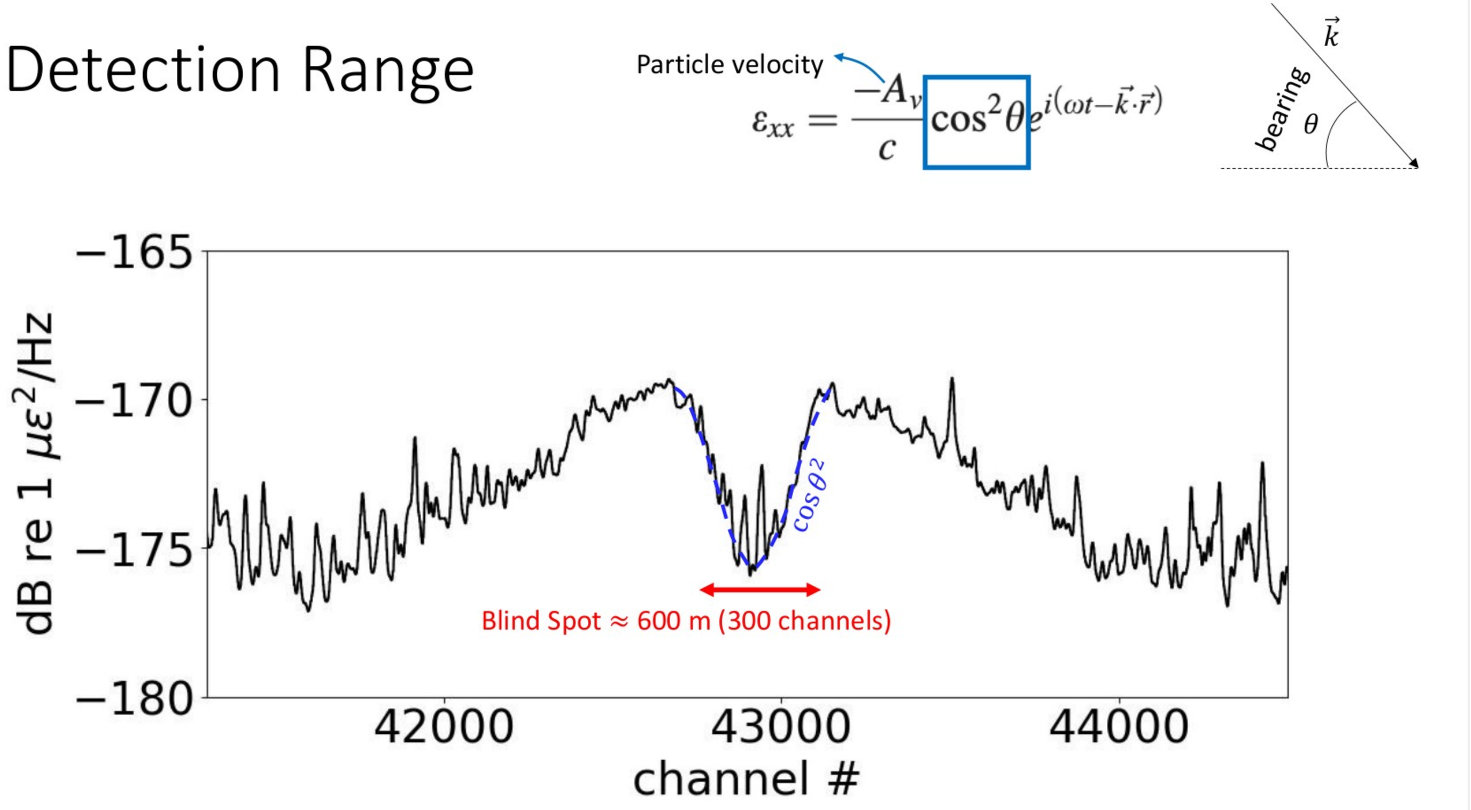
Broadside sensitivity

DAS can only measure longitudinal deformation (stretching or contraction of the fibre)

Broadside signals should not be recorded

But the sensing element is not a point, but rather a finite length

We do get some broadside signals, but extremely hard to interpret

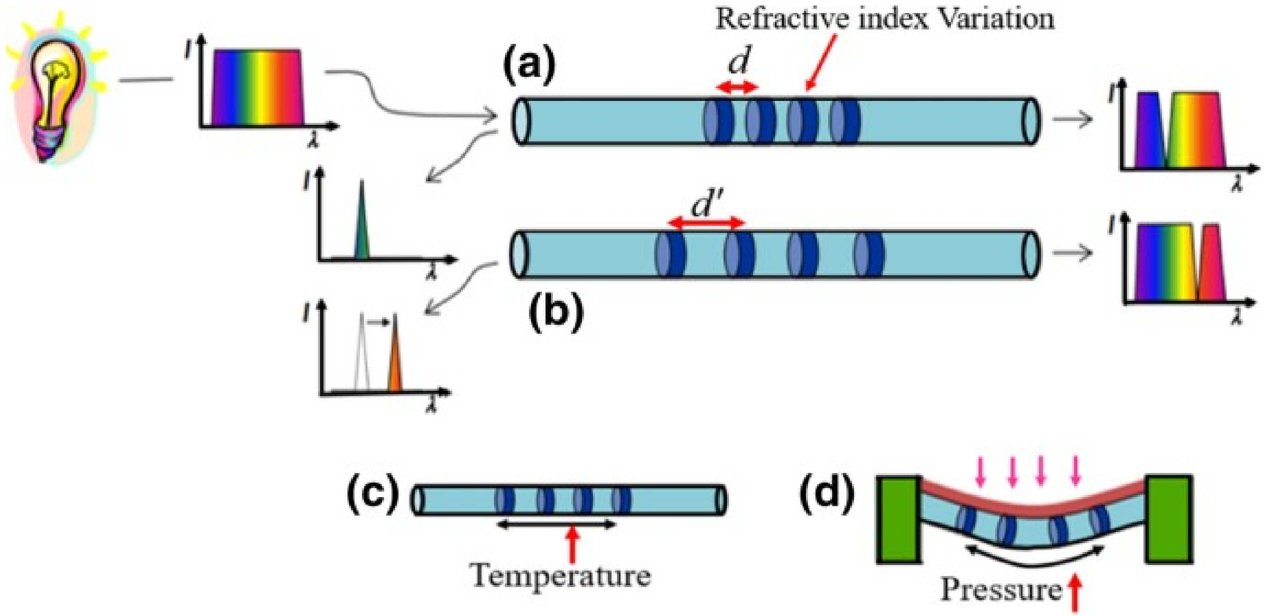


Abadi et al (2023)

How does the fibre respond to temperature?

$$\varepsilon_{ap} = \qquad + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} +$$

Measured strain* depends on:



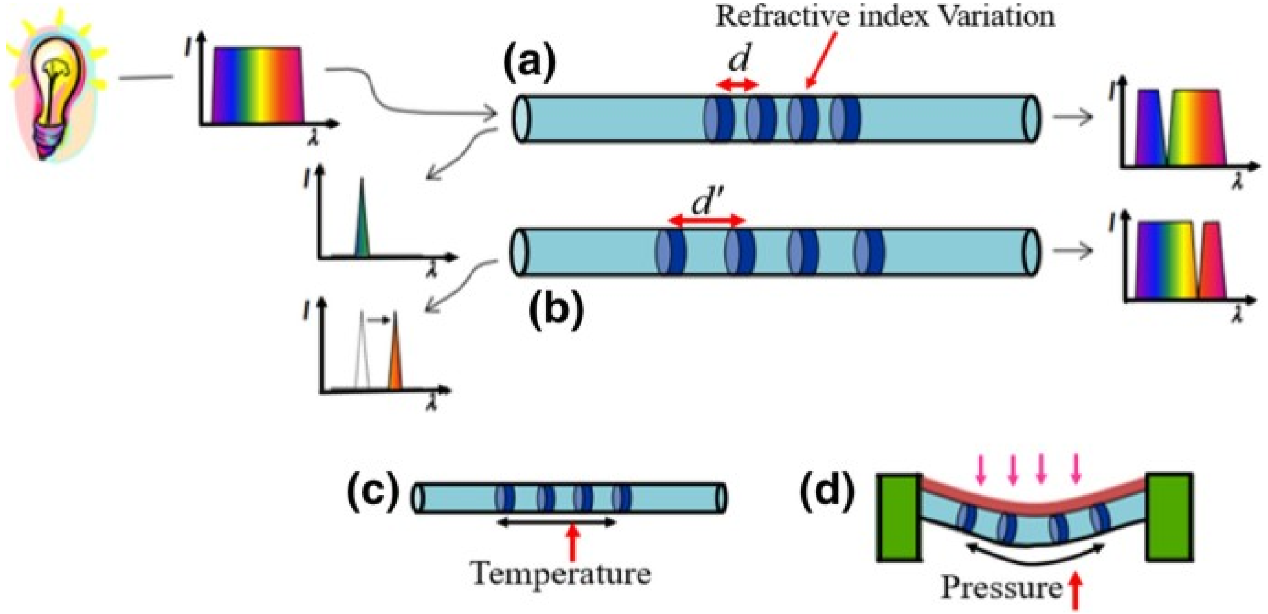
Fenta et al (2021)

How does the fibre respond to temperature?

$$\varepsilon_{ap} = \quad\quad\quad\quad + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} +$$

Measured strain* depends on:

1) The temperature variation



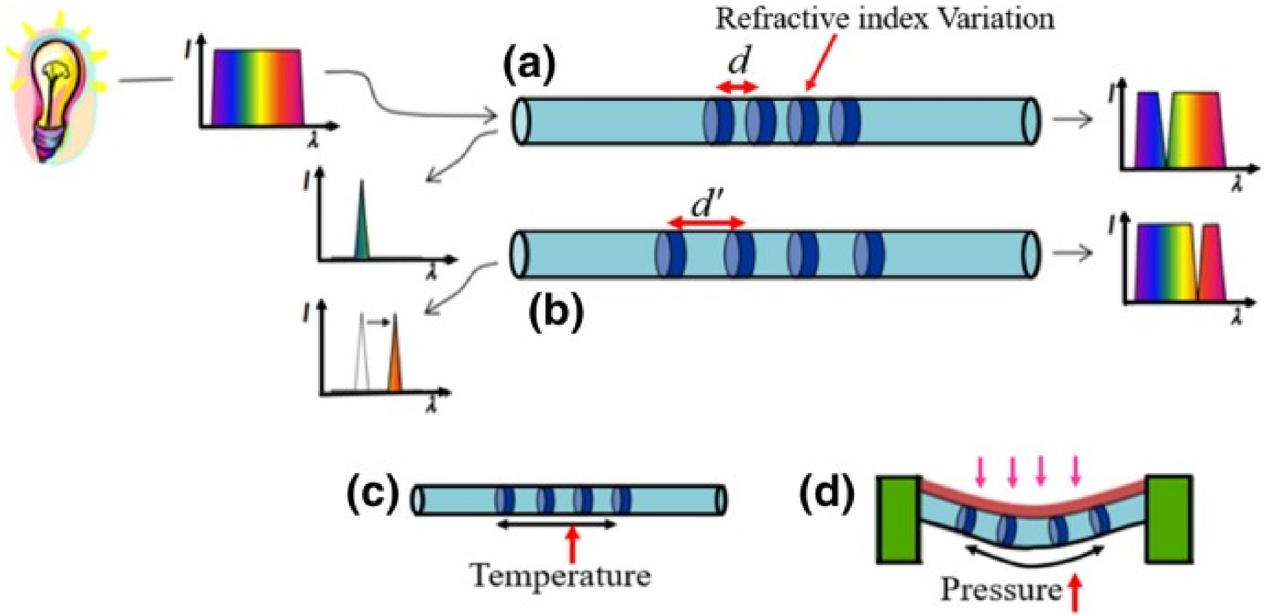
Fenta et al (2021)

How does the fibre respond to temperature?

$$\varepsilon_{ap} = \qquad + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} +$$

Measured strain* depends on:

1) The temperature variation
2) The thermal response parameters



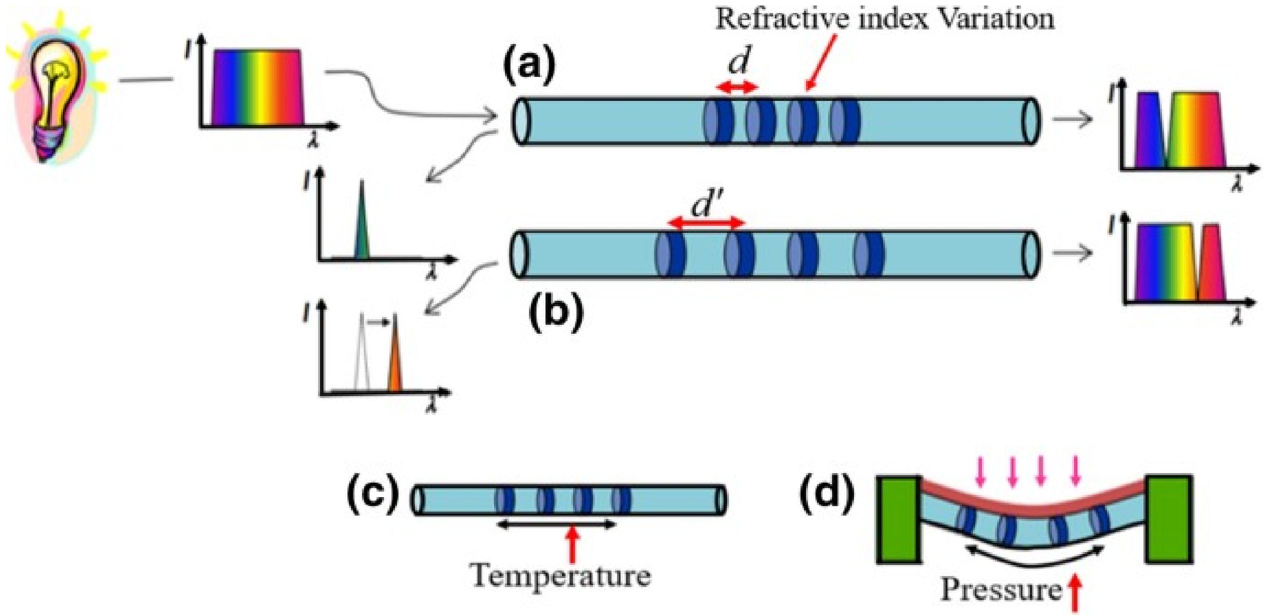
Fenta et al (2021)

How does the fibre respond to pressure?

$$\varepsilon_{ap} = \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

When dealing with pressure, the sensing element is not only the fibre, but the entire cable and even the ground itself

Measured strain* depends on:



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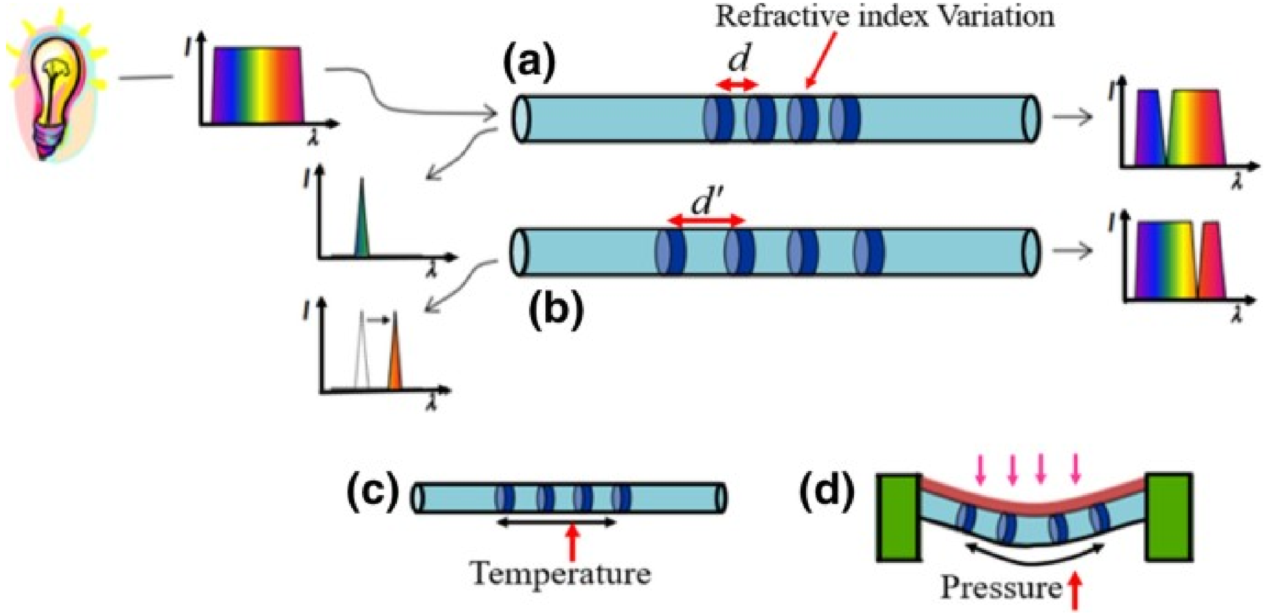
When dealing with pressure, the sensing element is not only the fibre, but the entire cable and even the ground itself

Measured strain* depends on:

1) The creep compliance term



Fenta et al (2021)

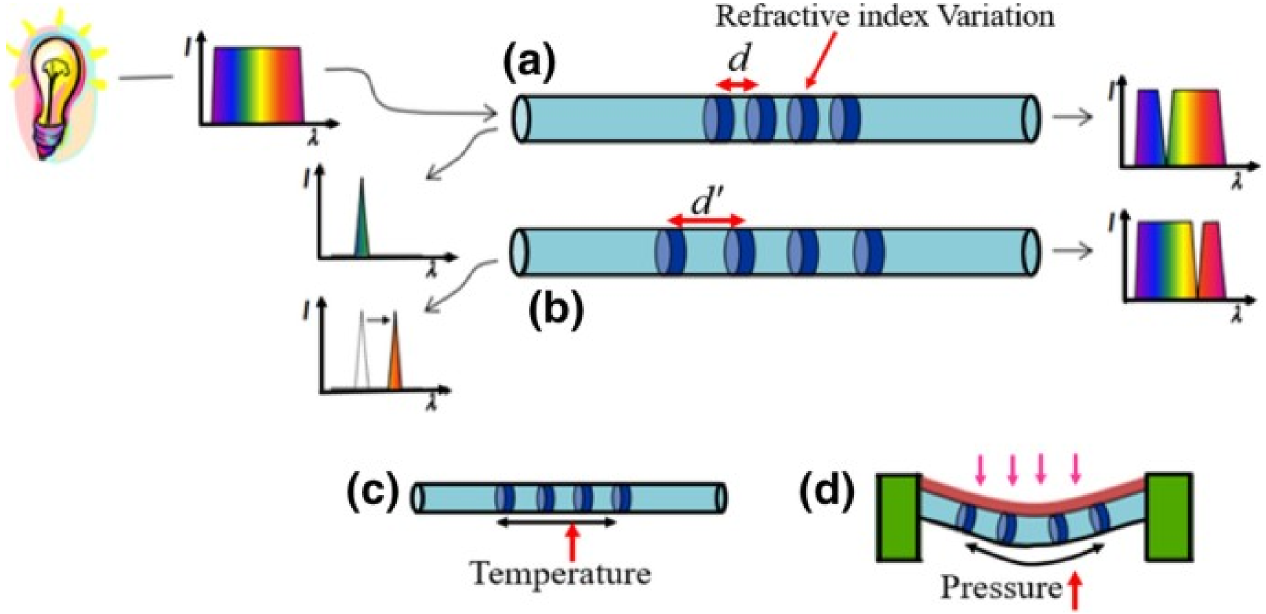
How does the fibre respond to pressure?

$$\varepsilon_{ap} = \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

When dealing with pressure, the sensing element is not only the fibre, but the entire cable and even the ground itself

Measured strain* depends on:

1) The creep compliance term
   1) Compliance of the seafloor



Fenta et al (2021)

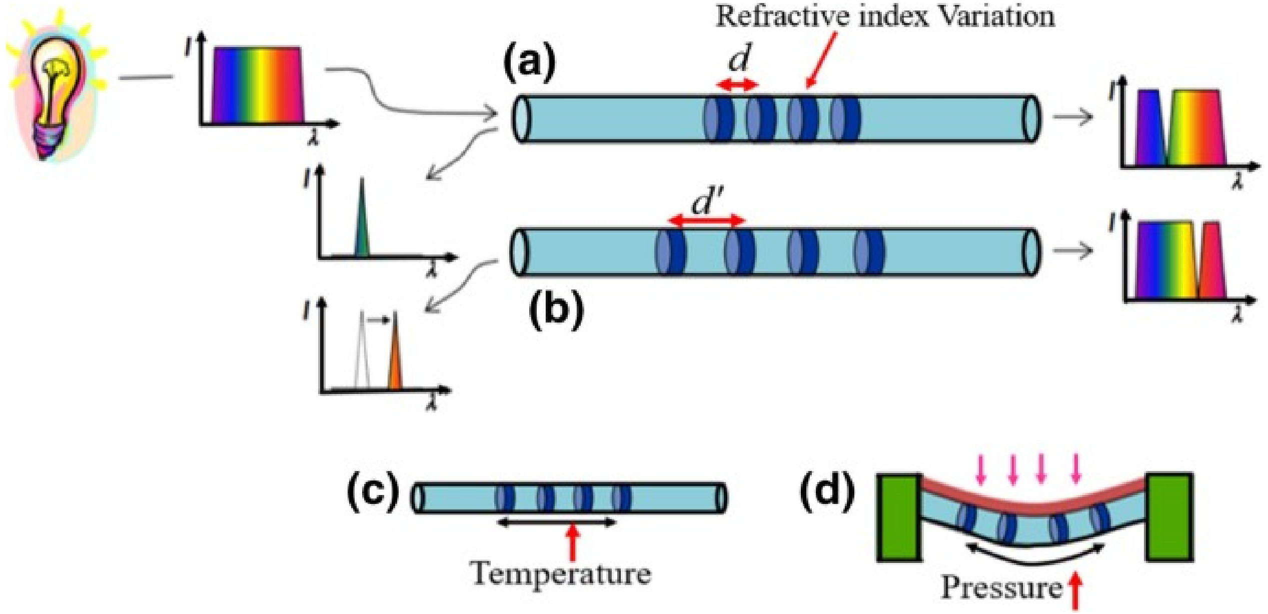
How does the fibre respond to pressure?

$$\varepsilon_{ap} = \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

When dealing with pressure, the sensing element is not only the fibre, but the entire cable and even the ground itself

Measured strain* depends on:

1) The creep compliance term
   1) Compliance of the seafloor
   2) Longitudinal deformation of the fibre via Poisson's effect



Fenta et al (2021)

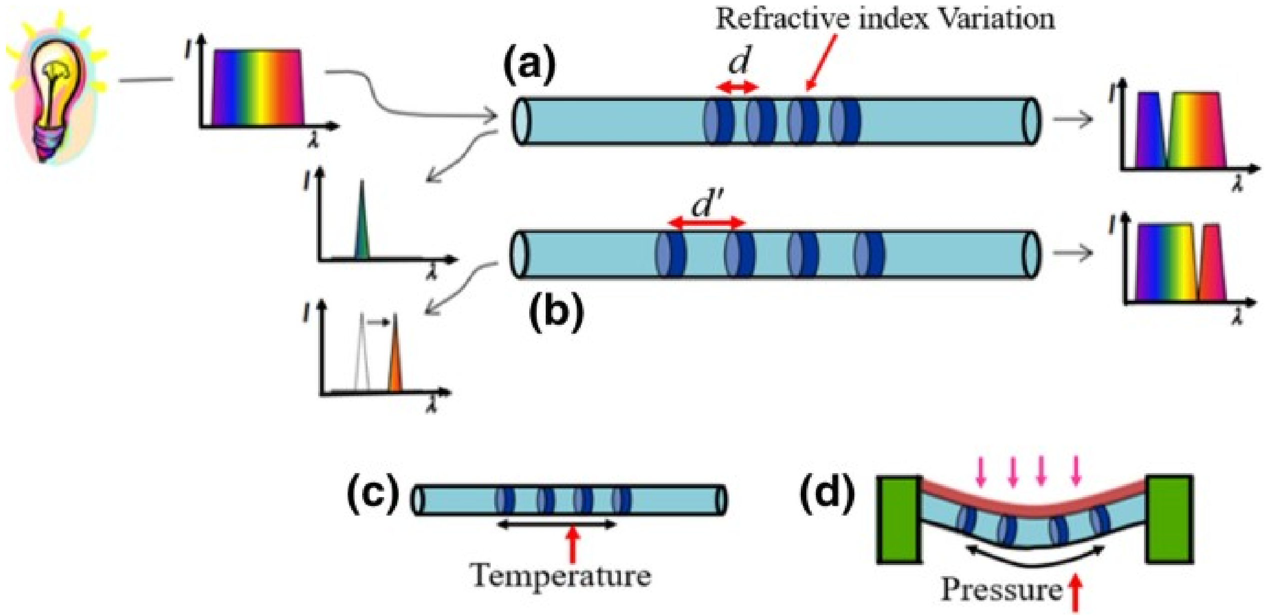
How does the fibre respond to pressure?

$$\varepsilon_{ap} = \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

When dealing with pressure, the sensing element is not only the fibre, but the entire cable and even the ground itself

Measured strain* depends on:

1) The creep compliance term
   1) Compliance of the seafloor
   2) Longitudinal deformation of the fibre via Poisson's effect
2) Non-newtonian effects



Fenta et al (2021)

How can we deal with cross-sensitivity

In subsea cables, each field acts upon the fibre at different timescales:

- Pressure from shoaling waves and tides have specific periods (seconds to hours)
- Temperature hysteresis limits the temporal sensitivity (more than 10 seconds)
- Strain is usually from fast-acting events or slow creep

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}} + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} + \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

Knowing this, we can begin to separate the contributions of each field

Extracting temperature signals

$$\varepsilon_{ap} = \underbrace{g(\theta, GL)C(t_a)a(t_a)\varepsilon}_{\text{Strain term}} + \underbrace{\alpha\beta\Delta T}_{\text{Temperature term}} + \underbrace{J(t_p)(p_S + p_T)}_{\text{Pressure term}}$$

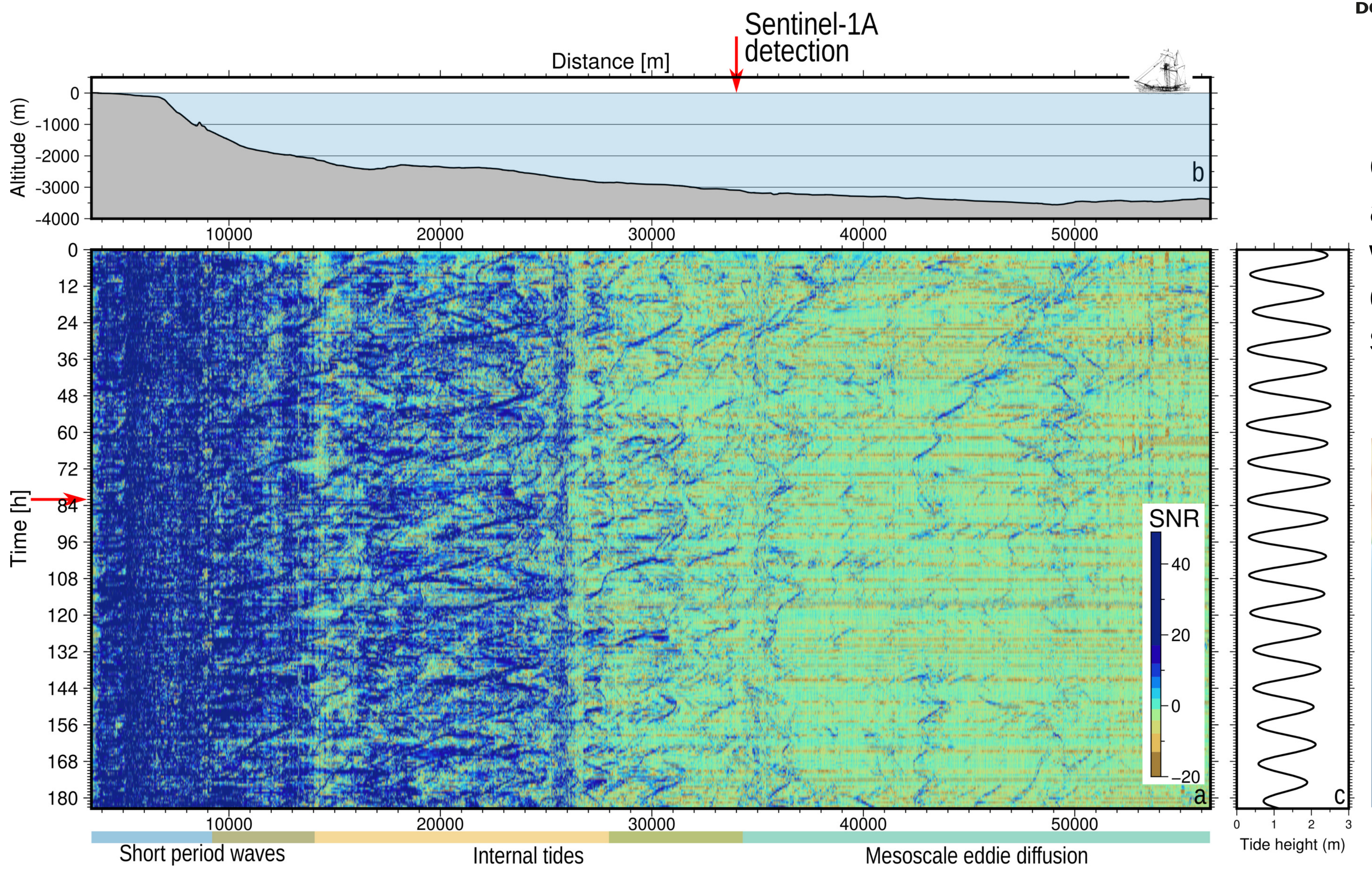
A band-pass filter applied to the apparent strain data can:

- Remove the very short and very long period contributions of strain and pressure
- Enhance only the imprint of temperature fluctuations

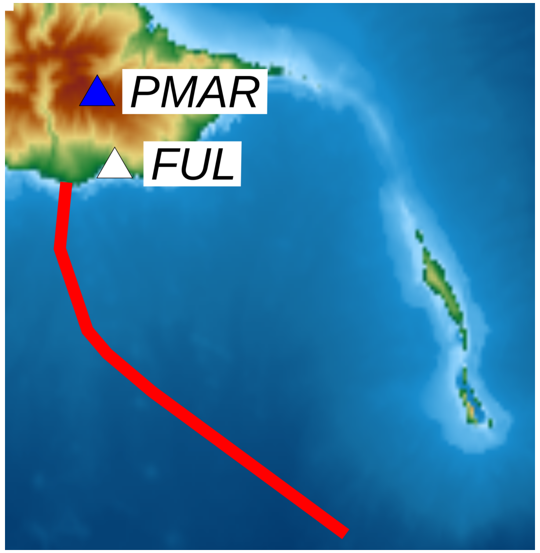
A simple approach is to calculate the average apparent strain over periods of a few minutes to one hour

For long enough time series, patterns start to emerge

Temperature signal



One week of data, averaged on 30-min windows, and divided by the standard deviation

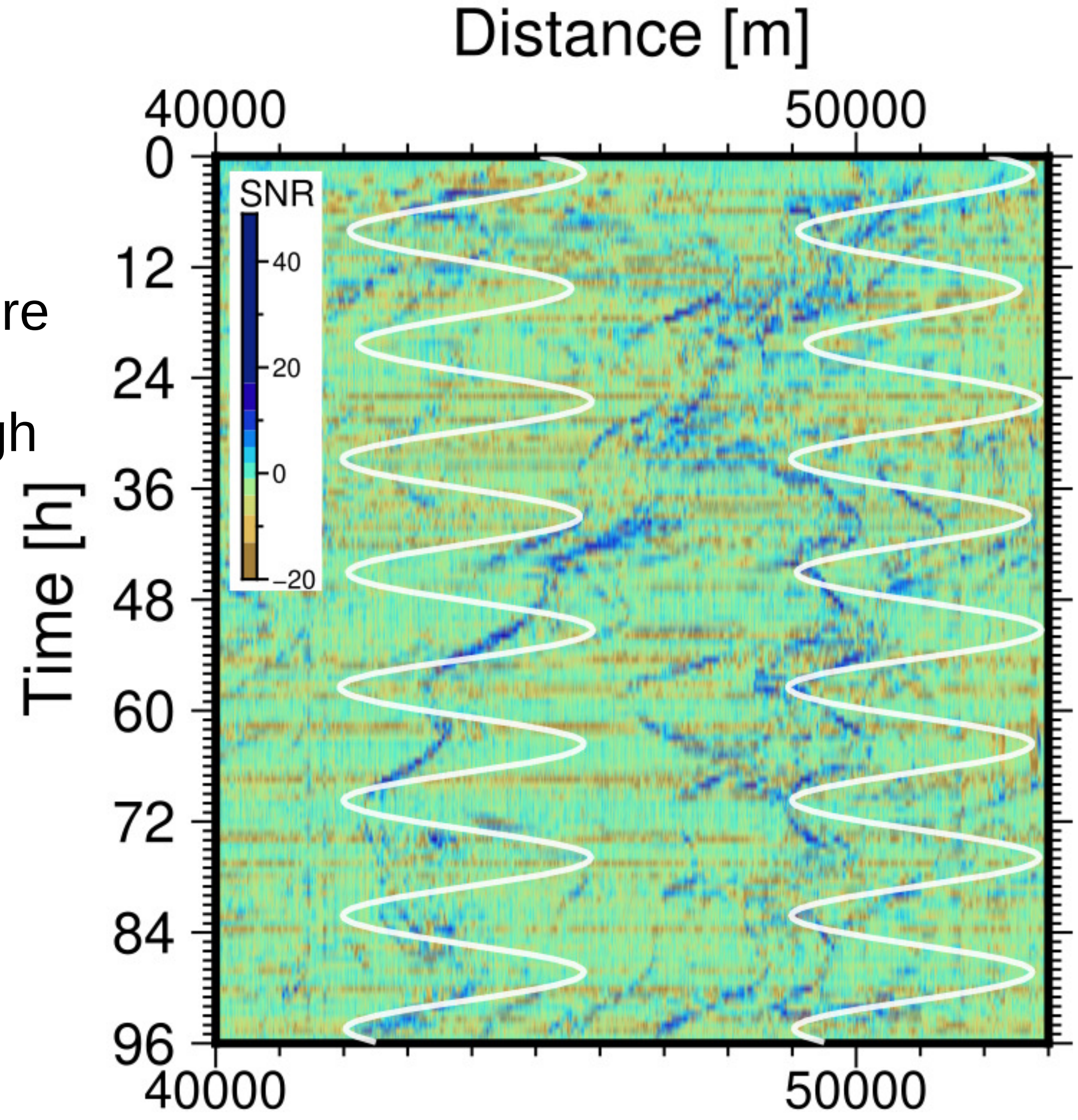


Temperature signal

Tidal cycle overlaid on the temperature signal in the deep basin

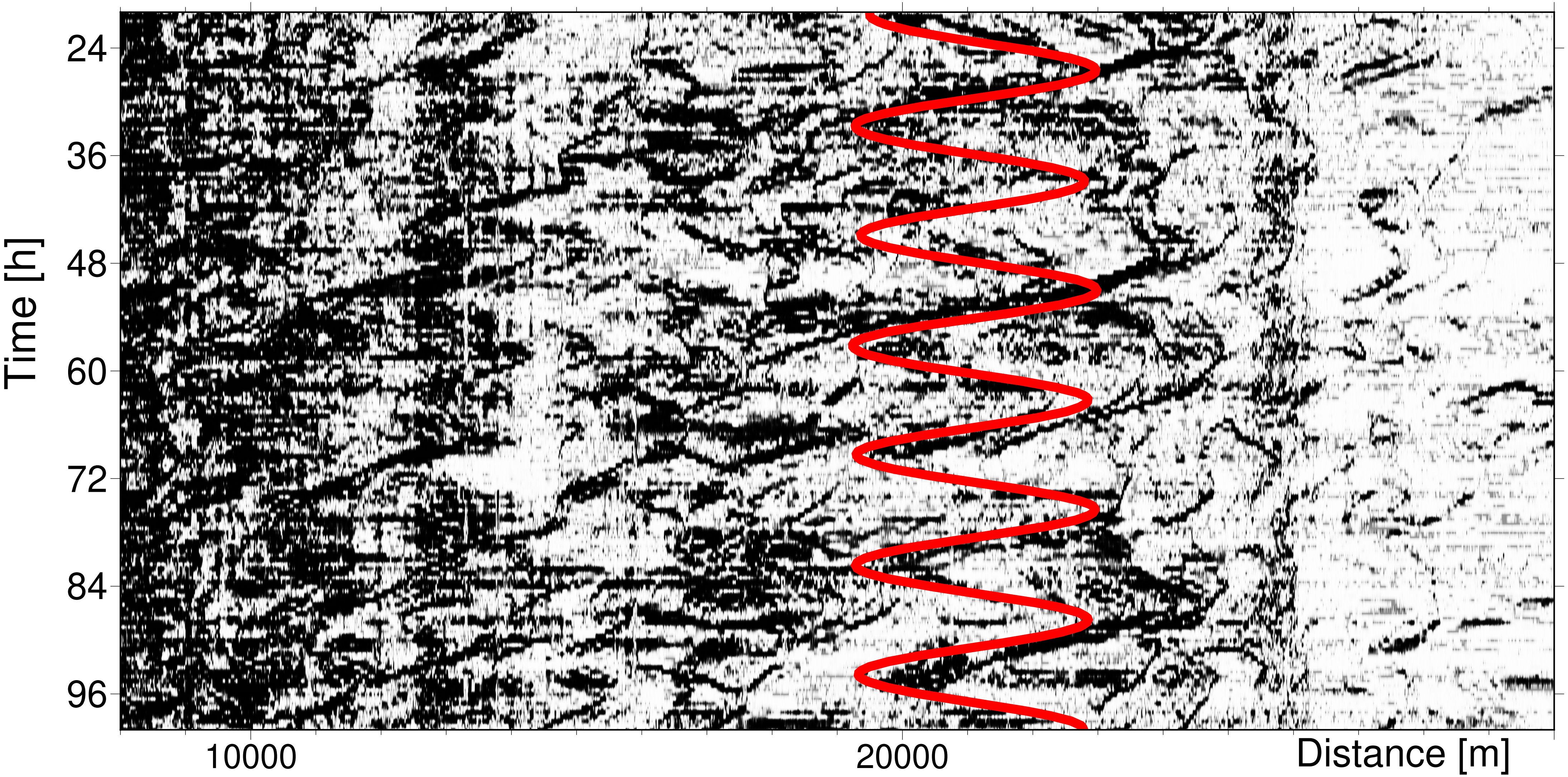
Changes in the optical properties of the fibre at the contact of water masses at different temperatures are detected as localized high values of apparent strain

Tides cause these water masses to move



Internal tides

Tidal cycle overlaid on the temperature signal on the island slope



Conclusions

1) Correct amplitudes for seismic, temperature, and pressure signals are hard to obtain

2) Cross-sensitivity of ϕ-OTDR systems hinders interpretation

3) But, even without calibration, simple band-pass filtering can enhance different responses

Geo-INQUIRE: Call for Transnational Access to the GeoLab fibre are open until September 12th