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Towards Tsunami Early-Warning with Distributed Acoustic Sensing (DAS)

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ICG/PTWS-XXXI Assembly

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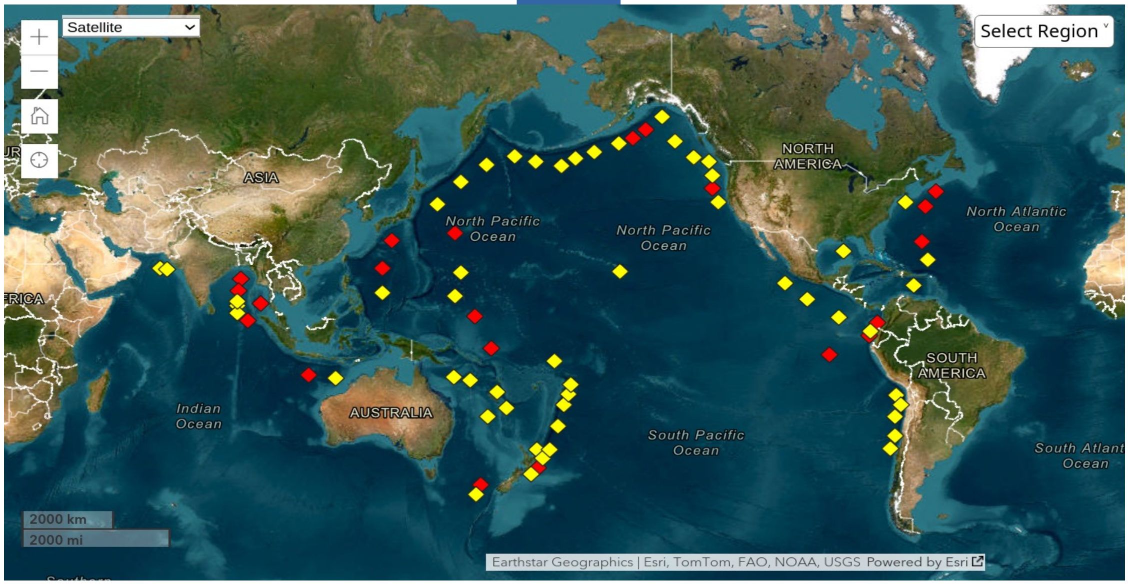
Tsunami Early Detection

DART System

- Global tsunami warning system
- ~ 60 Buoys worldwide
- Far-field tsunami forecast



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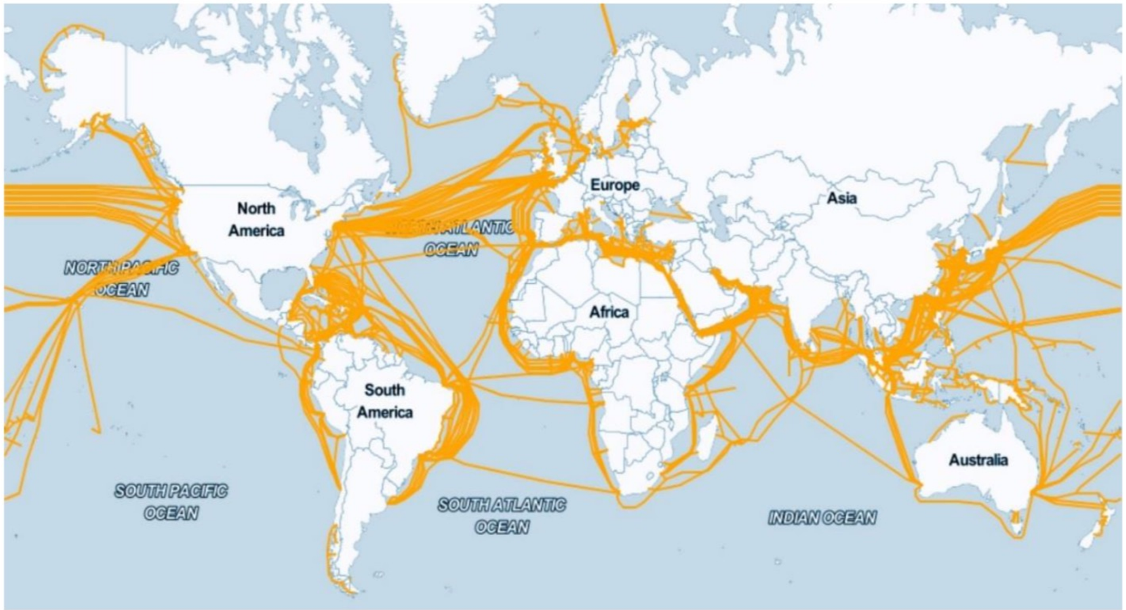
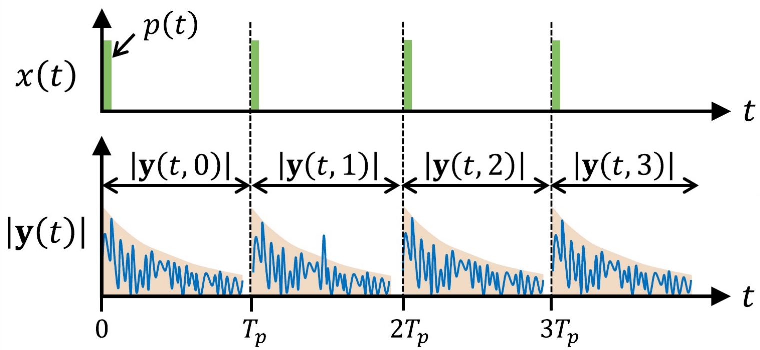
90% of deaths in the Pacific are from local or regional tsunamis

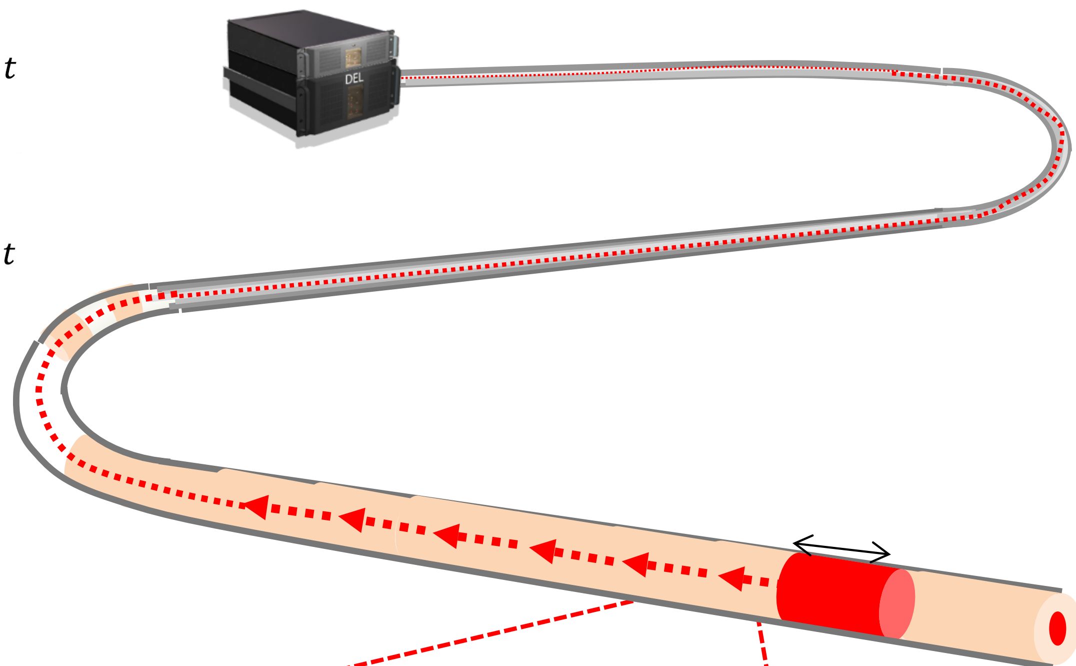
Global fibre network

- Data in real-time
- Transoceanic cable network = Dense array of Strain sensors
- +1.3 million km's of cable



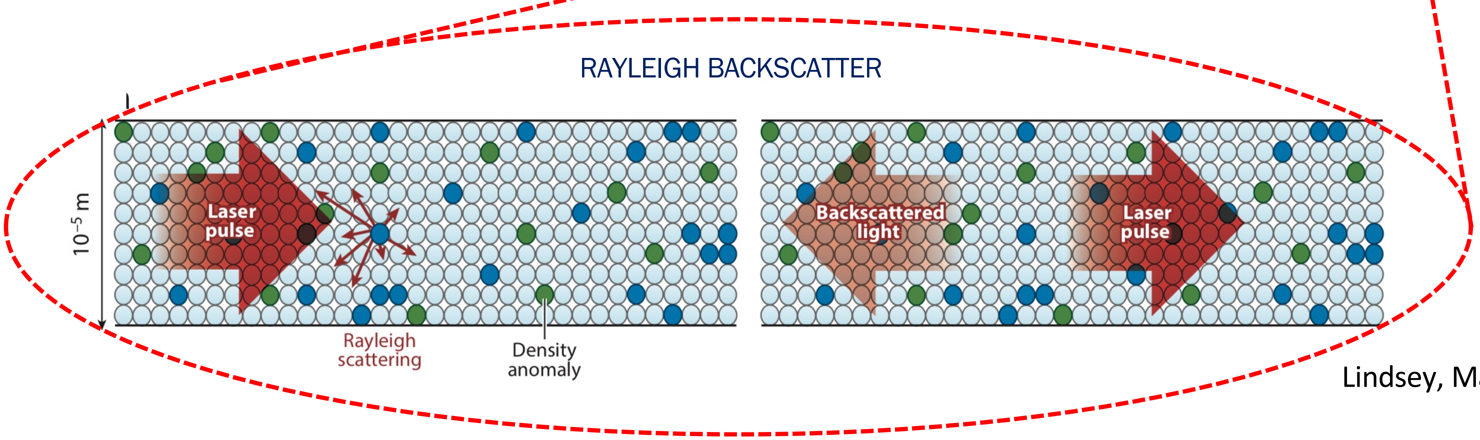
Distributed acoustic sensing (DAS)





Advantages

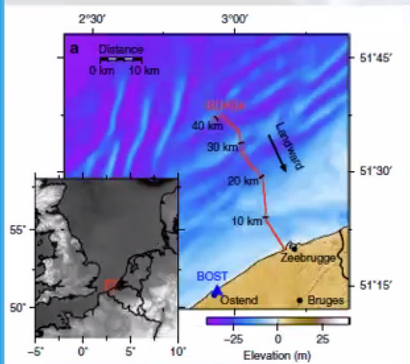
- Dynamic Detection (fast sampling)
- Large amplitudes (SNR)
- Long distances (>100km)



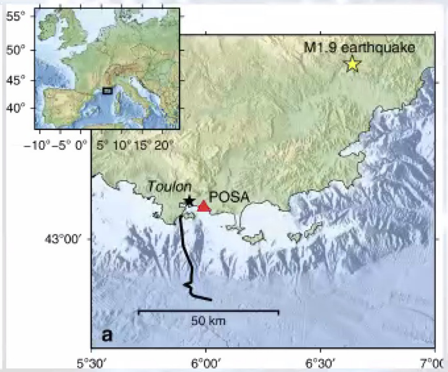
Lindsey, Martin, 2020

DAS Instrumentation

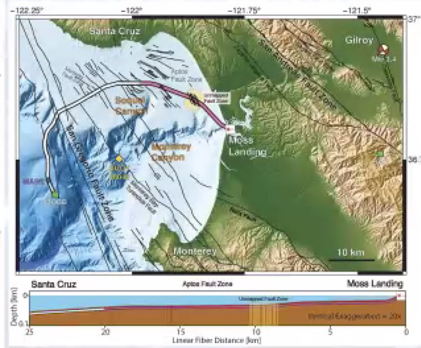
Ocean-bottom Observations with Fiber-Optic Cables (DAS)



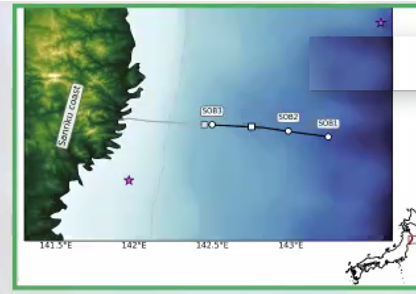
Williams et al., 2019, 2021
Belgium



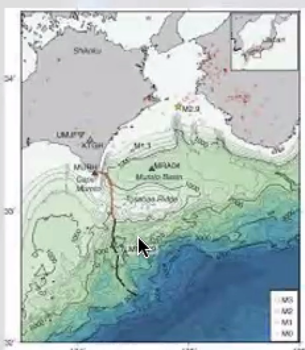
Sladen et al., 2019
Rivet et al., 2021, France



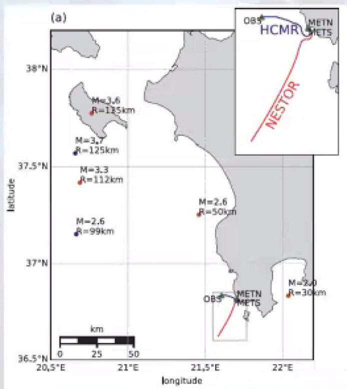
Lindsey et al., 2019, CA
Cheng, 2021



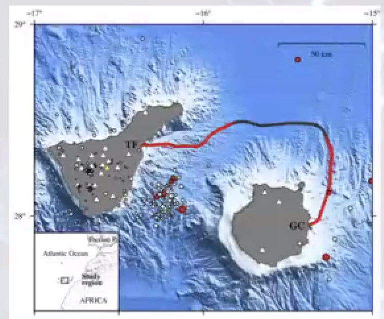
Spica et al., 2020-22, Japan



Ide et al., 2020
Tonegawa et al., 2022
Japan

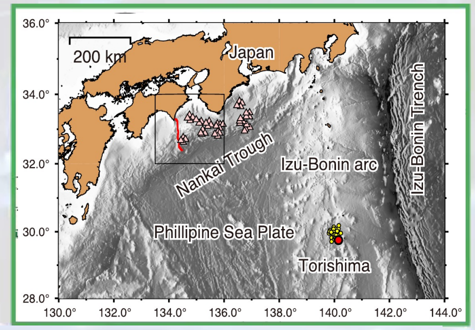


Lior et al., 2021a,b
(Mediterranean)

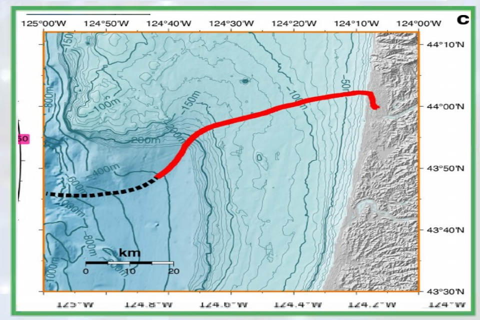


Ugalde et al., 2021
(Spain)

- Alaska
- Chile?
- …

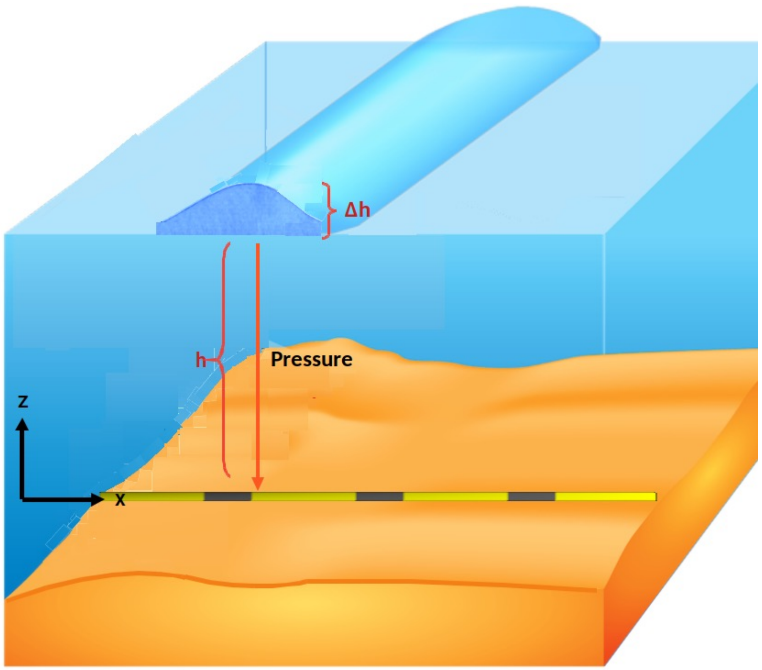


Tonegawa et al., 2024, Japan

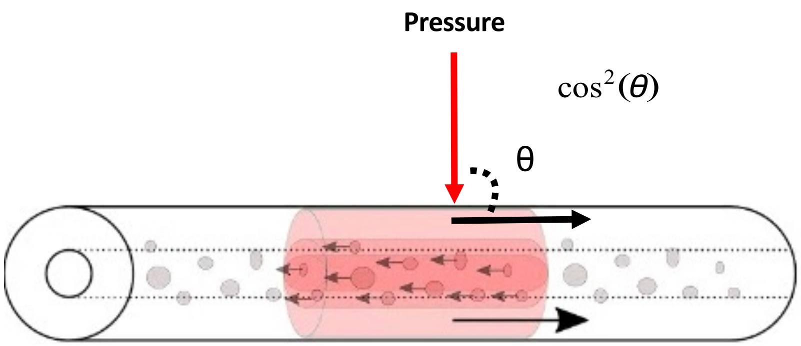


Xiao et al., 2024, Oregon

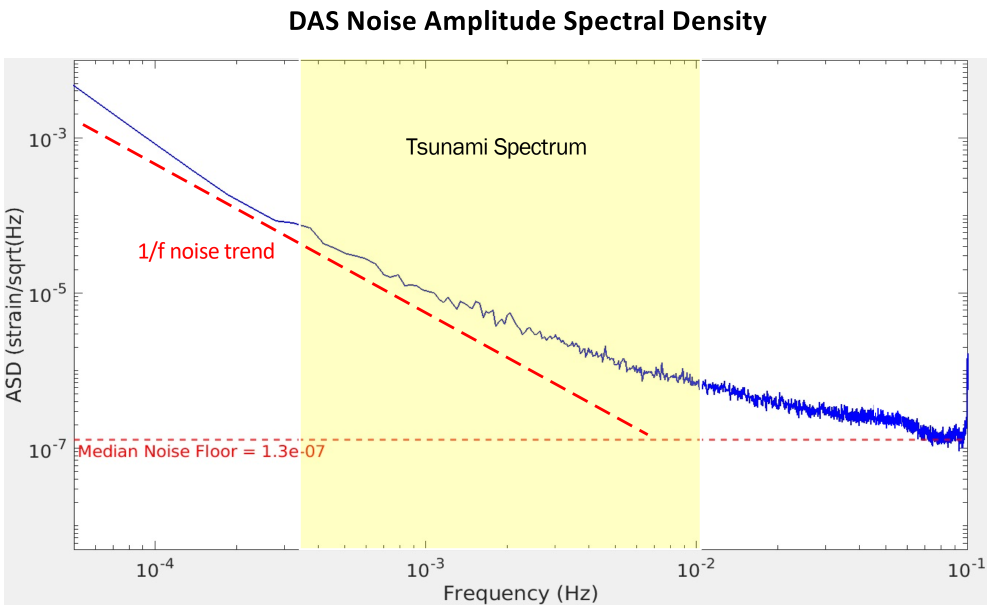
Tsunami Detection with DAS?



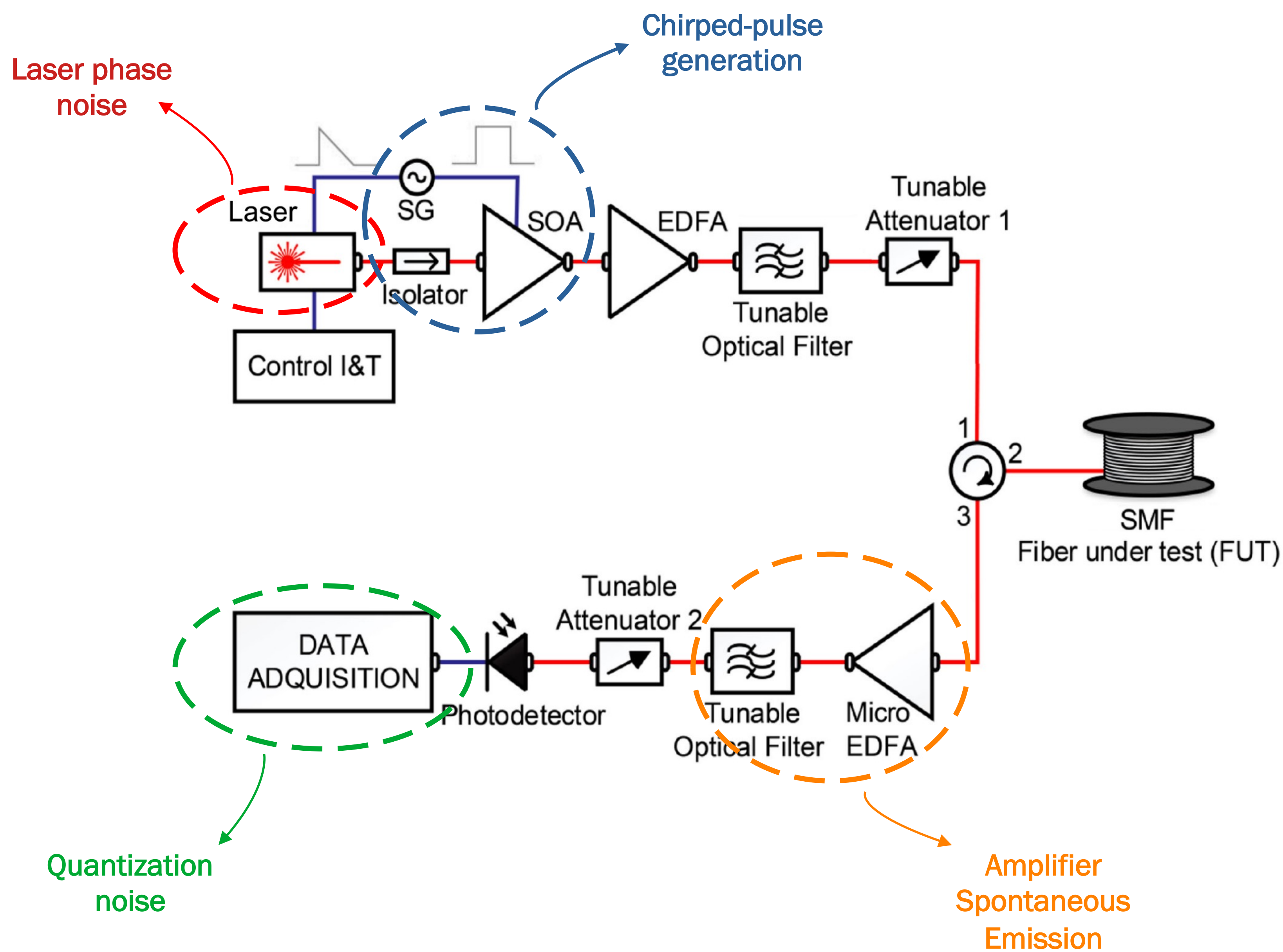
Direct tsunami observations are made mostly by monitoring pressure at the seafloor



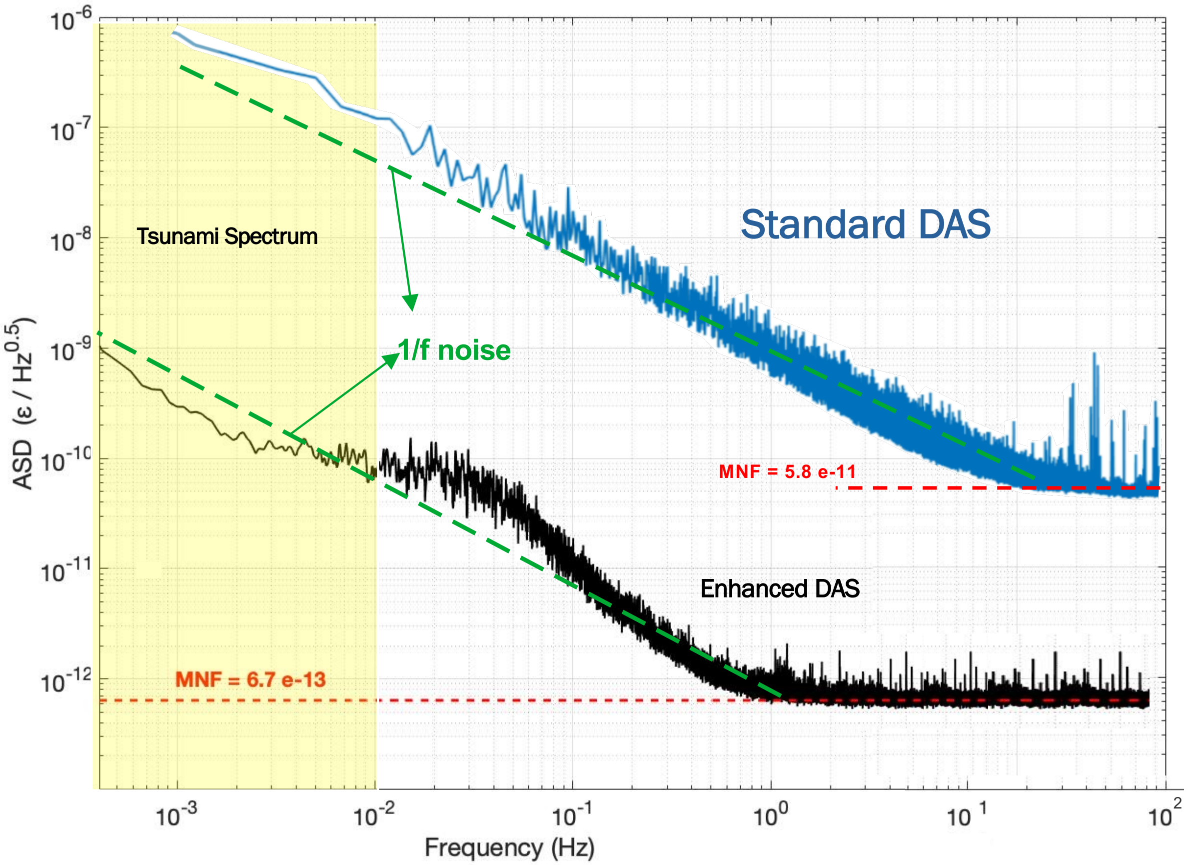
Minimizing noise at frequencies below 0.01 Hz



Towards Minimizing Noise Sources



Towards Minimizing Noise Sources



DAS Sensitivity

Sources of Strain Studied

What signals will a tsunami generate?

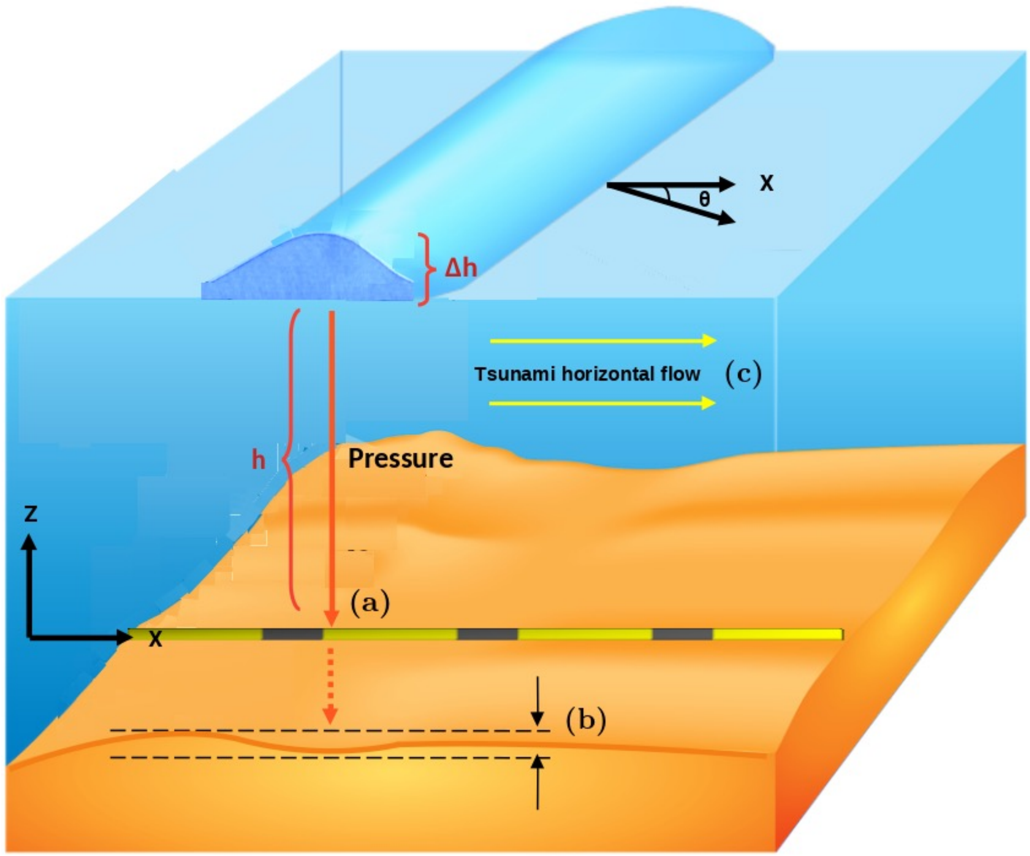
ESS OPEN ARCHIVE

Towards tsunami early-warning with Distributed Acoustic Sensing: Expected seafloor strains induced by tsunamis

GEOPHYSICS

DISTRIBUTED ACOUSTIC SENSING | EARLY WARNING | STRAIN | TSUNAMI

Carlos Becerril, Anthony Sladen, Jean-Paul Ampuero, Pedro J Vidal-Moreno, Miguel Gonzalez-Herraez, Fabian Kutschera, Alice-Agnes Gabriel, Frédéric Bouchette



Tsunami Signal due to

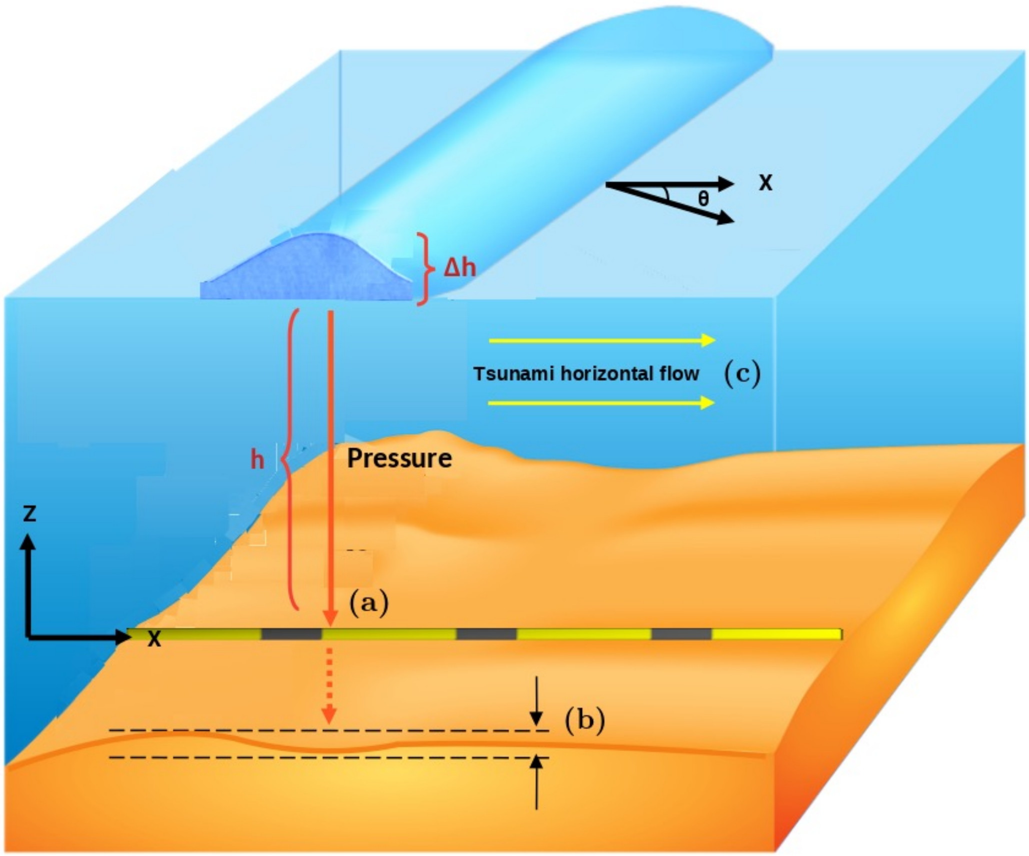
Effect from Pressure

- Poisson effect on the cable
- Seafloor compliance

Effect from Horizontal Displacement

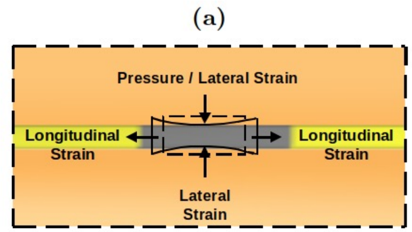
- Seafloor Shear
- Shear strain on the cable

Sources of Strain Studied - Pressure



- Cable is laid (not buried) and coupled onto the seafloor

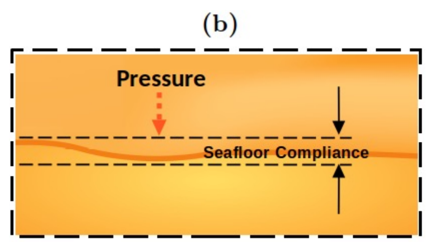
Poisson effect



$$\epsilon_x = 2\frac{1-2\nu}{E}P$$

$\varepsilon \longrightarrow$ Strain along x dir.
$P \longrightarrow$ Pressure
$E \longrightarrow$ Young's modulus
$\nu \longrightarrow$ Poisson's ratio

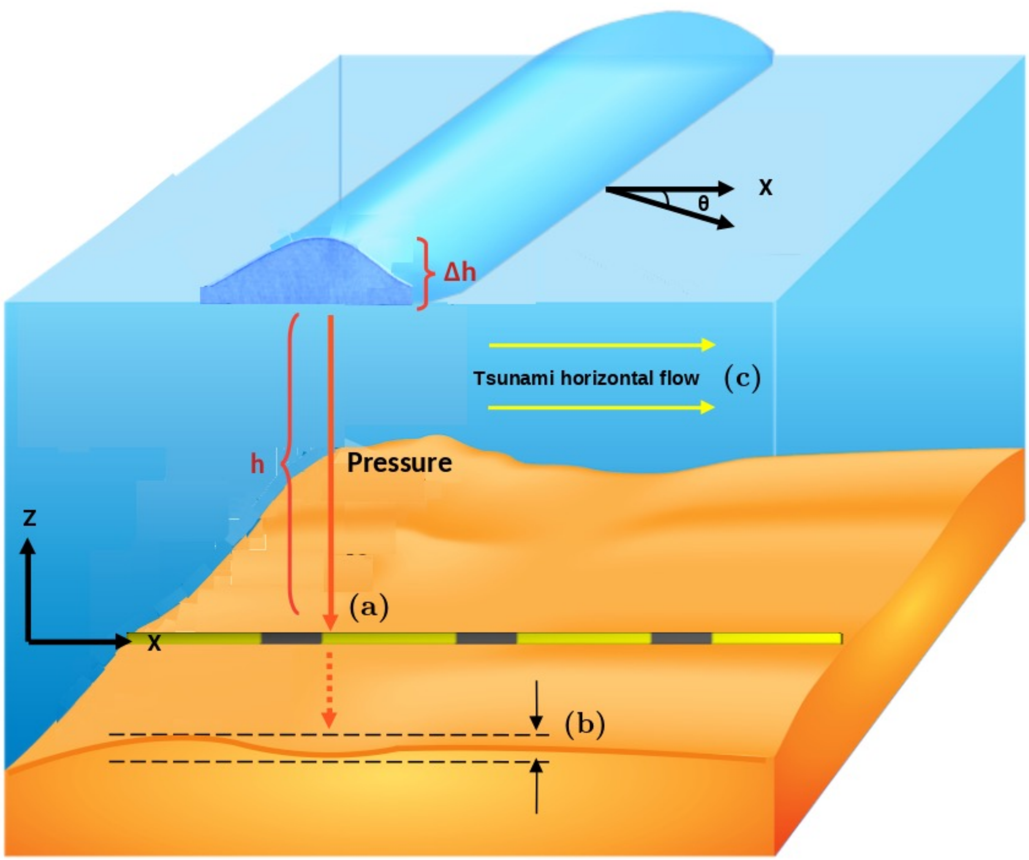
Seafloor Compliance



$$\epsilon_x = \frac{P\cos^2\theta}{2(\lambda+\mu)}$$

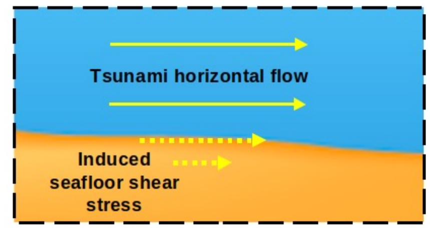
- Derivation based on Boussinesq's formulation, where solid Earth is a
  - Homogeneous
  - Isotropic
  - Linear elastic
- λ, $\mu \longrightarrow$ Lamé's constants

Sources of Strain Studied – Horizontal Displacement



Induced Shear Strain on the Seafloor

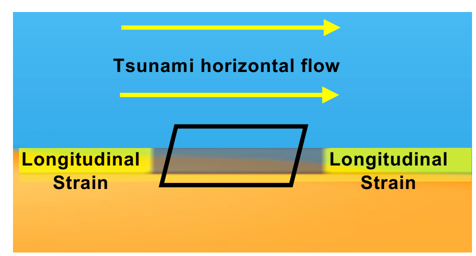
(c)



$$\epsilon_{xx} = \frac{\tau_w}{2\mu\alpha}$$

- Derivation based on Cerruti's formulation, for tangential (shear) loads
- ⟶ Bottom shear stress

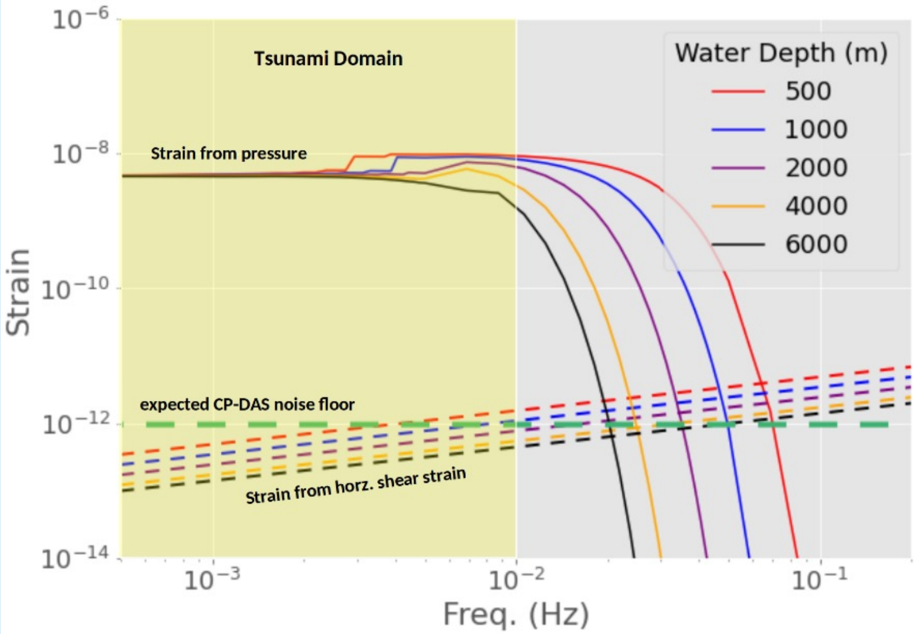
Shear Strain Imparted on the Cable



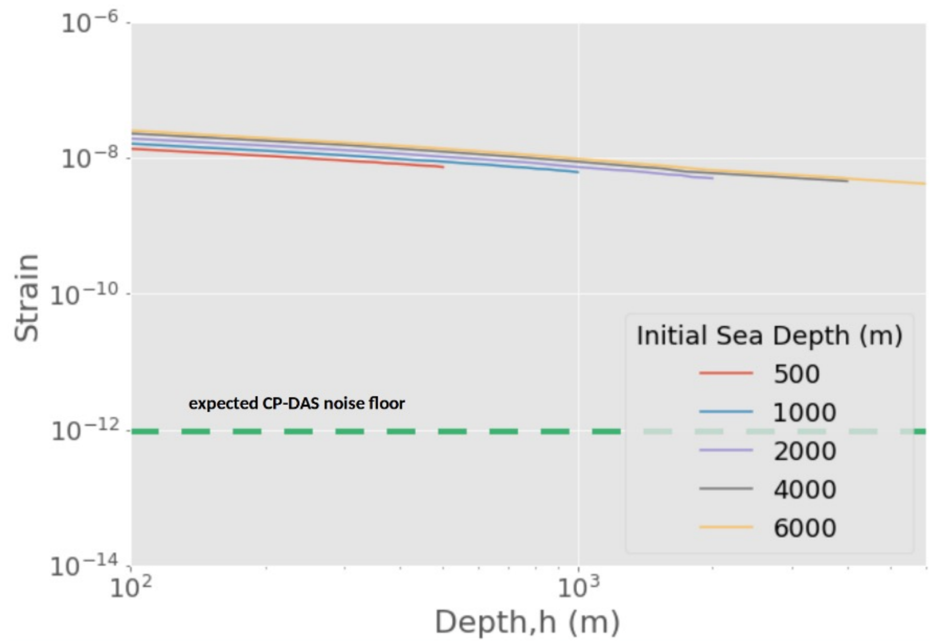
$$\epsilon_{xx} \sim \frac{r}{G} \cdot \frac{2\pi}{\lambda_{tsu}} \tau_w$$

- Derived from the elastic strain due to flow-induced shear stress ⟶ $\tau_w = 2G\,\epsilon_{xz} \sim G\frac{u_x}{r}$
- G ⟶ Cable's shear modulus
- r ⟶ Cable radius

Expected Strain Amplitudes

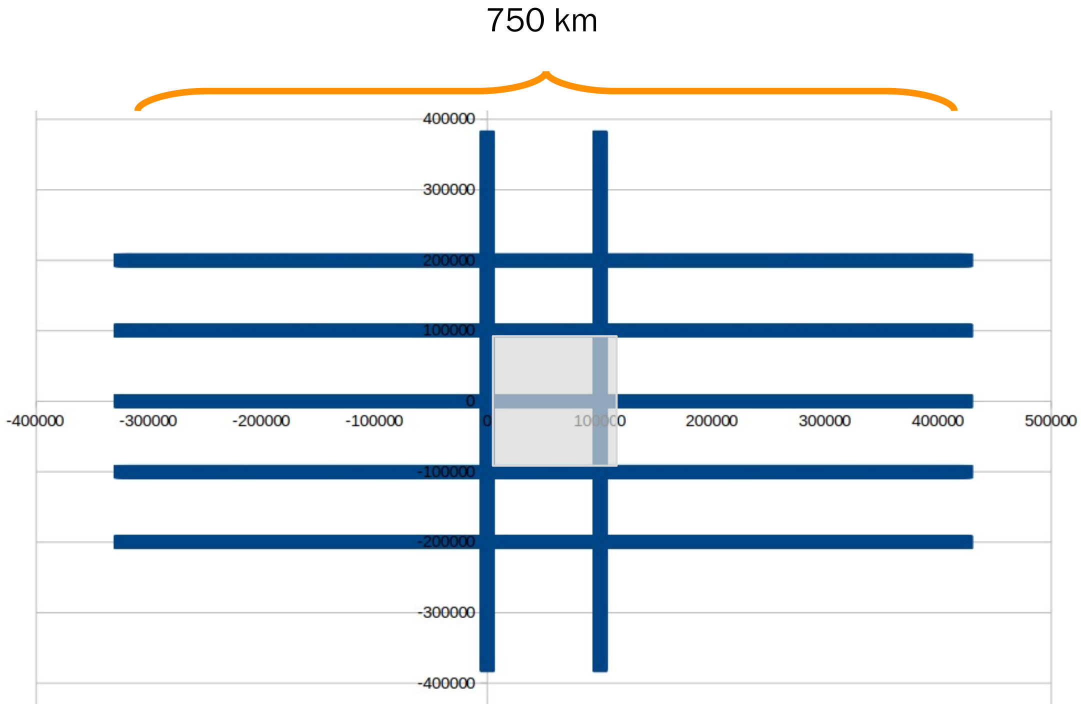


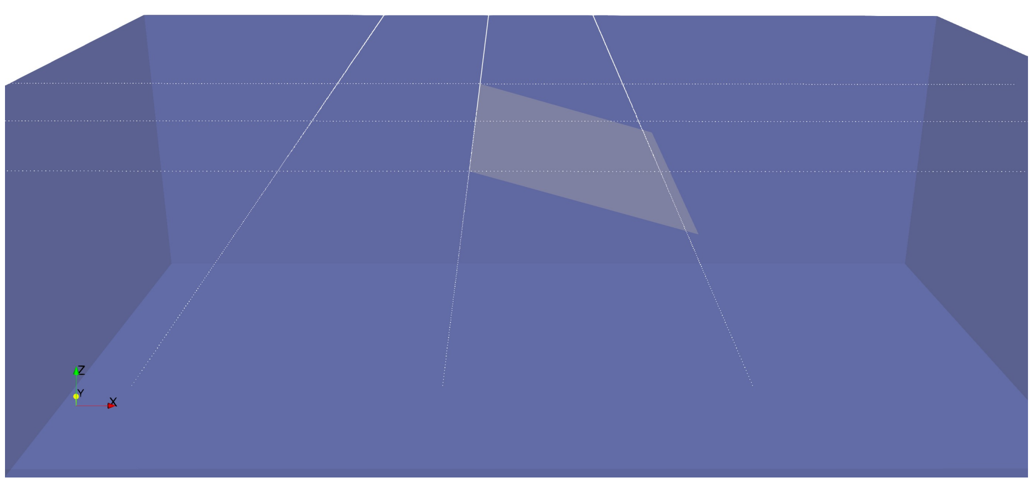
Expected strain amplitudes for a tsunami height of 0.01 m at various water depths h



Strain amplitudes from traveling tsunami waves generated at various sea depths

Generic megathrust setup: Earthquake-Tsunami benchmark scenario



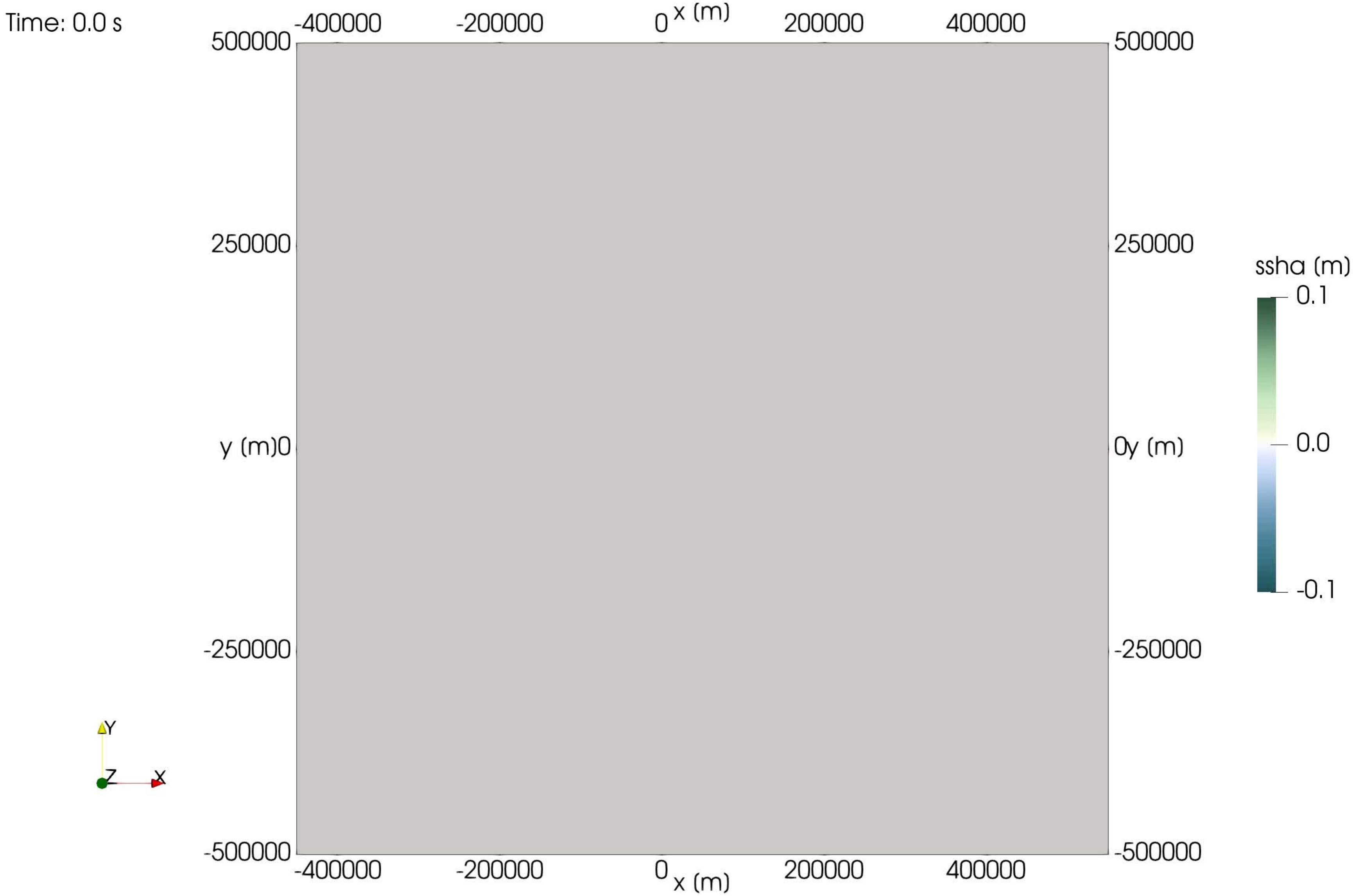


Earthquake rupture (Mw=8.5) on a planar fault:
- 200km wide
- From the surface to 35 km depth
- 16° dip

- Tsunami generation and propagation in a basin with flat bathymetry

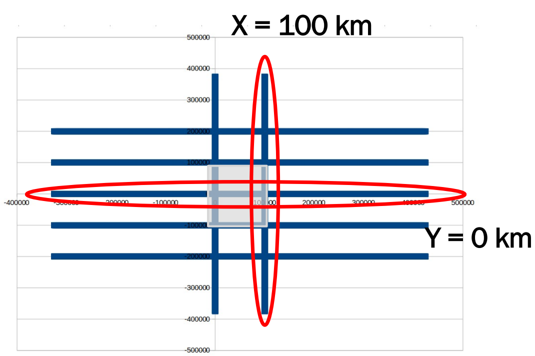
- 2 km water depth

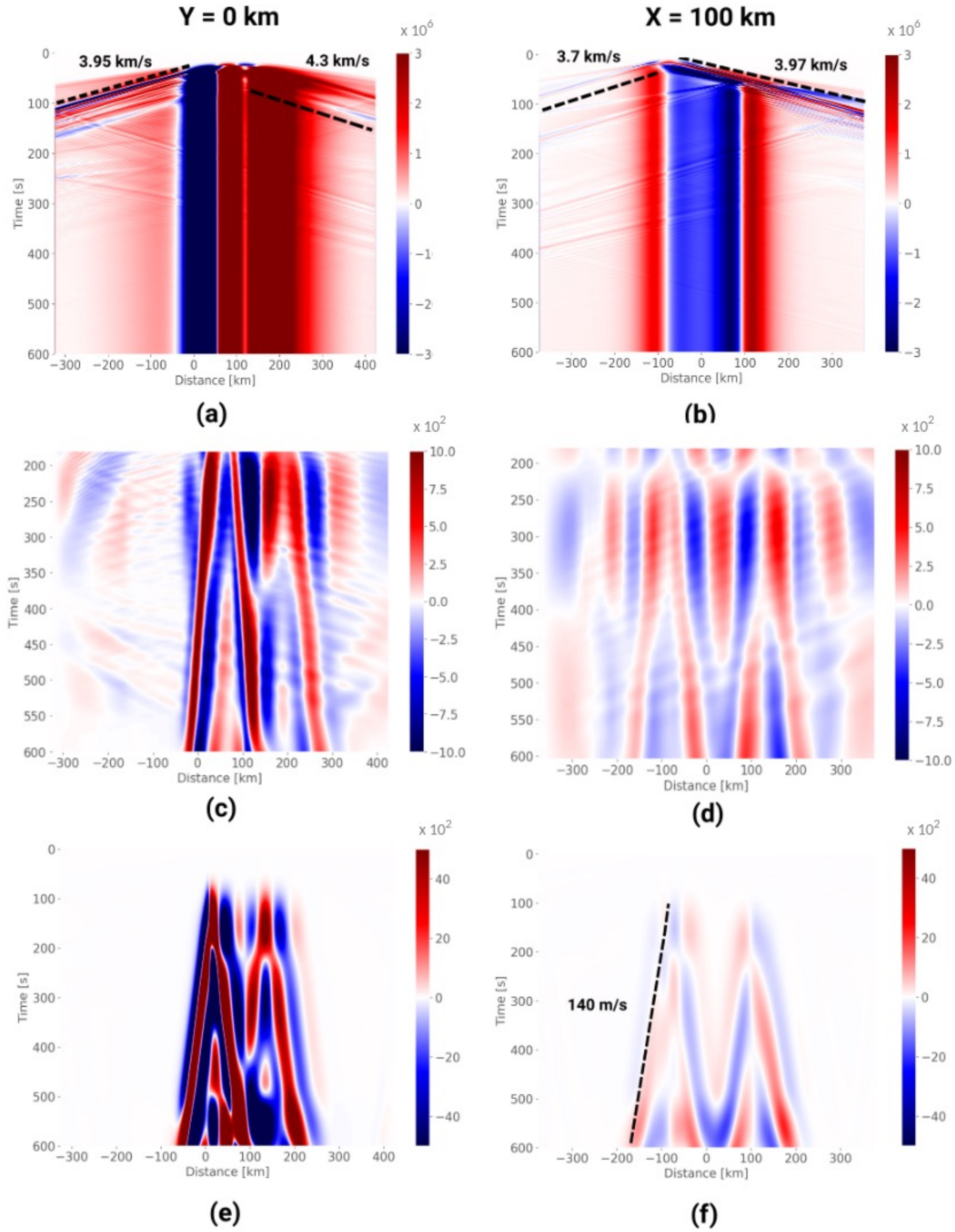
A megathrust Earthquake…



Tsunami detection at the Ocean-Bottom

Generic megathrust setup: Earthquake-Tsunami benchmark scenario



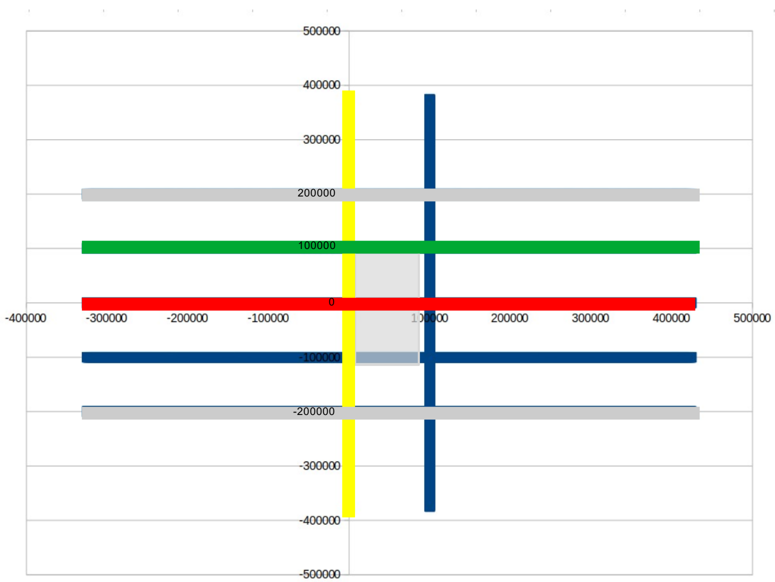


Broadband strain Signal at the seafloor

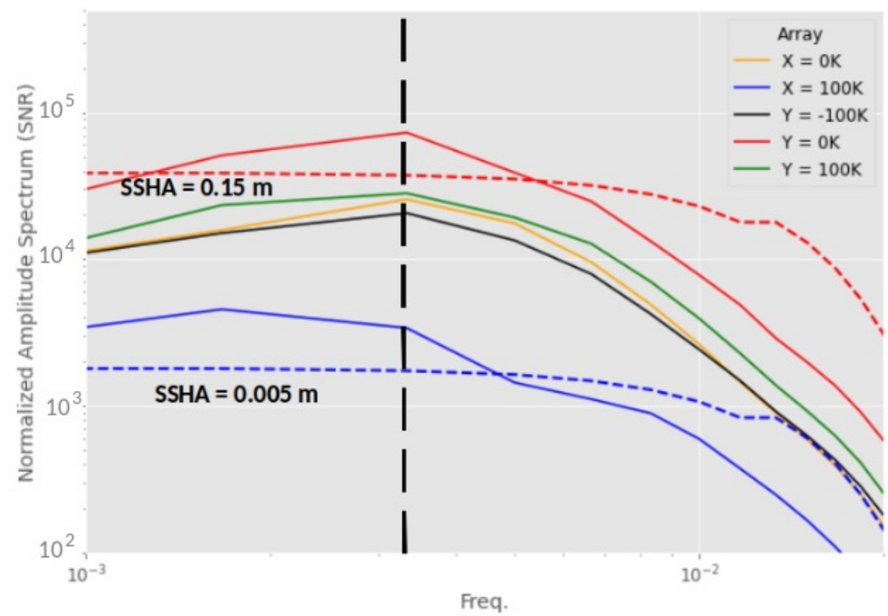
Filtered strain Signal at the seafloor

Filtered strain Signal at the sea surface

Summary



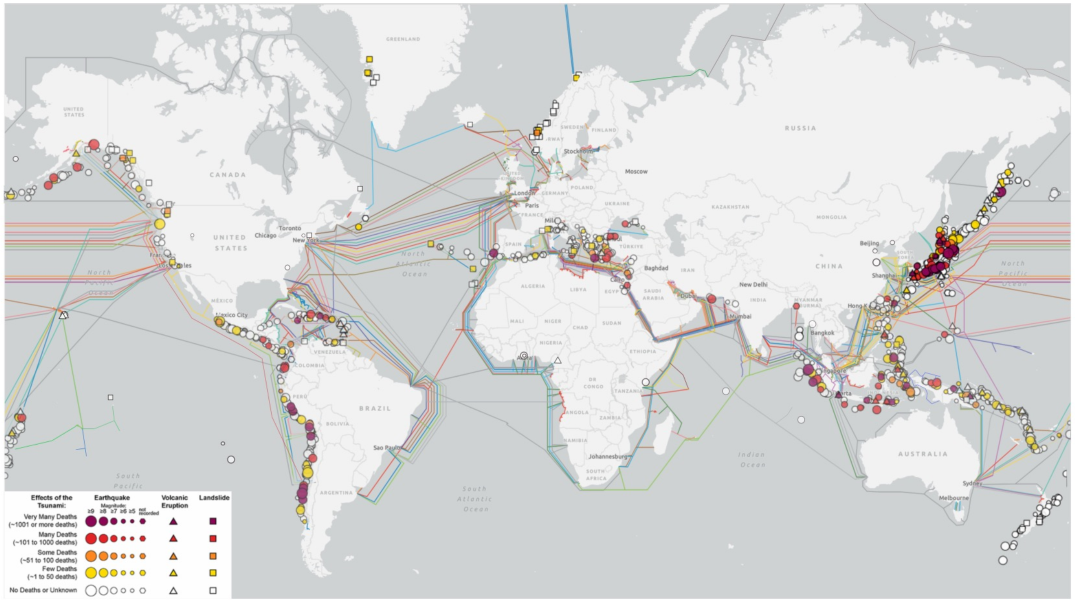
Strain signal from
Seafloor Compliance + Poisson Effect on the cable



- Detection of tsunamis with seafloor telecom cables should be posible.
- It is feasible for a DAS-driven TEWS system to detect in the near-field of a large earthquake ruptures.

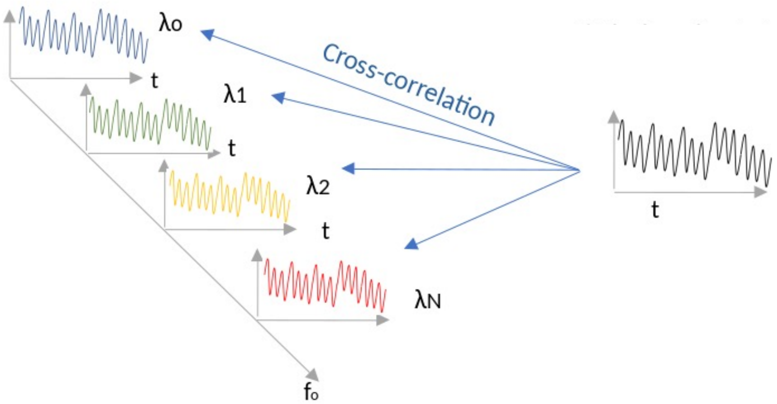
To be continued..

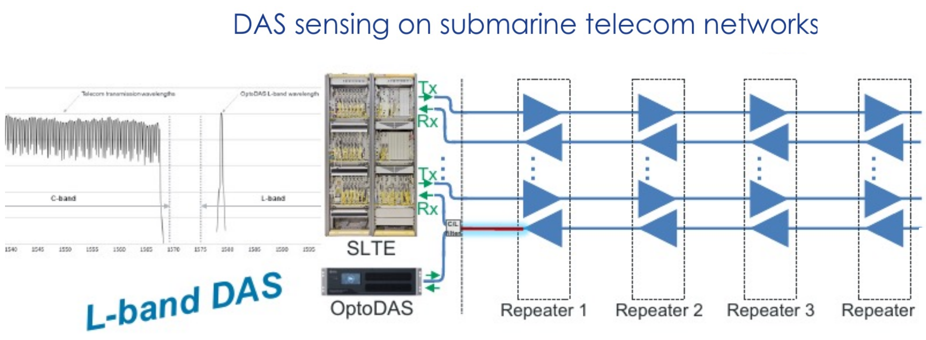
- Validate the model in the field.. with a real tsunami



- multi-frequency calibration to minimize 1/f noise

- Incorporating DAS to the
- communication infrastructure.





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