Distributed sensing of earthquakes and ocean-solid Earth interactions on seafloor telecom cables
-
from the coast to the abyssal plain

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Ocean floor instrumentation

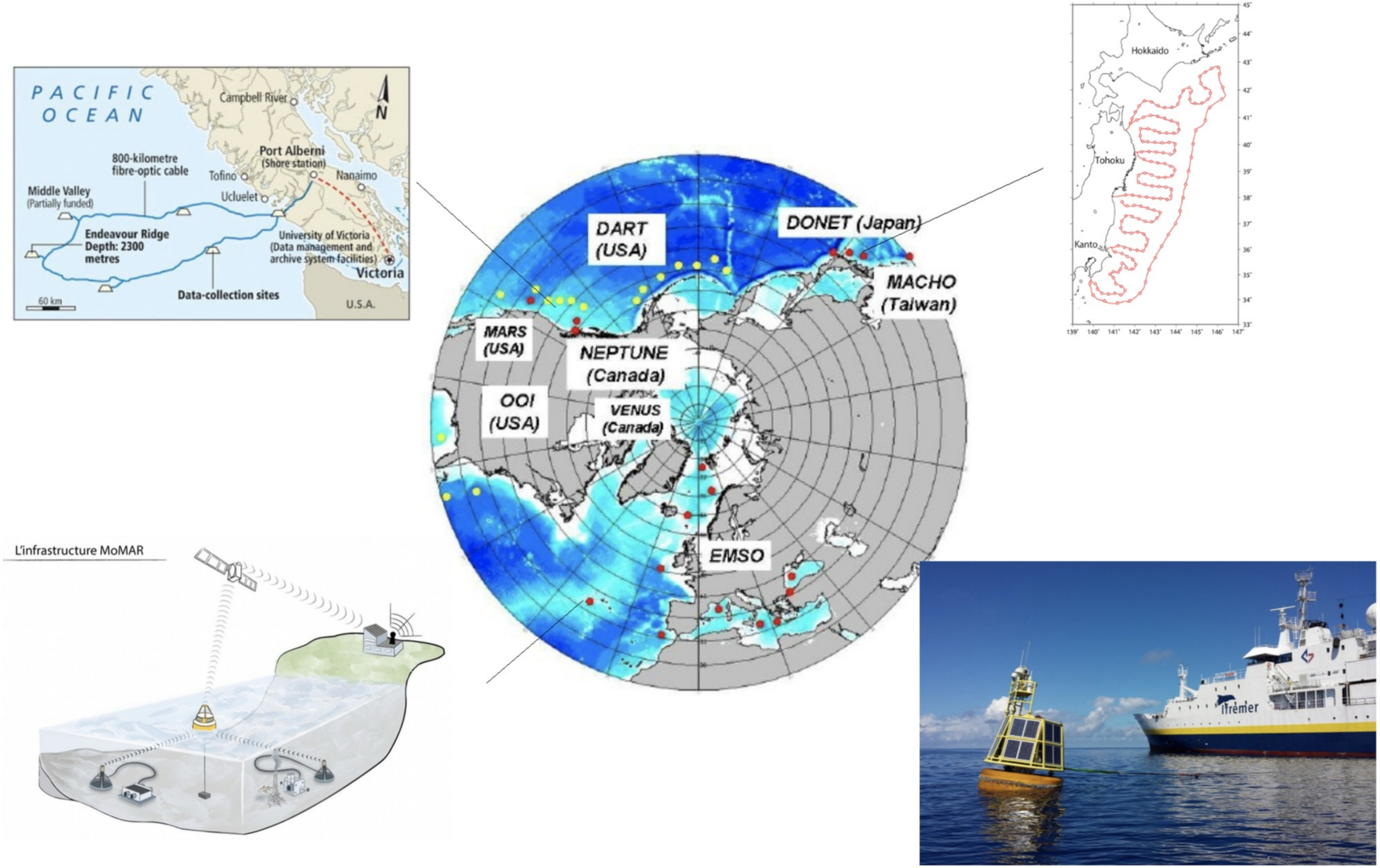
a long-standing quest with numerous scientific, societal and economic stakes

- Dynamics of the oceans
- Internal structure of the Earth
- Interaction between biology, geology and oceans

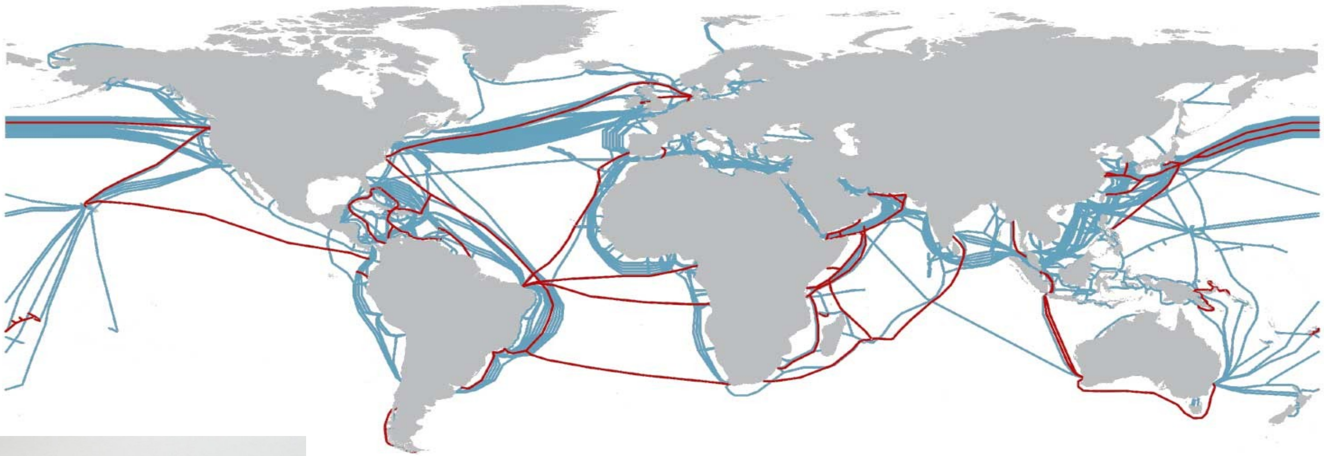
Monitoring of various natural resources

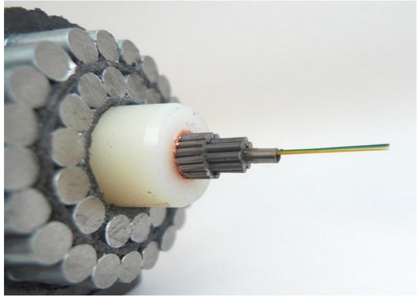
Natural hazards Earthquakes, tsunamis, landslides

...yet seafloor instrumentation is very limited

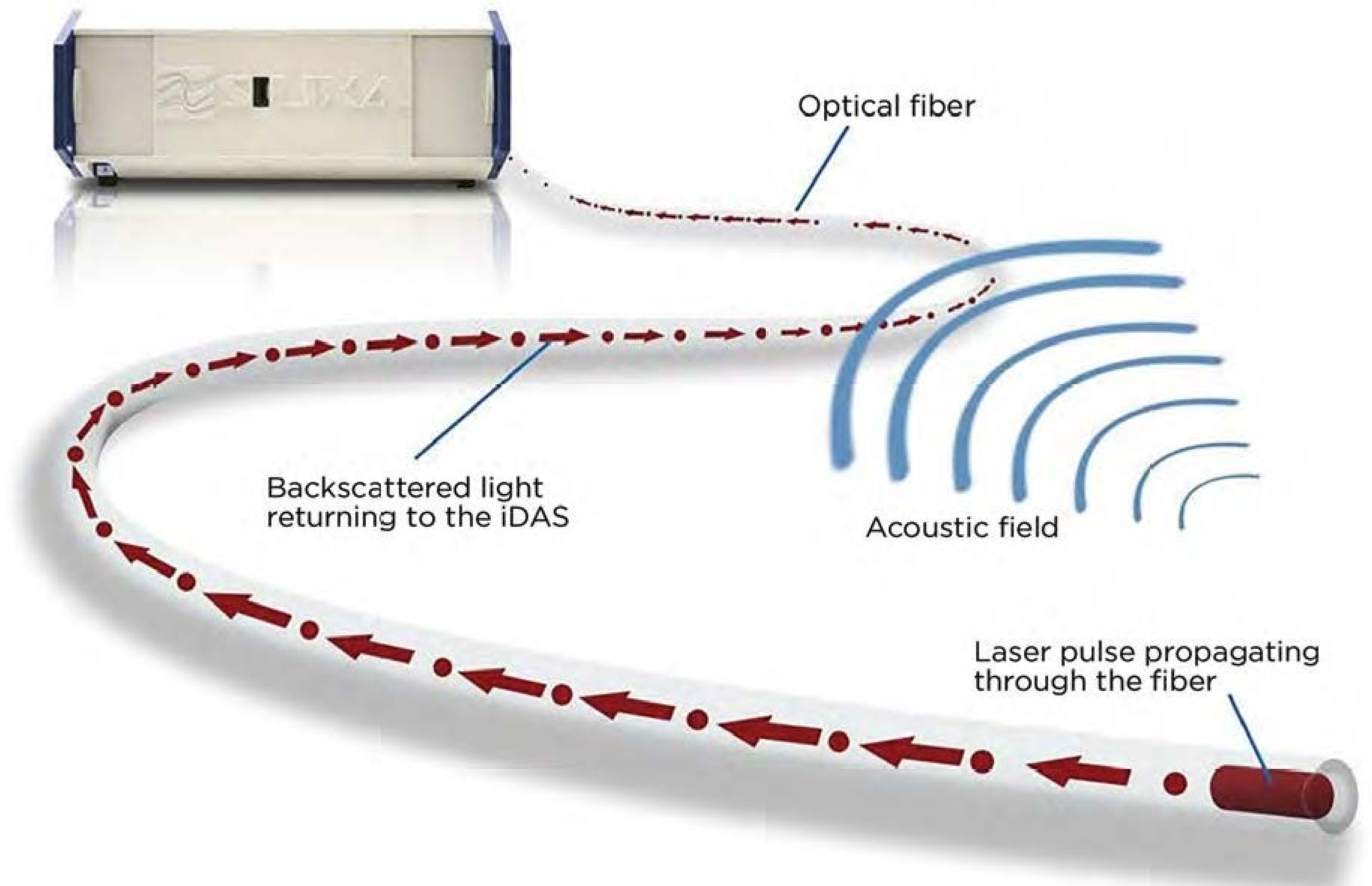


But what about seafloor telecom cables ?





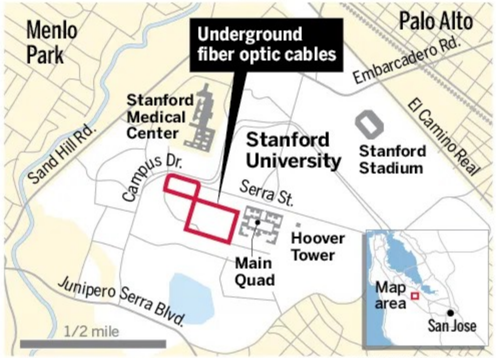
Distributed acoustic sensing (DAS)



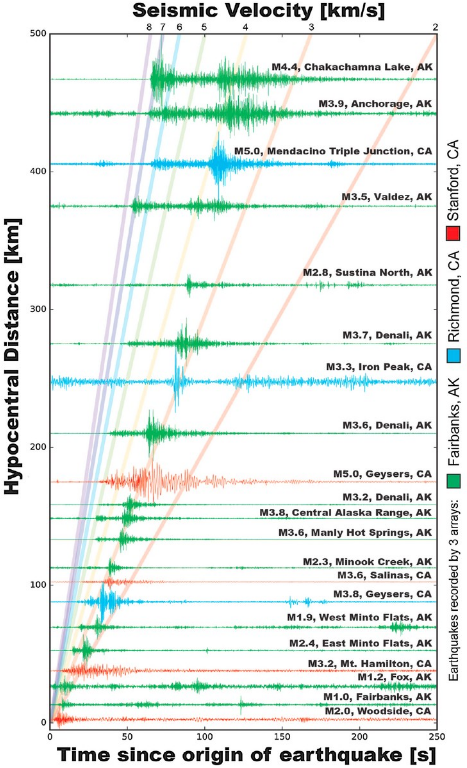
DAS works with non-coupled fibers!

LISTENING WITH FIBER OPTICS

The Big Glass Microphone project involves creating an online animation demonstrating what a three-mile stretch of fiber optic cables beneath the Stanford campus can detect. The cables, installed for seismic research, can distinguish between a pedestrian and a bicyclist and should eventually be able to tell the difference between different car models and how many people are riding in them.

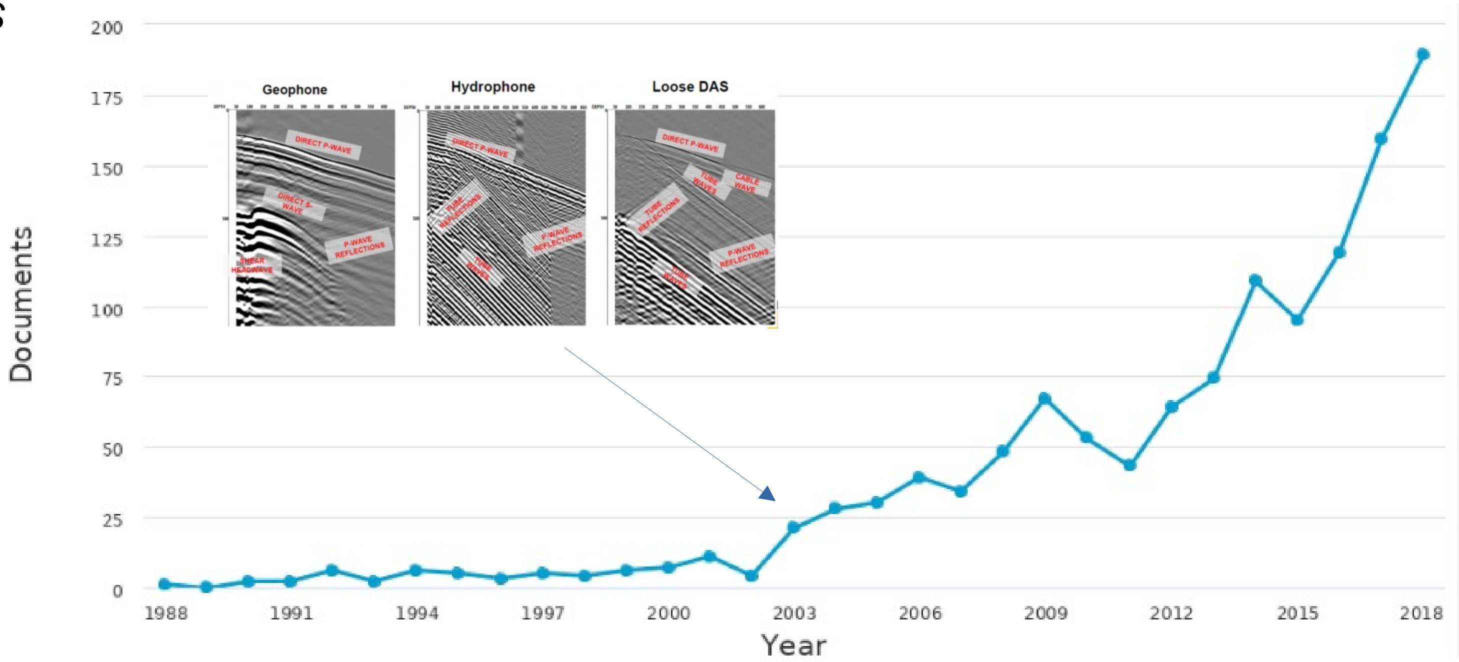


BAY AREA NEWS GROUP

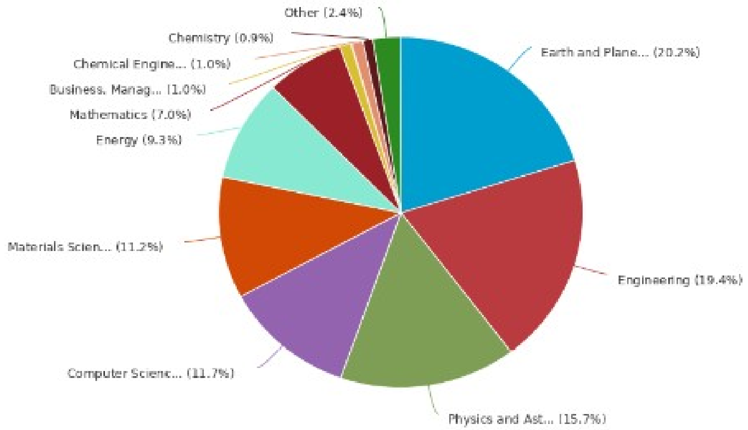


Lindsey N. J., Martin, E. R., Dreger, D. S., Freifeld, B., Cole, S., James, S. R., ... Ajo-Franklin, J. B. (2017). Fiber-optic network observations of earthquake wavefields. **Geophysical Research Letters**,44, 11,792–11,799.https://doi.org/10.1002/2017GL075722

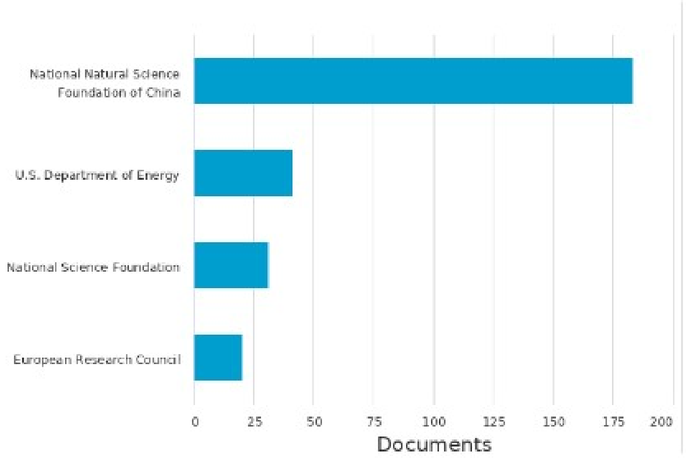
Nb of articles about DAS (Scopus)



(a)

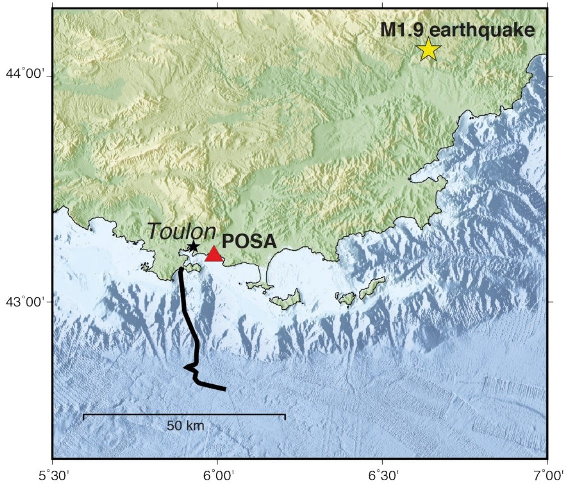


(b)

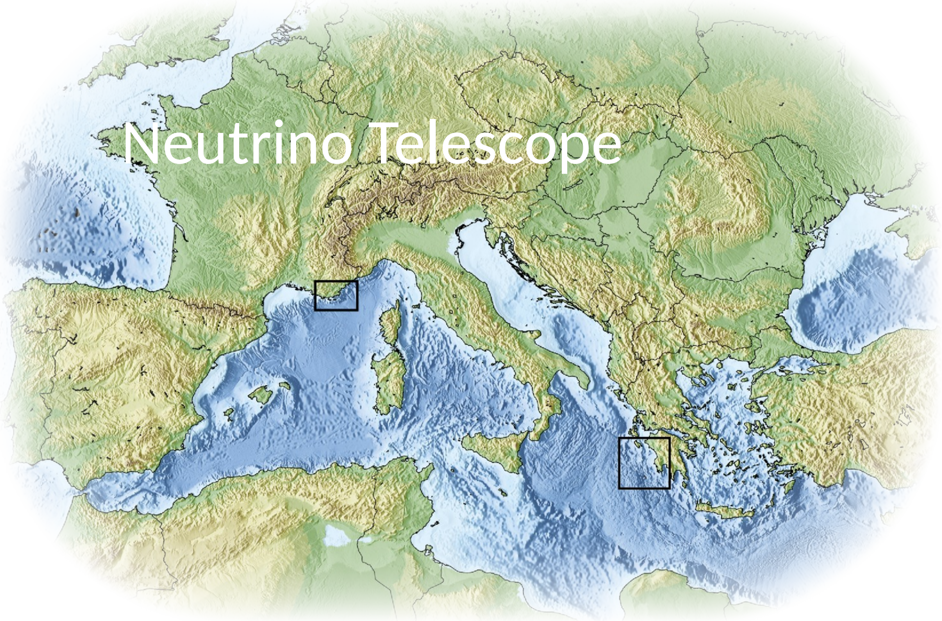


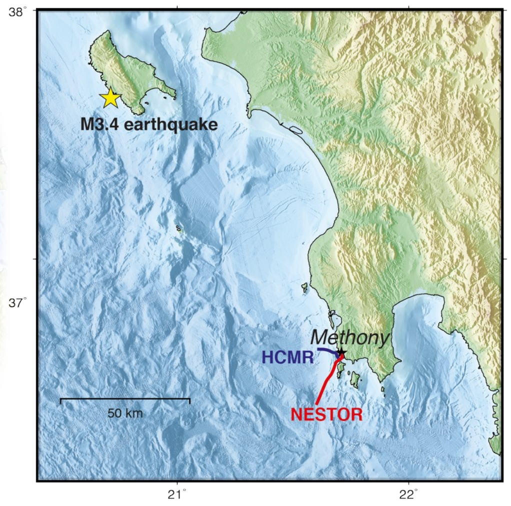
(c)

DAS experiments on 3 telecom-like cables in Toulon and SW Greece



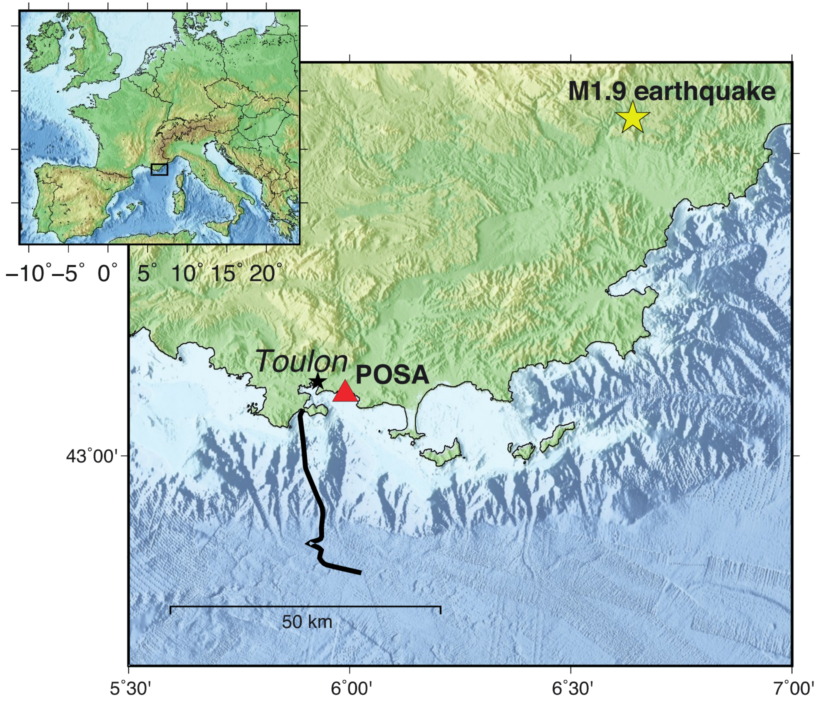
MEUST/KM3NET

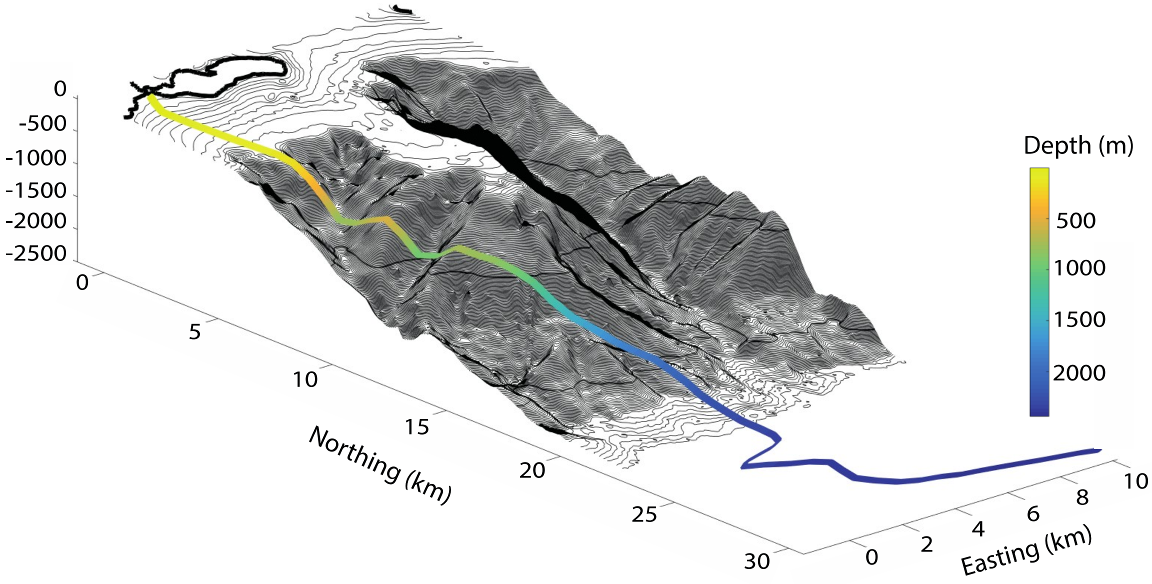


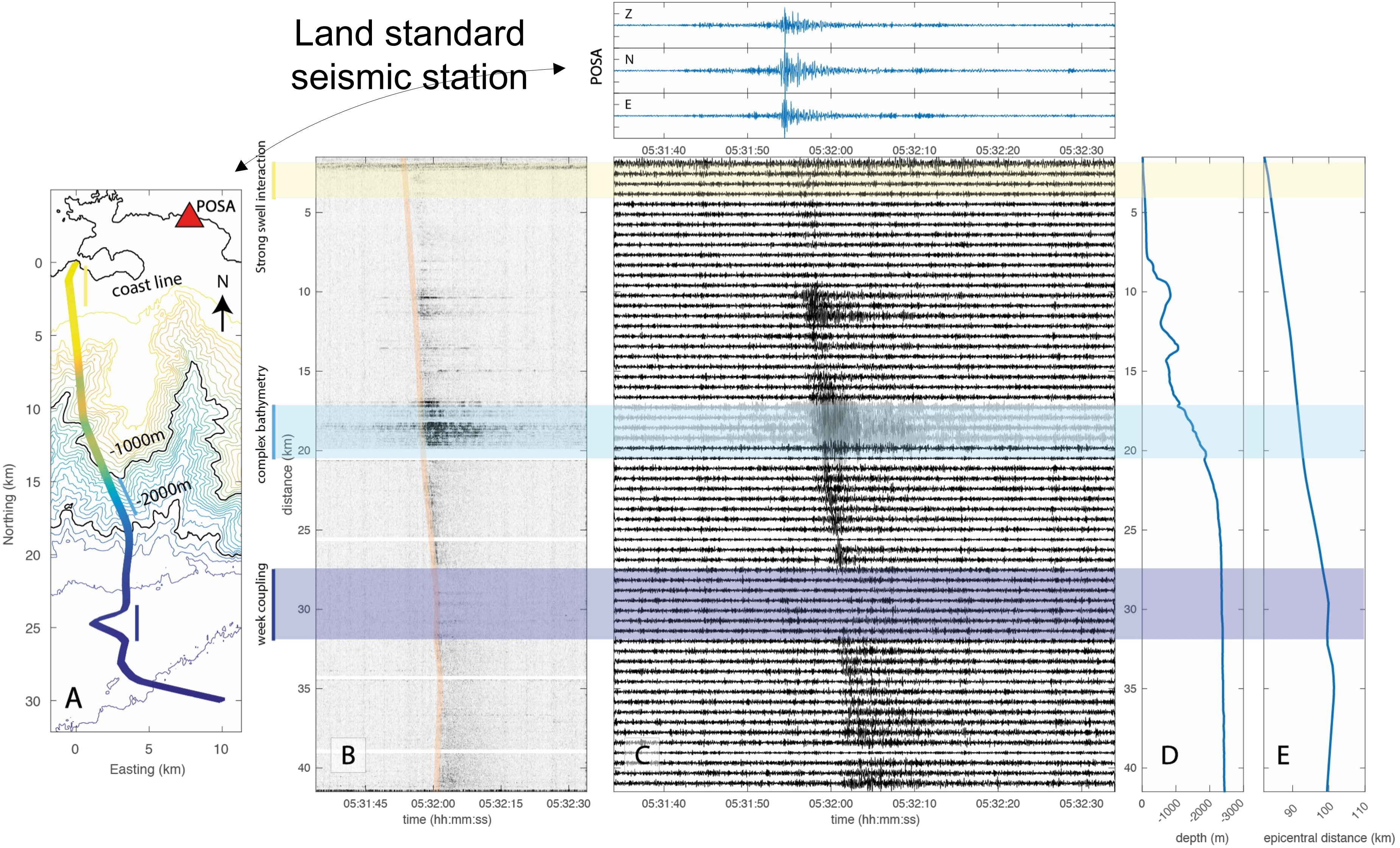


NESTOR project

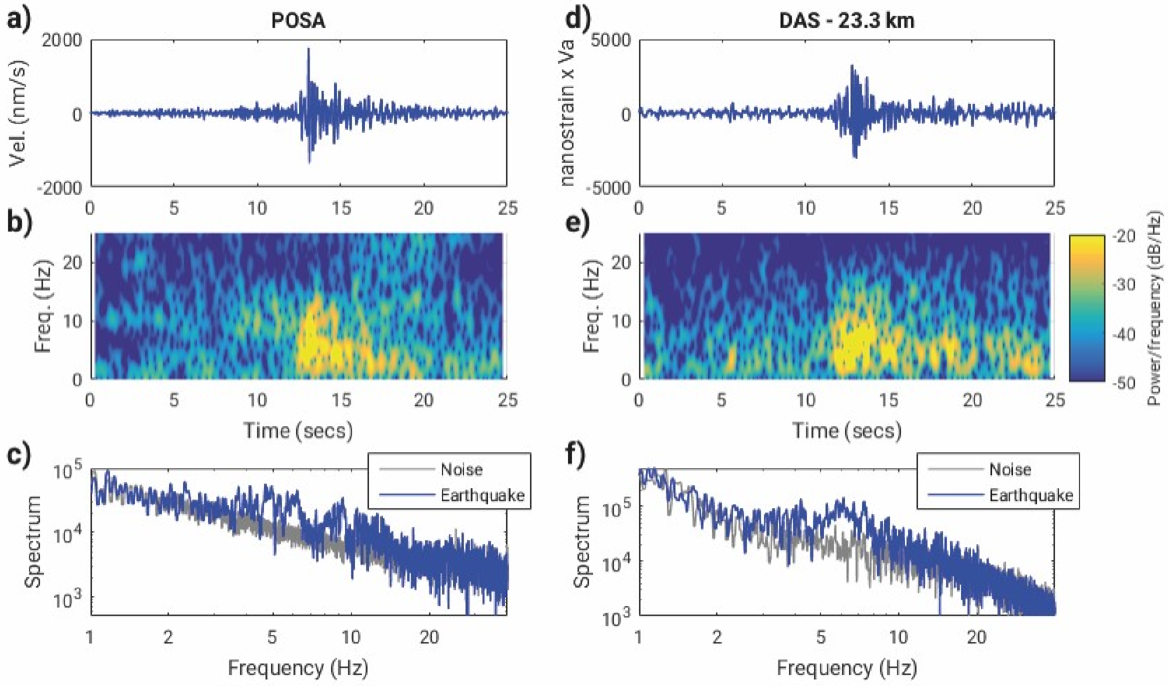
A M1.9 earthquake detected on the MEUST cable





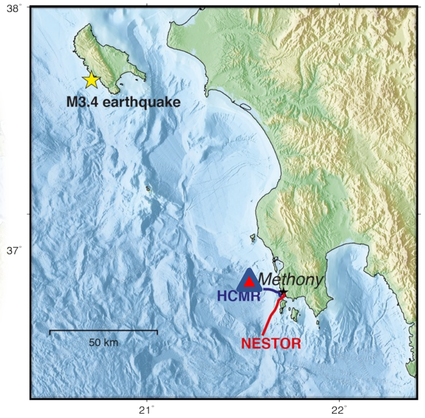


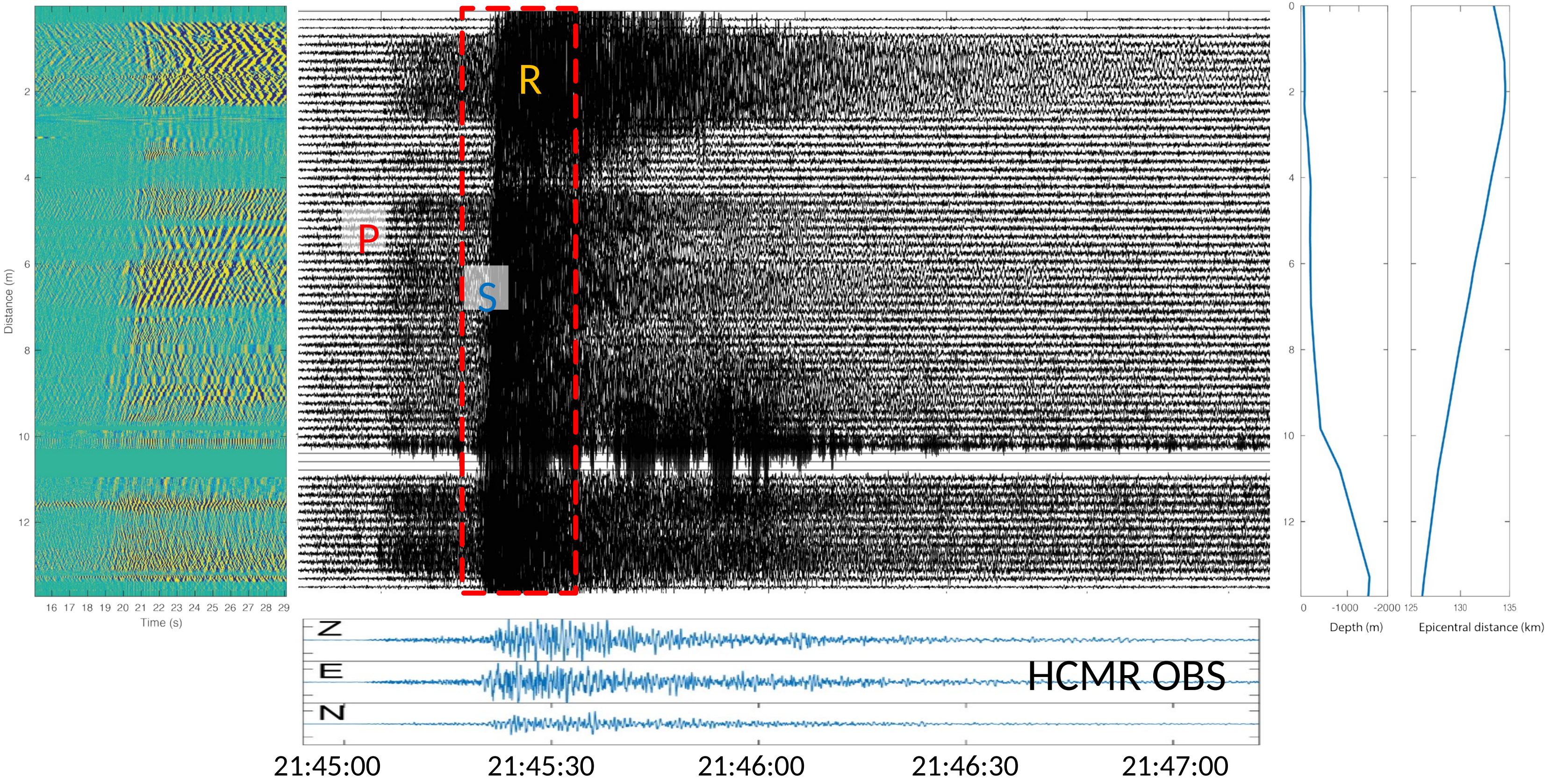
Land standard seismic station
POSA
Z
N
E
05:31:40
05:31:50
05:32:00
05:32:10
05:32:20
05:32:30
Strong swell interaction
complex bathymetry
week coupling
POSA
coast line
N
-1000m
-2000m
A
Northing (km)
Easting (km)
distance (km)
B
05:31:45
05:32:00
05:32:15
05:32:30
time (hh:mm:ss)
C
D
depth (m)
E
epicentral distance (km)



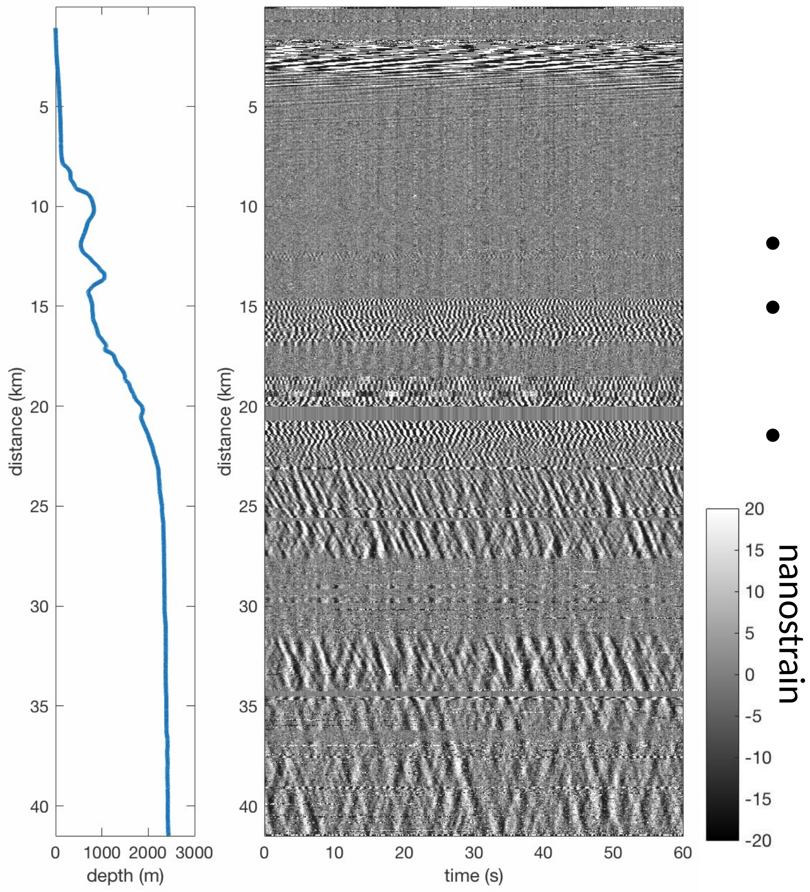
Averaged over 350m of cable
(~70 points of measurement)

A M3.4 earthquake detected on the HCMR cable



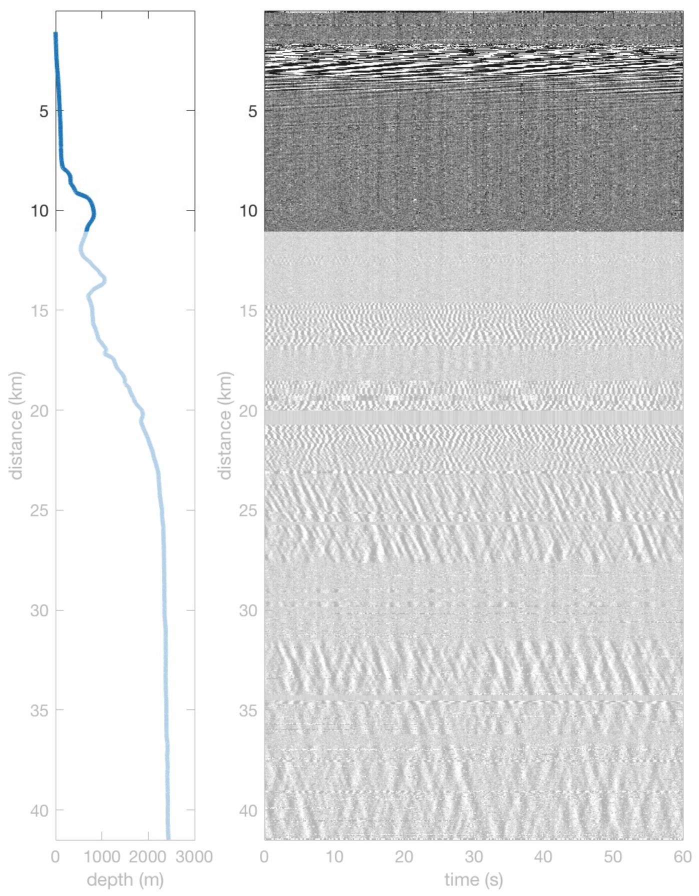


Ocean solid-Earth interactions



- Monitoring the evolution of different types of waves
- Multi-scale observation (m-km) of the wave-bathymmetry interaction
- Generation of microseismic noise

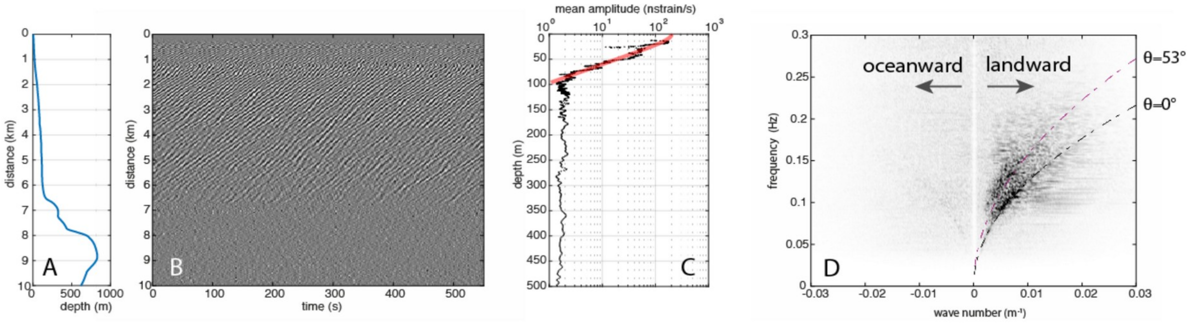
Ocean solid-Earth interactions

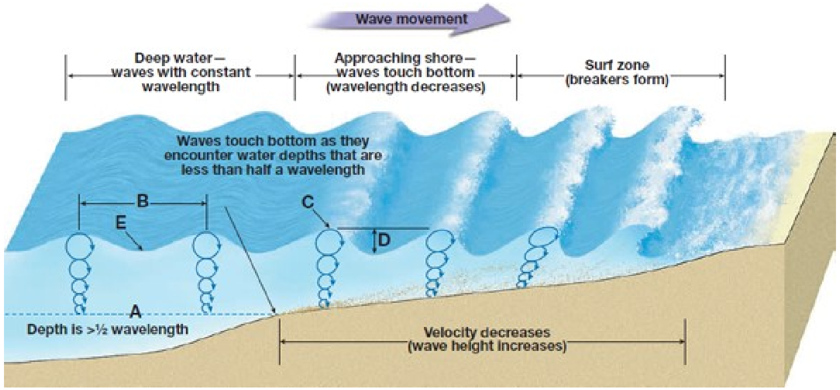


Depth < 100m

Coastal environment

Gravity waves and primary microseism

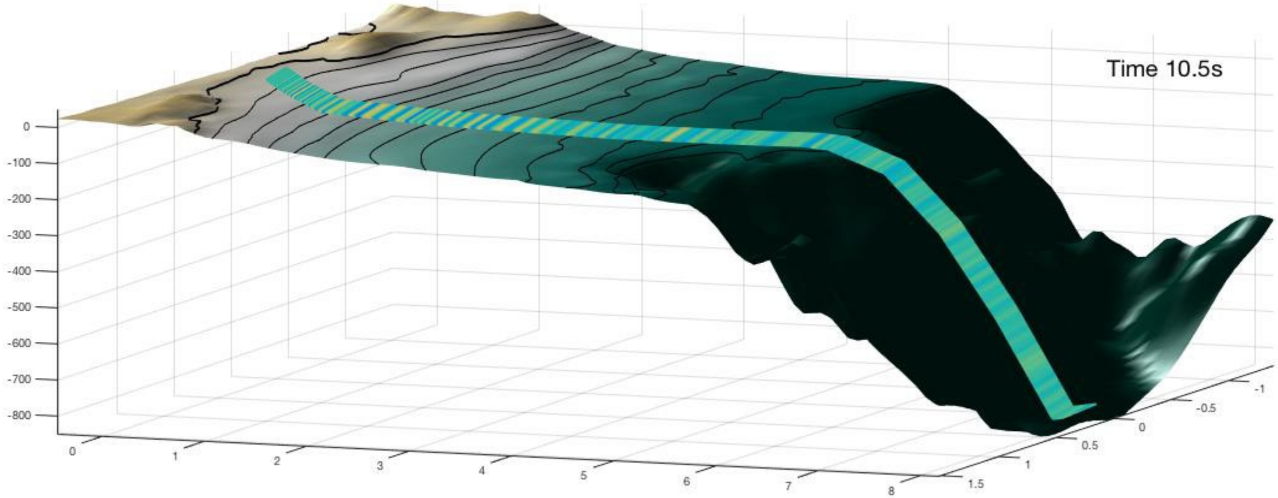




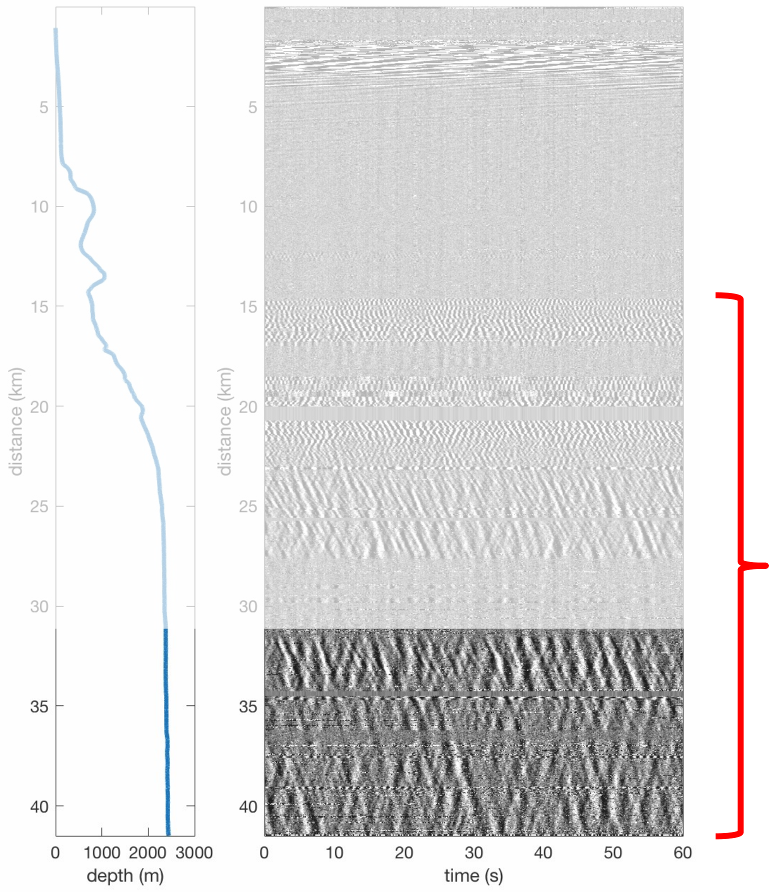
$$\frac{P_d(h)}{P_{d0}} = \frac{1}{\cosh\,(k.h)} \qquad \omega = \sqrt{g.k.tanh(k.h)}$$

Periodic oscillations 0.1 - 0.25 Hz, which propagate landward with **decreasing velocity** and **increasing amplitude**

Gravity waves and primary microseism

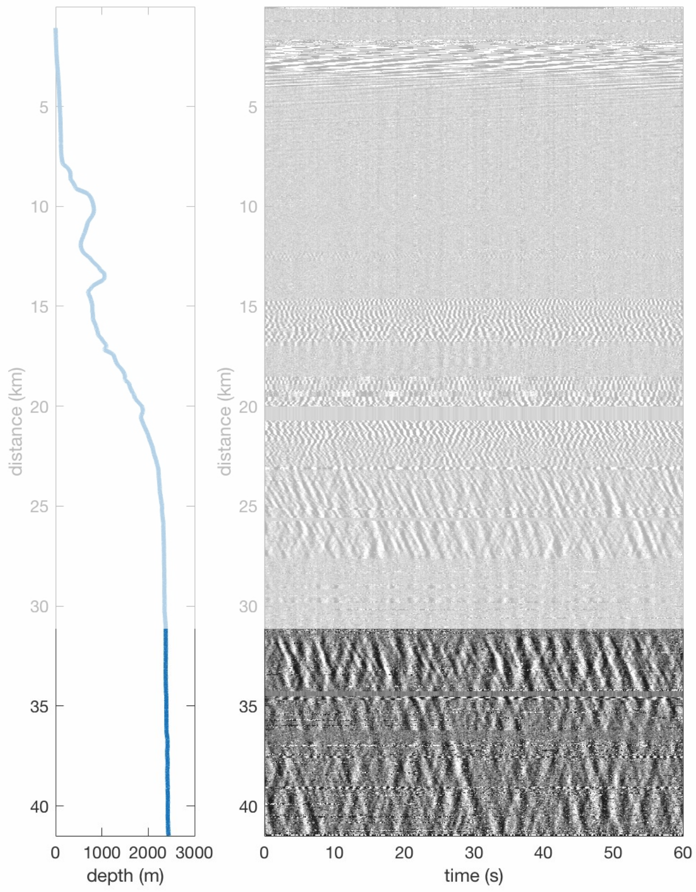


Nonlinear interaction - secondary microseism

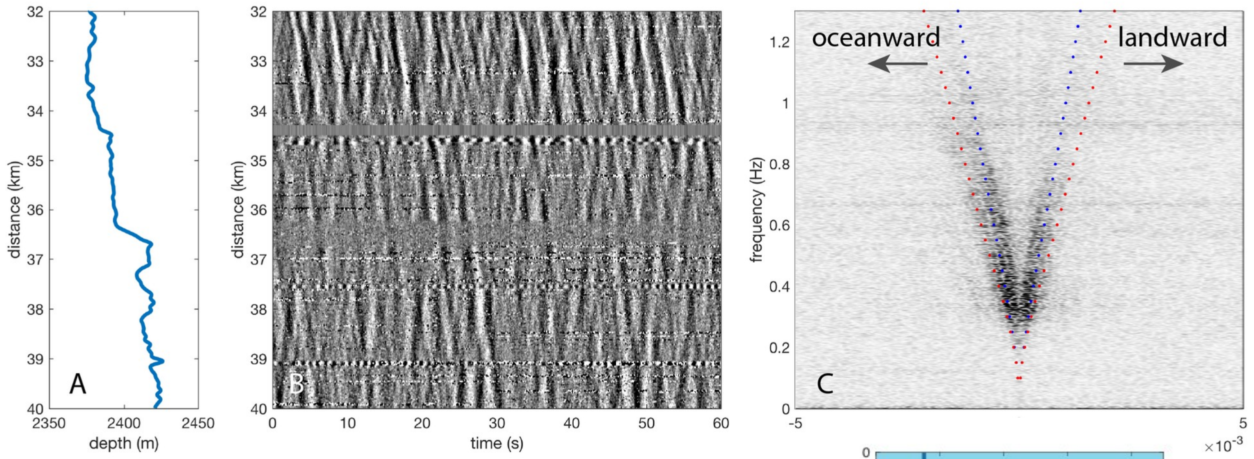


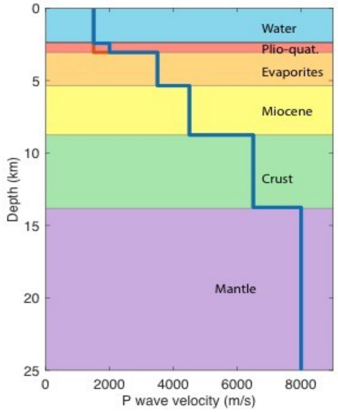
Depth = 2400m

Nonlinear interaction - secondary microseism

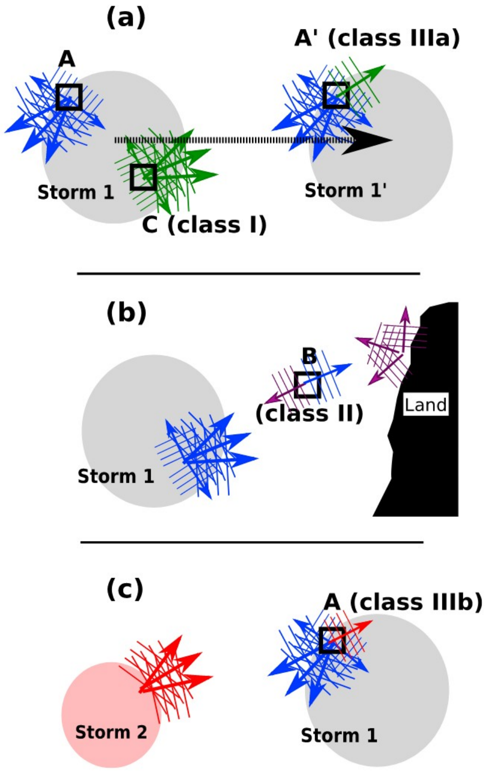


Depth = 2400m



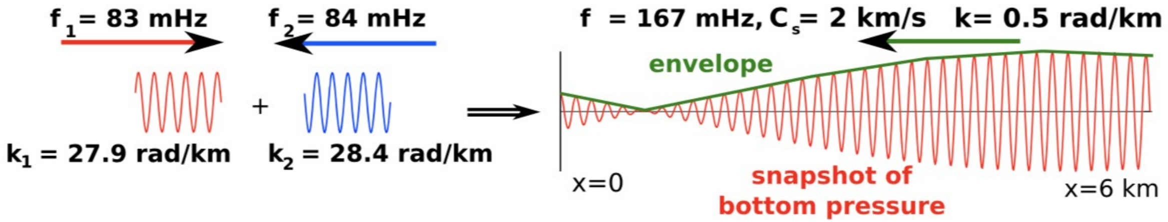


Nonlinear interaction - secondary microseism



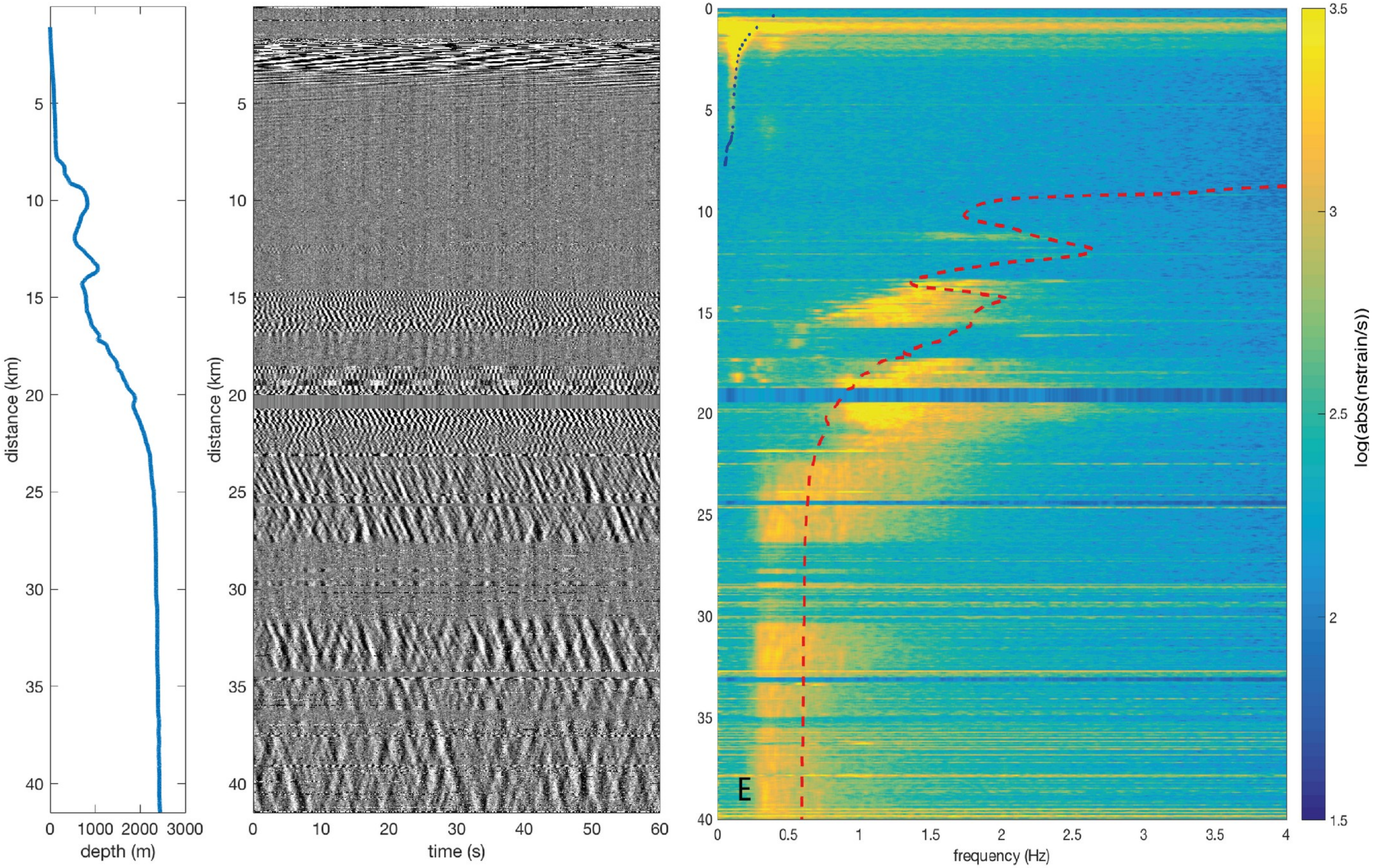
Ardhuin 2011

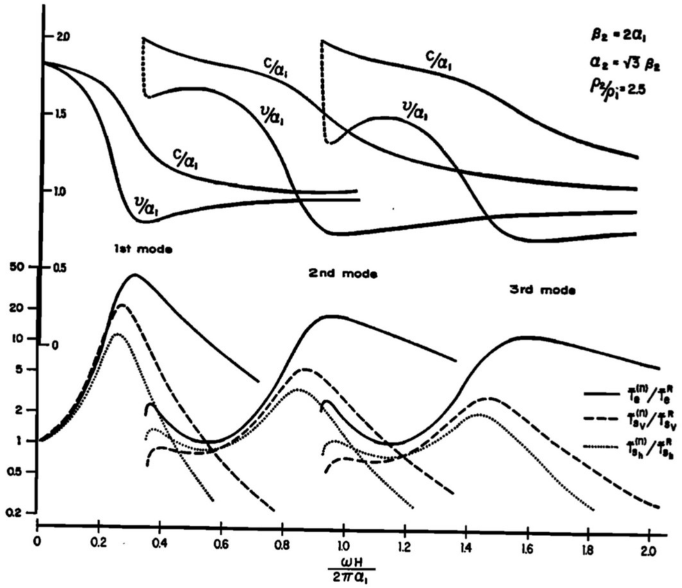
Longuet-Higgins (1950) showed that the unattenuated second-order pressure term in a standing wave pattern, was capable of generating microseisms.



Gualtieri et al. 2014

The ocean site effect on Sholte waves





Hasselman 1963

General conclusion

- Instrumental solution beyond hopes:
  - reliable,
  - large spectrum (0.1-5kHz range)
  - long distance (up to 40km)
  - Dense (every meters)
- Can sense earthquakes, ocean surface gravity waves, microseismic noise, boats… more ?
- Applications already within reach: earthquake+tsunami alert, marine weather, seafloor imagery

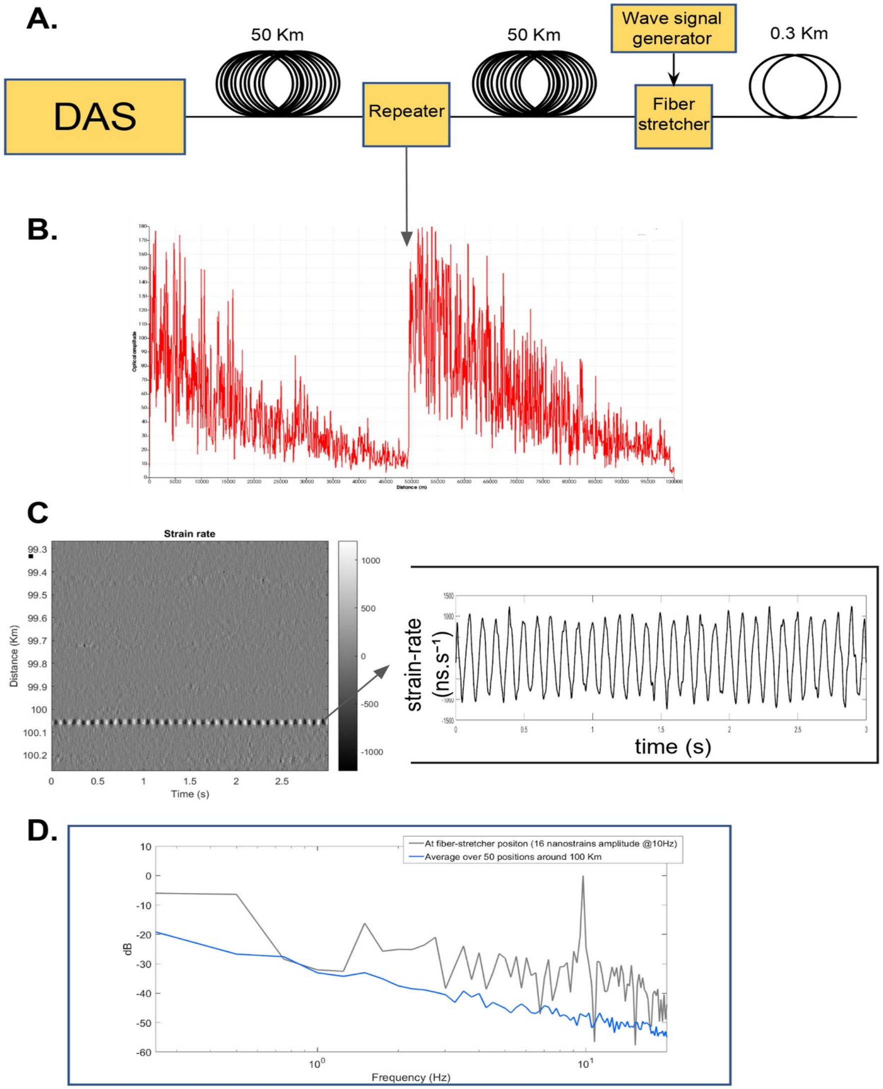
Sladen, A., Rivet, D., Ampuero, J., De Barros, L., Hello, Y., Calbris, G., & Lamare, P. (2019). Distributed sensing of earthquakes and ocean-solid Earth interactions on seafloor telecom cables, *Nature Communications* https://doi.org/10.31223/osf.io/ekrfy

Limitation and perspectives

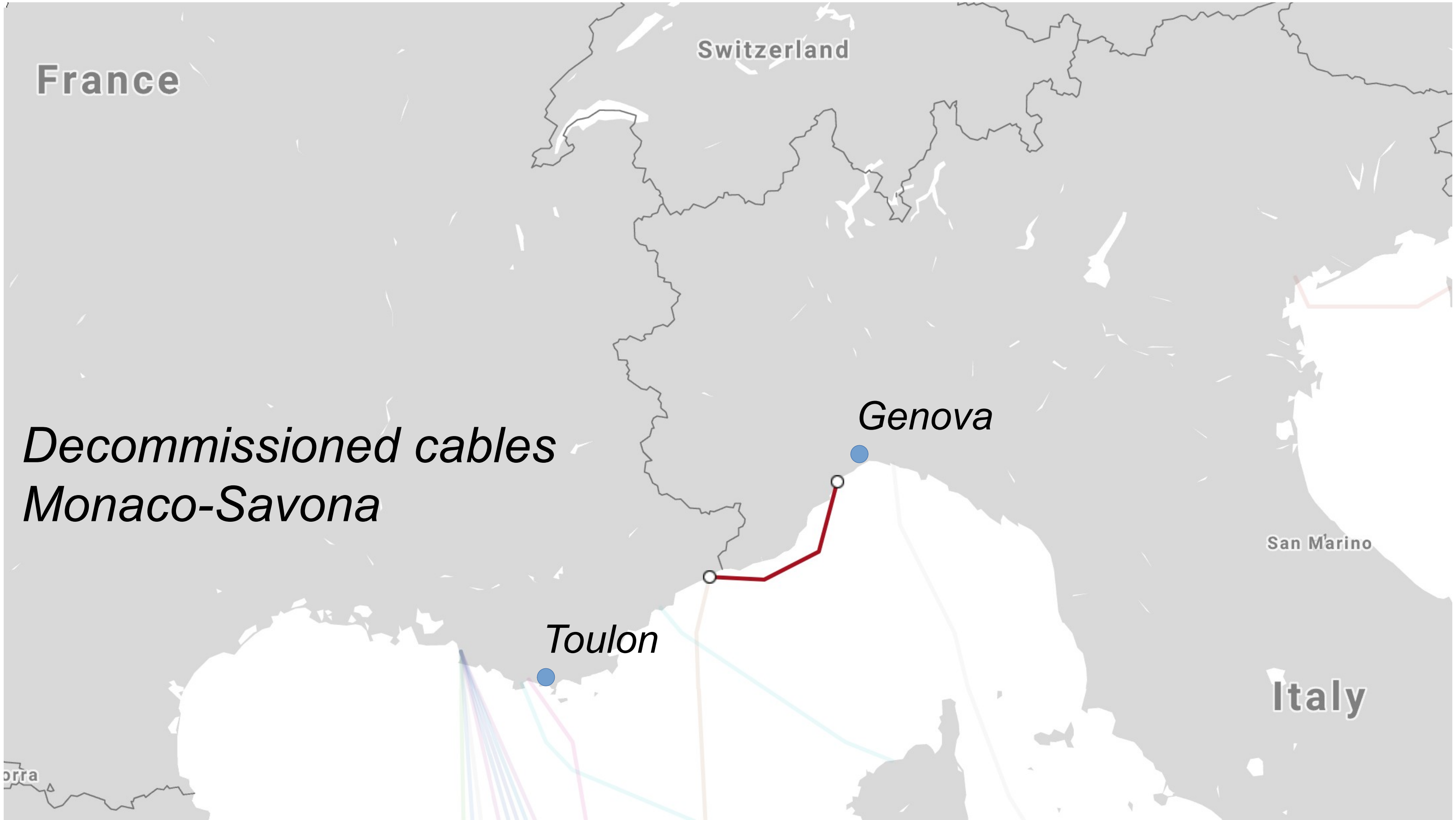
Bidirectional amplifier

- Standard range of DAS systems is about 50 km on a standard optical fiber
- Most existing cables were installed in the mid-2000’s and will have to be replaced in the next decade

FEBUS OPTICS
Distributed Optical Fiber Sensing



Instrumenting new sites for new observations

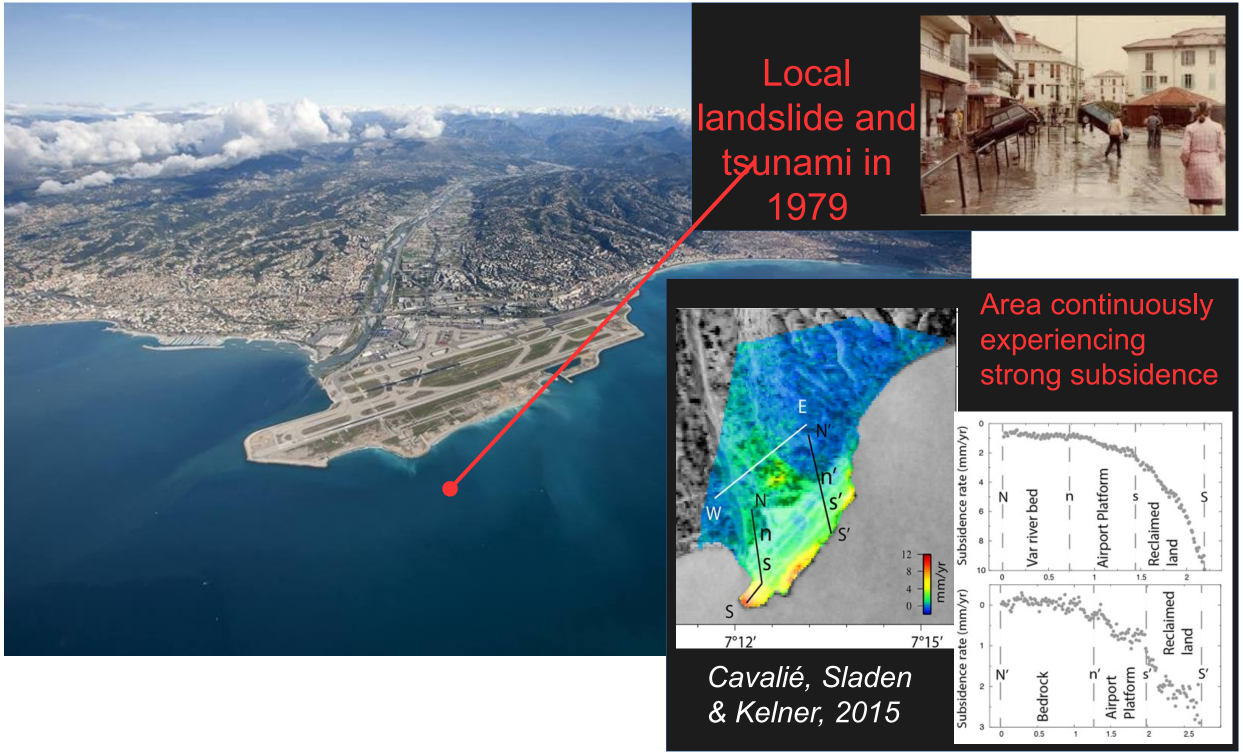


Instrumenting specific sites

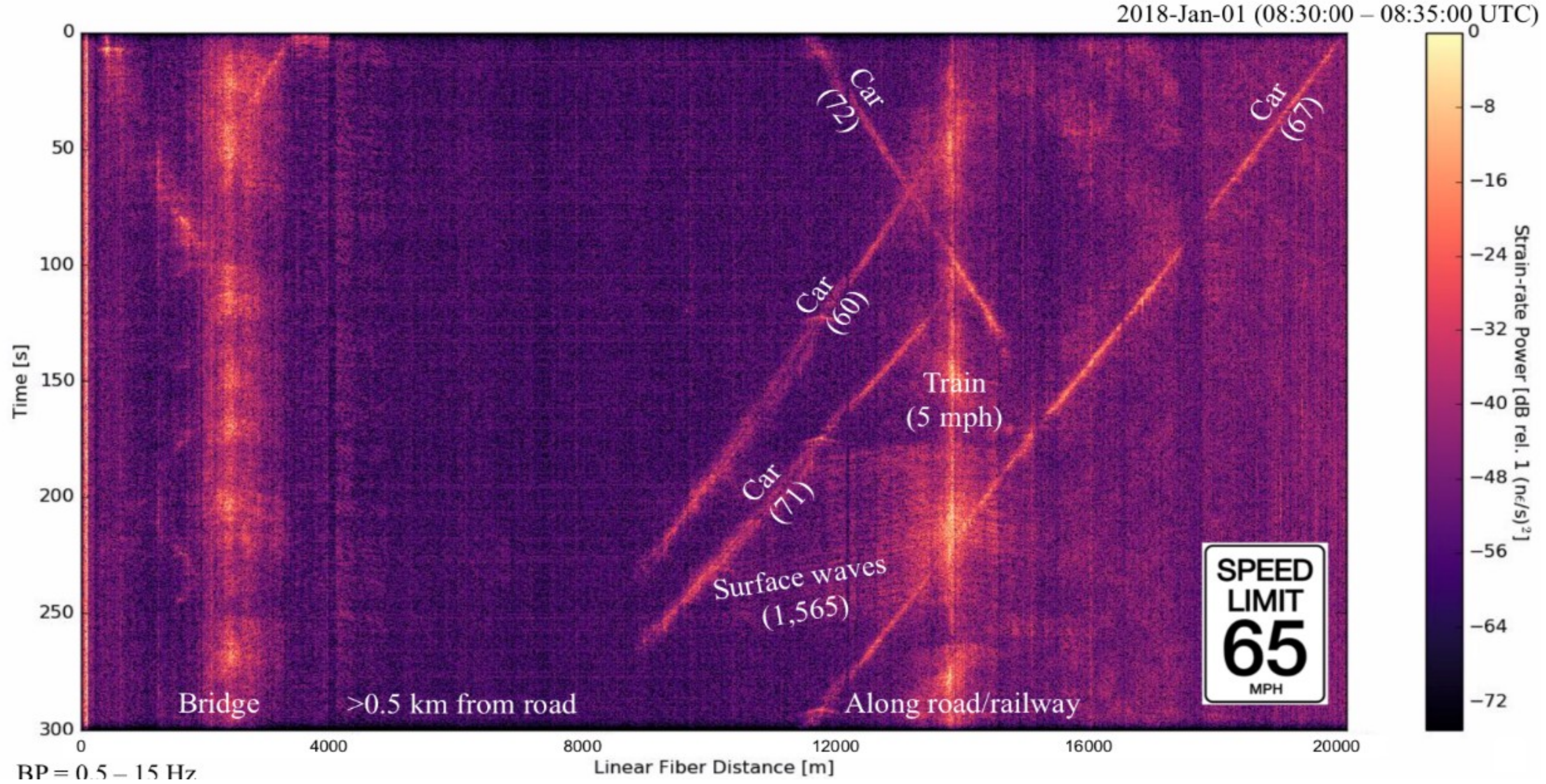
Dedicated cables

Cheap and can decide on the scientific target. But cable needs to be protected and anchored

Nice airport: a pilot test site



Land applications



Land applications

Teil earthquake M=5
November 11, 2019

~30 seismic station in 2 weeks

1400 DAS measurements in 3h