Challenges in Earthquake detection with Distributed Acoustic Sensing

Afonso Loureiro – ARDITI / Instituto Dom Luiz

What is Distributed Acoustic Sensing?

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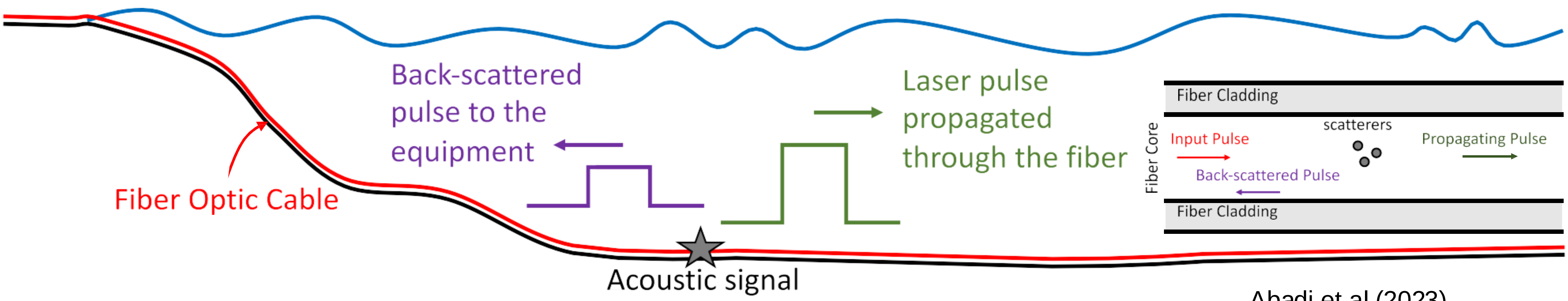
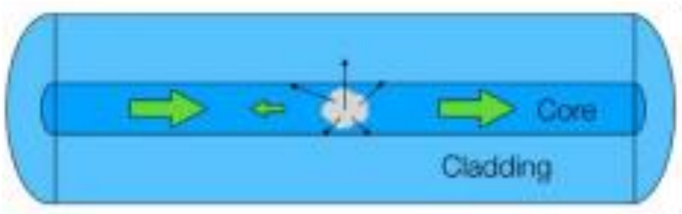
DAS uses light backscatter to provide extremely dense (mostly) strain* measurements

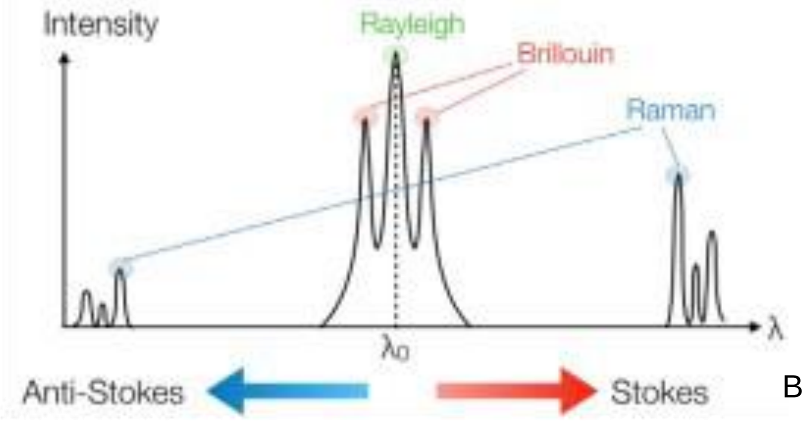


Abadi et al (2023)

* the optical properties of the fibre change with the acoustic, pressure, and temperature fields

Back-scattering modes





Blanc et al (2022)

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

Fibre optical properties → Raman and Brillouin (inelastic, wavelenght shift, allow to separate temperature and strain components)

Most DAS systems use Rayleigh scattering for increased range

Challenges in DAS

Currently, DAS presents challenges in three main topics:

- Volume of generated data
- Unclear sensitivity and smearing between different physical processes
- Unknown transfer function

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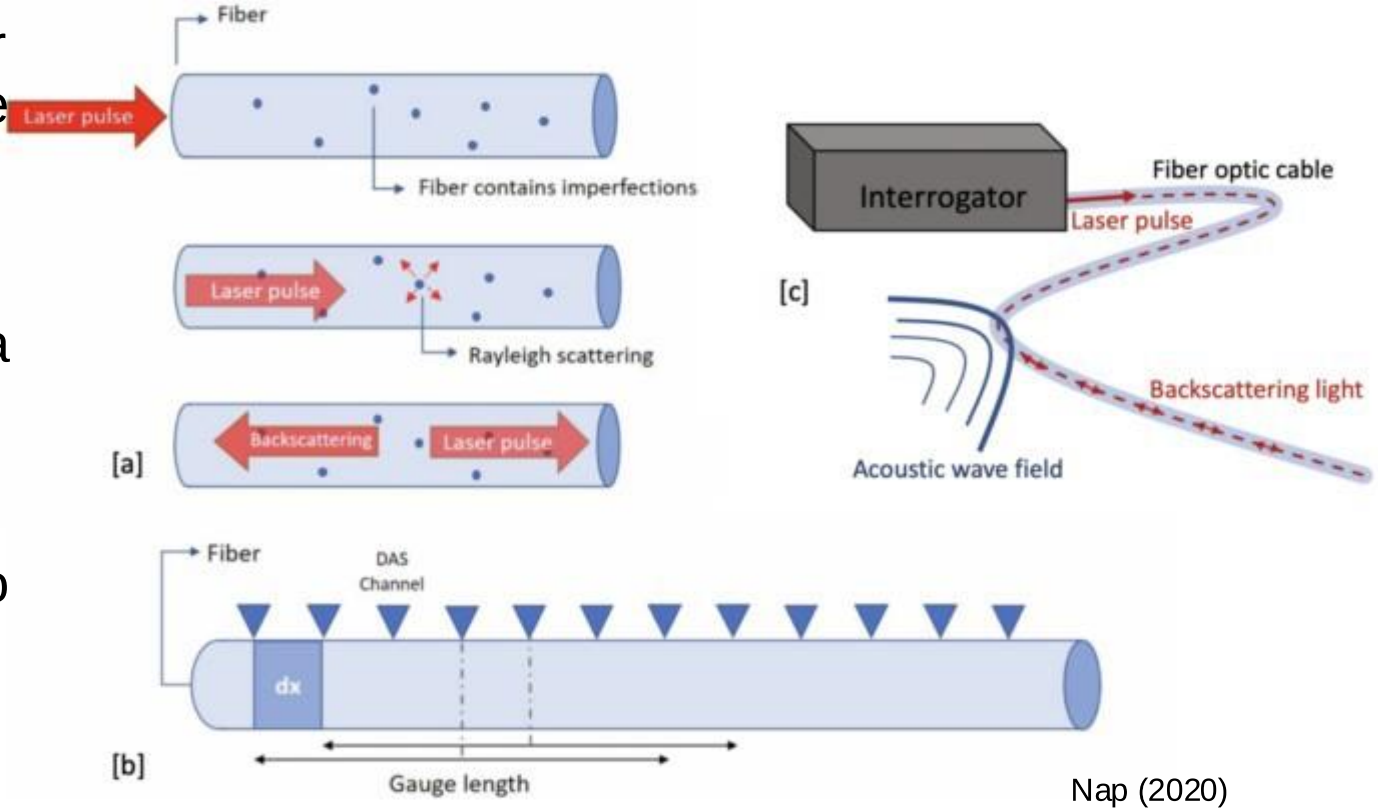
Data challenges

DAS integrates backscatter measurements over finite lenghts (dx)

Each channel generates a separate data stream

Practical data rates up to 2 kHz

It quickly adds up



Nap (2020)

Data challenges

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The shear size of the datasets dwarfs even the largest nodal experiments

- 15-50 GB/day/km are typical sizes
- 1-3 TB/day per 50 km of fibre

Uploading and downloading datasets requires time and **lots of storage space**

Much like broadband data a few decades ago, DAS data are routinely discarded

F.A.I.R. challenges

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Findable: DOI for each dataset are the norm 3

Accessible: Time and storage space limitations; some datasets can only be made public after scrubbing, masking and/or downsampling 3

Interoperable: There are still no established standards for either data or metadata 3

Reusable: Licensing is still an issue as most datasets are collected on privately owned infrastructure 3

Challenges in DAS

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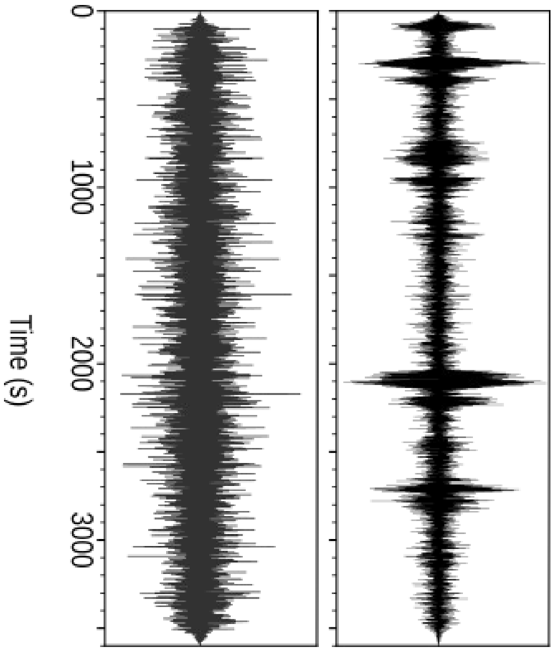
Major challenge: the response of DAS

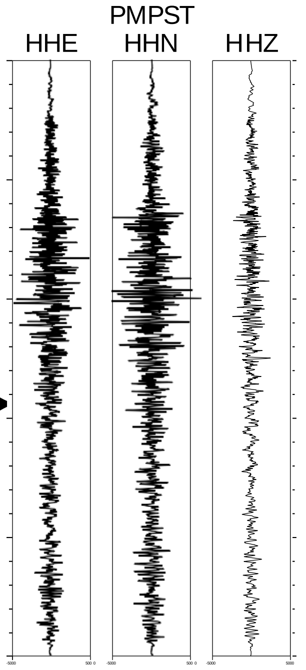
We still don't know how to precisely turn "DAS wiggles" into "Seismometer wiggles"



Single channel Stacked channels

DAS

$$\longrightarrow T_e(\omega) \longrightarrow$$



Broadband seismometer

Major challenge: the response of DAS

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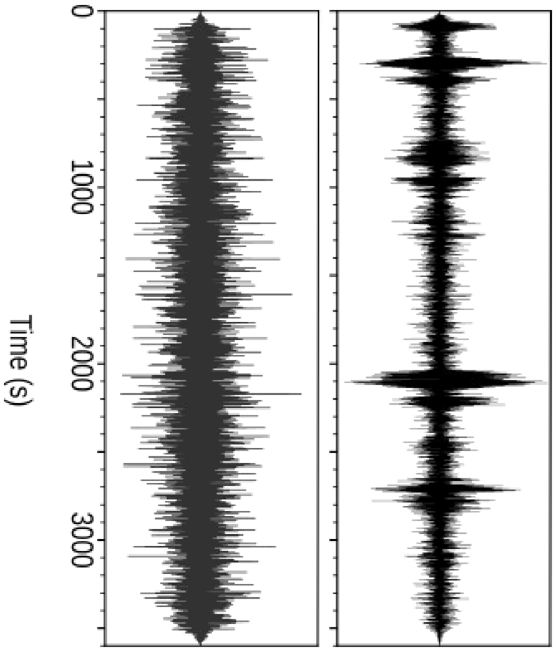
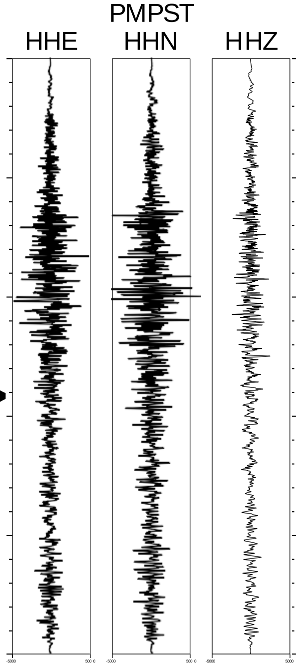


Single channel Stacked channels

DAS

$$\longrightarrow T_e(\omega) \longrightarrow$$

?



Broadband seismometer

Major challenge: the response of DAS

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The search for the Holy Graal of DAS

Geophysical Prospecting — EAGE European Association of Geoscientists & Engineers

Geophysical Prospecting, 2016, 64, 1318–1334 doi: 10.1111/1365-2478.12324

Field testing of modular borehole monitoring with simultaneous distributed acoustic sensing and geophone vertical seismic profiles at Citronelle, Alabama

T.M. Daley[1*], D.E. Miller[2], K. Dodds[3], P. Cook[1] and B.M. Freifeld[1]
[1]Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California, USA, [2]Silixa Ltd, and [3]BP

Empirical Investigations of the Instrument Response for Distributed Acoustic Sensing (DAS) across 17 Octaves

Patrick Paitz[*1], Pascal Edme[1], Dominik Gräff[2], Fabian Walter[2], Joseph Doetsch[1], Athena Chalari[3], Cédric Schmelzbach[1], and Andreas Fichtner[1]

Geophysical Journal International

Geophys. J. Int. (2023) 235, 2372–2384
Advance Access publication 2023 October 05
GJI Seismology

From strain to displacement: using deformation to enhance distributed acoustic sensing applications

Alister Trabattoni[1], Francesco Biagioni[2], Claudio Strumia[3], Martijn van den Ende[1], Francesco Scotto di Uccio[3], Gaetano Festa[3], Diane Rivet[1], Anthony Sladen[1], Jean Paul Ampuero[1], Jean-Philippe Métaxian[2] and Éléonore Stutzmann[2]
[1]Université Côte d'Azur, Observatoire de La Côte d'Azur, CNRS, IRD, Géoazur, 06560 Valbonne, France. E-mail: alister.trabattoni@gmail.com
[2]Université Paris Cité, Institut de Physique du Globe de Paris, 75005 Paris, France
[3]Università di Napoli Federico II, Dipartimento di Fisica "Ettore Pancini", 80126 Napoli, Italy

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JGR Solid Earth

RESEARCH ARTICLE
10.1029/2019JB018145

On the Broadband Instrument Response of Fiber-Optic DAS Arrays

Nathaniel J. Lindsey[1,2,3], Horst Rademacher[1], and Jonathan B. Ajo-Franklin[2,4]

Key Points:
- DAS instrument response for a telecom cable experiment is quantified emp… broadband seis…
- Amplitude res… ground motion… enhanced at sh…

Solid Earth, 12, 1421–1442, 2021
https://doi.org/10.5194/se-12-1421-2021

Solid Earth — EGU

Strain to ground motion conversion of distributed acoustic sensing data for earthquake magnitude and stress drop determination

Itzhak Lior[1,2], Anthony Sladen[1], Diego Mercerat[3], Jean-Paul Ampuero[1], Diane Rivet[1], and Serge Sambolian[1]

Solid Earth, 12, 915–934, 2021
https://doi.org/10.5194/se-12-915-2021

Solid

Evaluating seismic beamforming capabilities of distributed acoustic sensing arrays

Martijn P. A. van den Ende and Jean-Paul Ampuero
Université Côte d'Azur, IRD, CNRS, Observatoire de la Côte d'Azur, Géoazur, Valbonne, France
Correspondence: Martijn P. A. van den Ende (martijn.vandenende@geoazur.unice.fr)

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journal homepage: www.elsevier.com/locate/optlastec
ELSEVIER

Full length article

Field demonstration of an optical fiber hydrophone for seismic monitoring at Campi-Flegrei caldera

M. Janneh[a], F.A. Bruno[a], S. Guardato[b], G.P. Donnarumma[b], G. Iannaccone[b], G. Gruca[c], S. Werzinger[c], A. Gunda[c], N. Rijnveld[c], A. Cutolo[a], M. Pisco[a,*], A. Cusano[a,*]
[a]Optoelectronic Division - Engineering Dept., University of Sannio, c.so Garibaldi 107, 82100 Benevento, Italy
[b]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, via Diocleziano 328, 80124 Napoli, Italy
[c]OPTICS11 Hettenheuvelweg 37-39 1101 BM Amsterdam, the Netherlands

Major challenge: the response of DAS

Compared to seismometers, DAS has a lower SNR, variable angular sensitivity, and a still undetermined transfer function from ground velocity to strain

The transfer function for DAS (single component) is: $u_e(x,\omega)=T_e(\omega)g_e(x,\omega)+\epsilon$

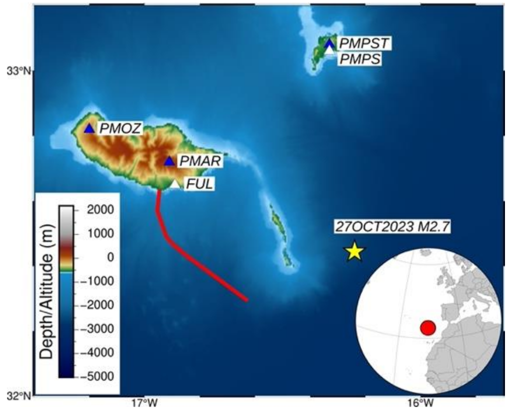
This is actually the most important part of the equation!

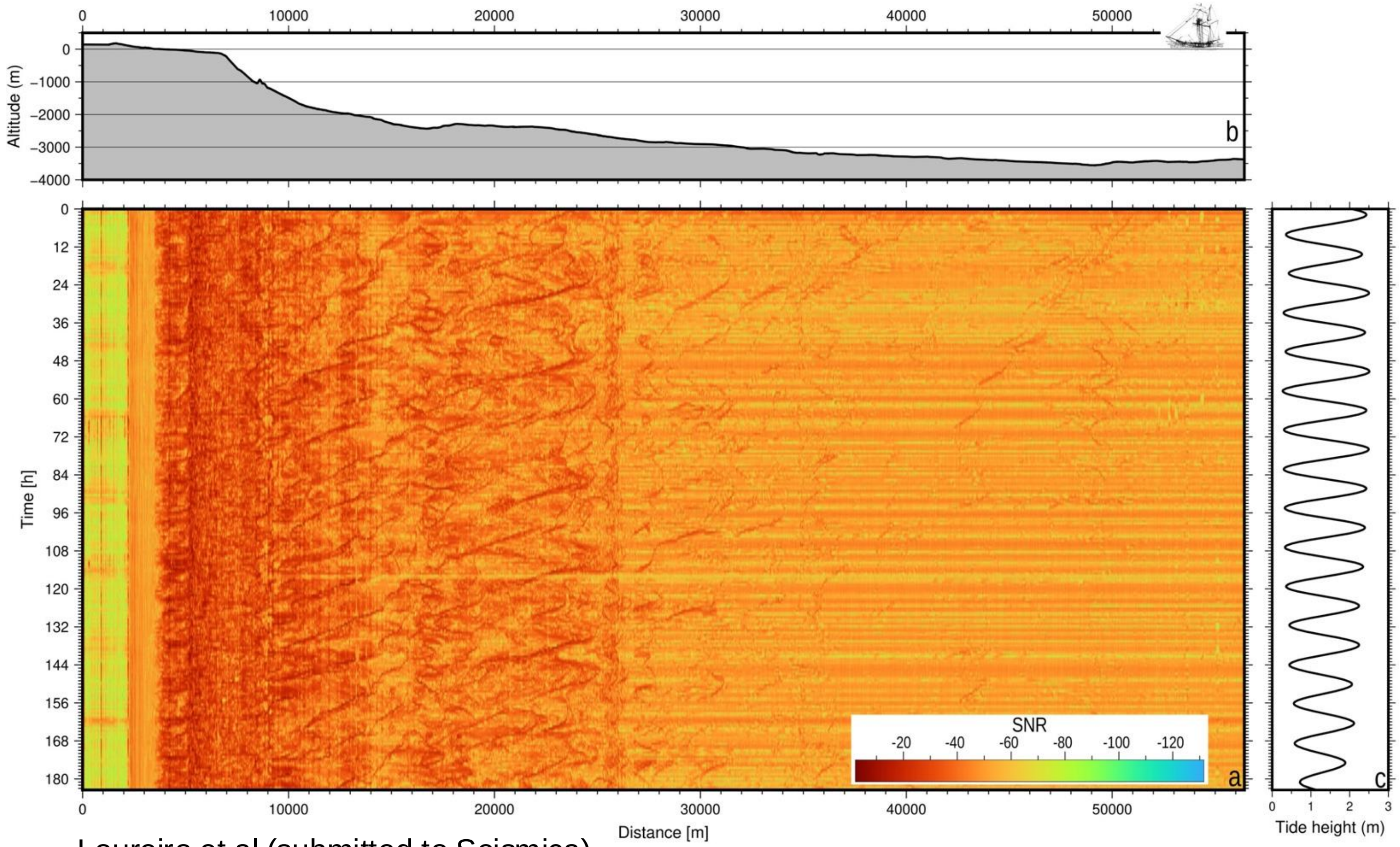
ϵ encompasses all factors not present on seismometers:
Temperature, pressure, non-linear angular sensitivity, geometric low-pass filtering, etc.

Major challenge: the response of DAS

An example of ϵ:

Imprint of temperature fluctuations on “strain” data



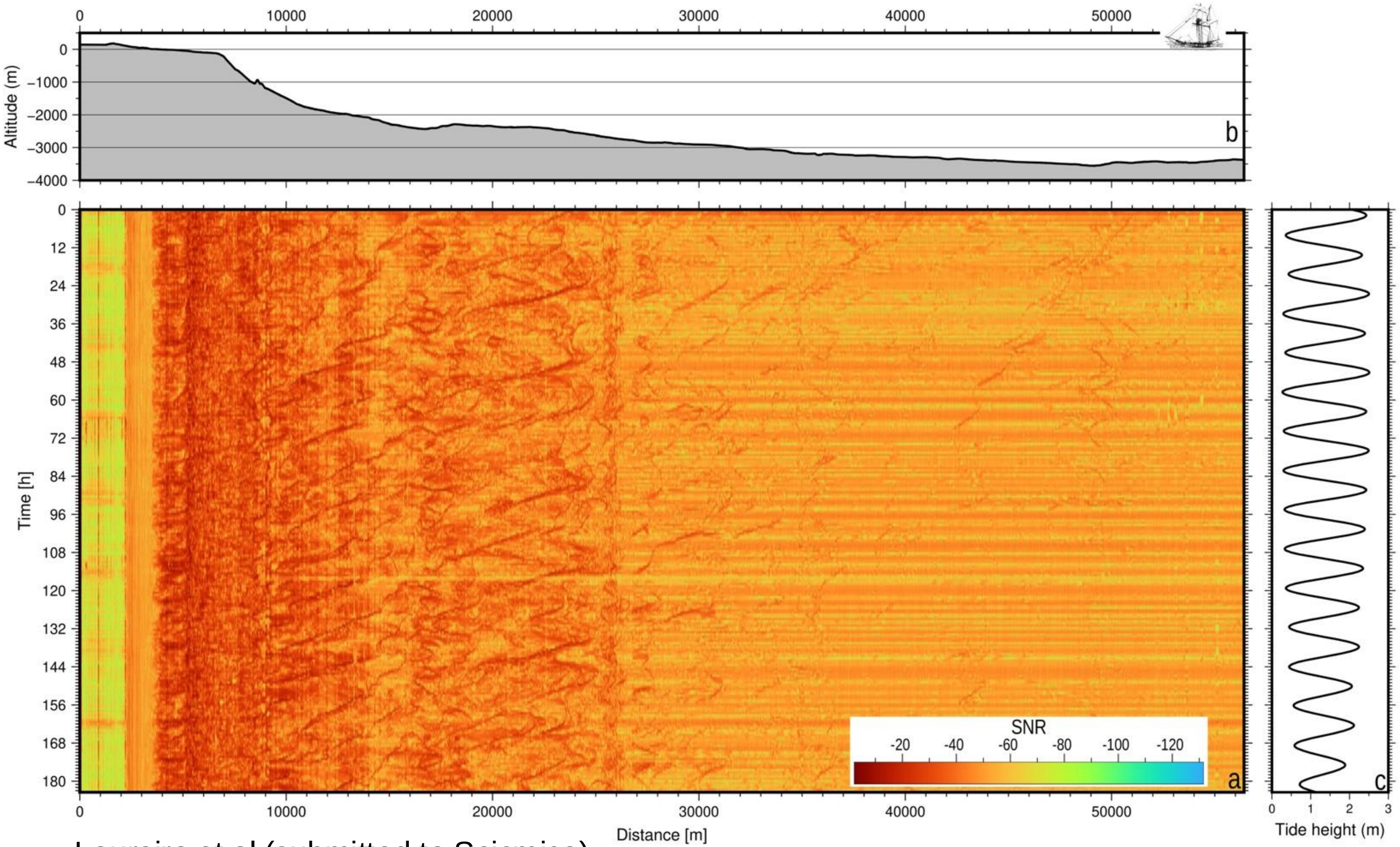


Loureiro et al (submitted to Seismica)

Major opportunity: interdisciplinary studies

Being sensitive to more than one parameter can also bridge more than one scientific area

e.g. seismology and oceanography



Loureiro et al (submitted to Seismica)

Major opportunity: interdisciplinary studies

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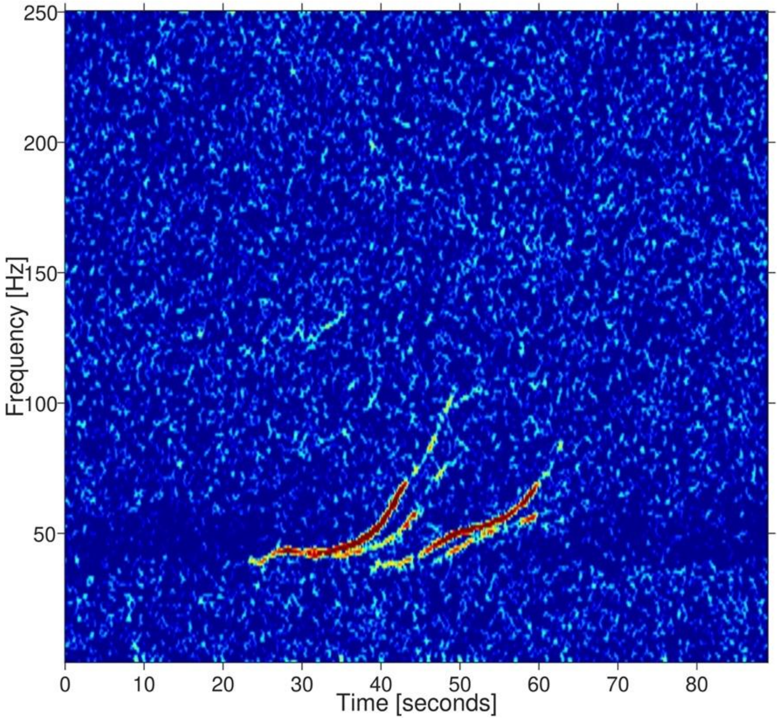
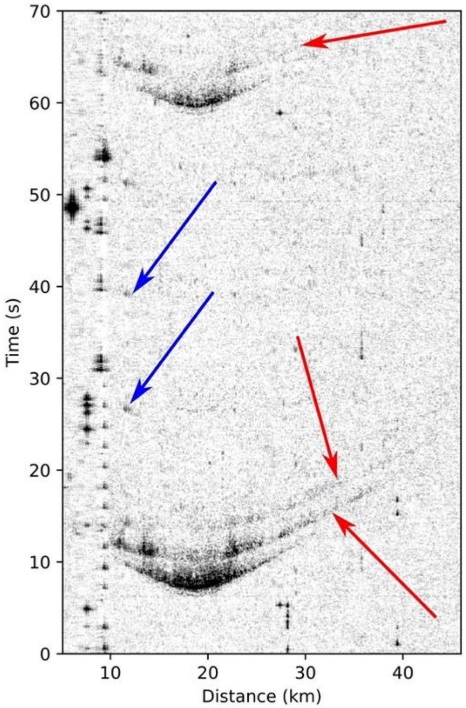
Whale identification and tracking





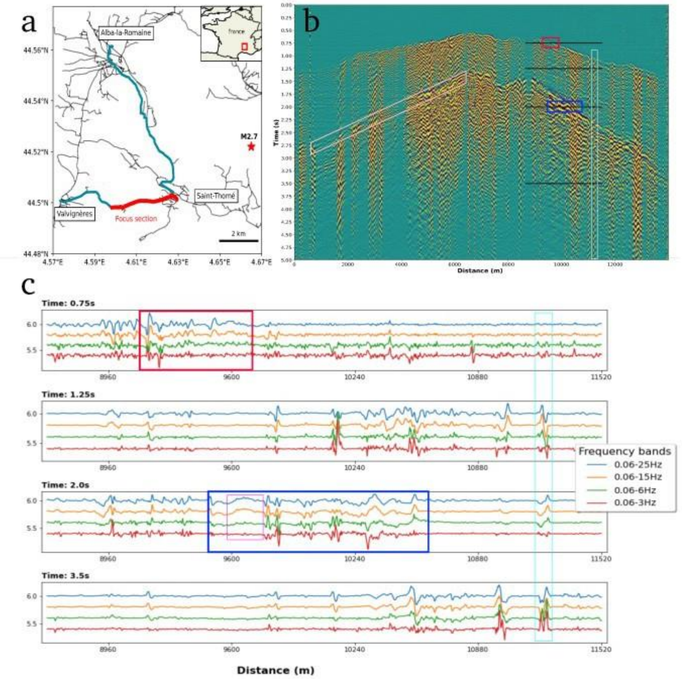
Loureiro et al (submitted to Seismica)

Recording earthquakes with DAS

Not having a transfer function doesn't affect the ability to record seismic events, especially if multiple channels are combined to increase SNR

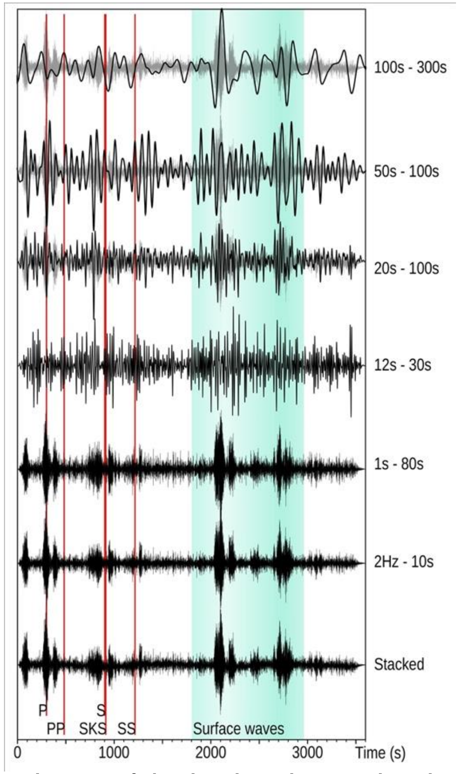
However, combining neighbouring DAS channels introduces a low-pass filter

And, different arrival azimuths also introduce different low-pass filters



Capdeville et al (2024)

Mw 6.7 (31/10/2023 12:33:44)
Near Coast of Central Chile

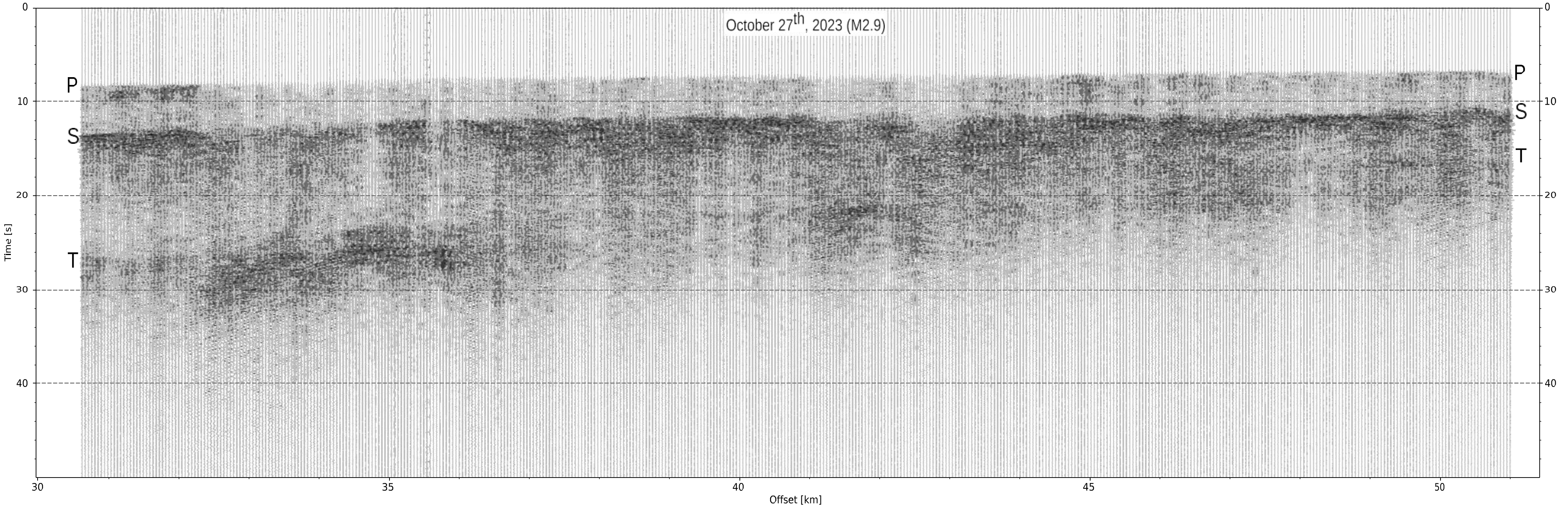


Loureiro et al (submitted to Seismica)

Recorded amplitudes and waveforms are not reliable!

Recording earthquakes with DAS

The ultra-dense network of sensors partly compensates for the drawbacks

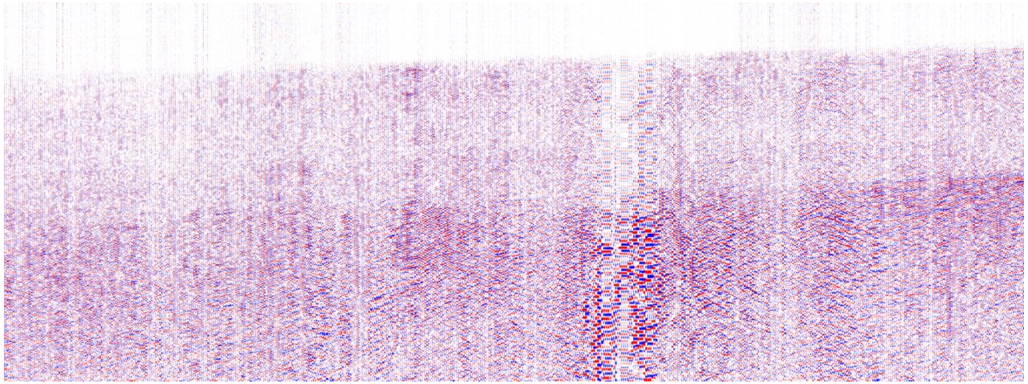


Loureiro et al (submitted to Seismica)

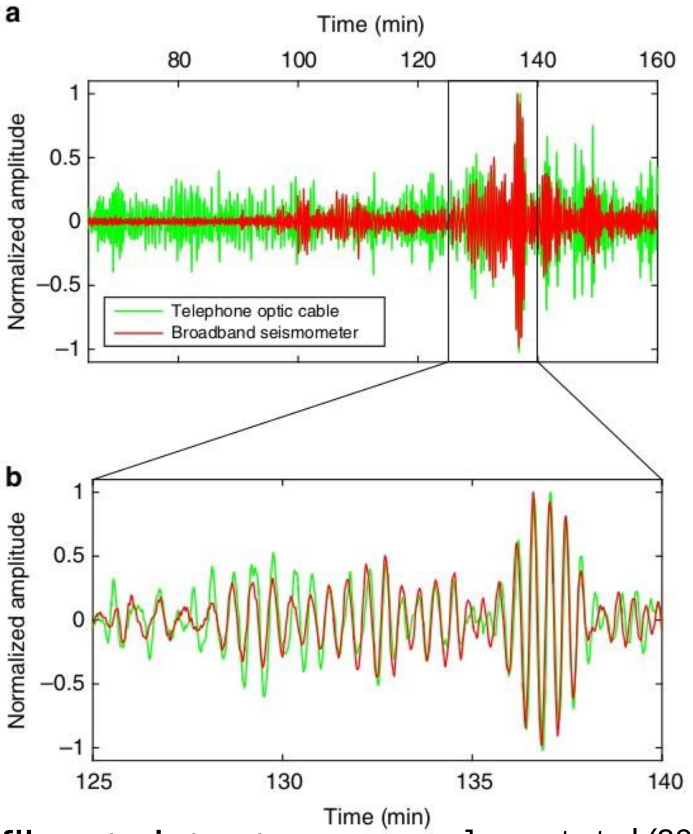
Getting a transfer function

Experiments with co-located seismometers allow to obtain local transfer functions valid for **<u>short</u>** cable sections

- Coupling* is highly variable



Loureiro et al (submitted to Seismica)



Jousset et al (2018)

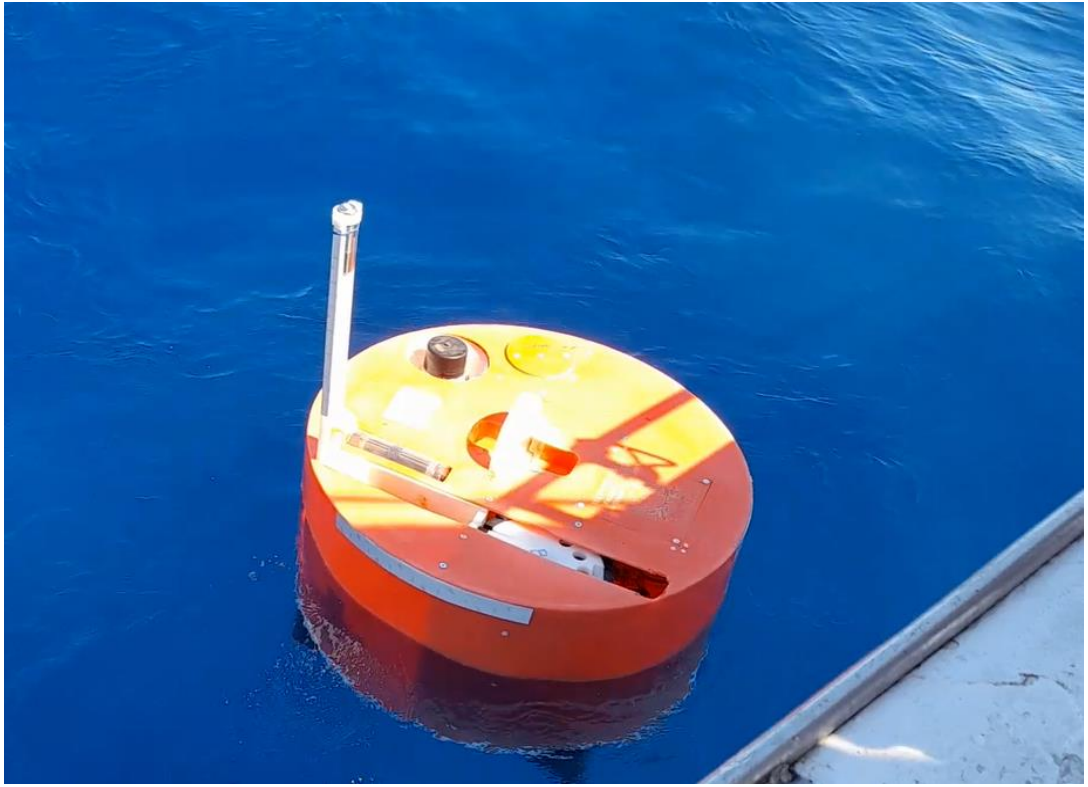
* ground coupling, fibre casing and jacketing transmission, fibre twist, etc.

Getting a transfer function

Site calibration is necessary to reduce the ϵ term in the transfer function

Target areas should be the highest SNR channels, or groups of neighbouring channels with similar SNR

OBS deployments are crucial for the characterisation of undersea cables



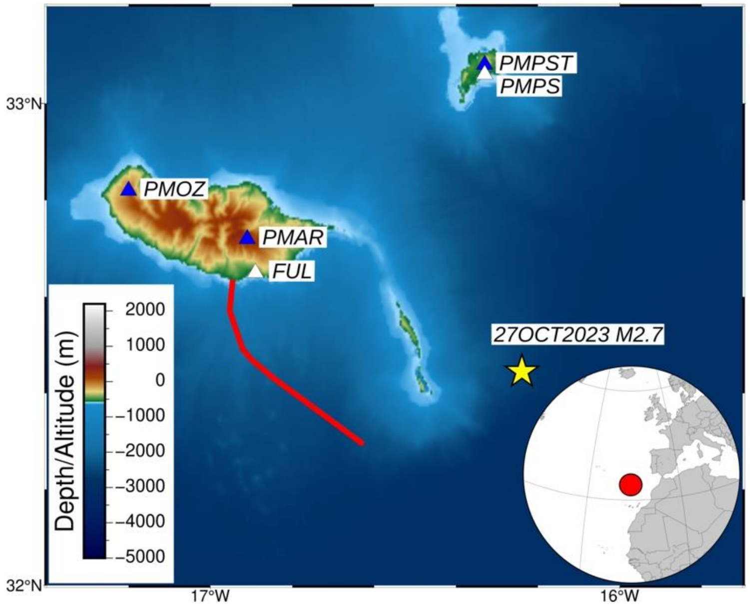
Call for collaborative projects

Within the framework of Geo-INQUIRE, the EllaLink GeoLab Madeira testbed is providing Transnational Access for collaborative projects

ARDITI will support in the configuration of the interrogator for each experiment target

GFZ provides long-term preservation of the datasets

Call for projects will be open on December 9th through geo-inquire.eu



Take-home message

1) Data density is unmatched, but the size of DAS datasets impose challenges on time, storage and manpower

2) A (still) open problem is the response of optical fibre to ground motion
Site calibration is a partial solution

3) Data richness far beyond the original concept behind the acquisition opens up opportunities for international and inter-disciplinary collaboration

4) Geo-INQUIRE calls for Transnational Access to the GeoLab fibre are open

Thank you!