

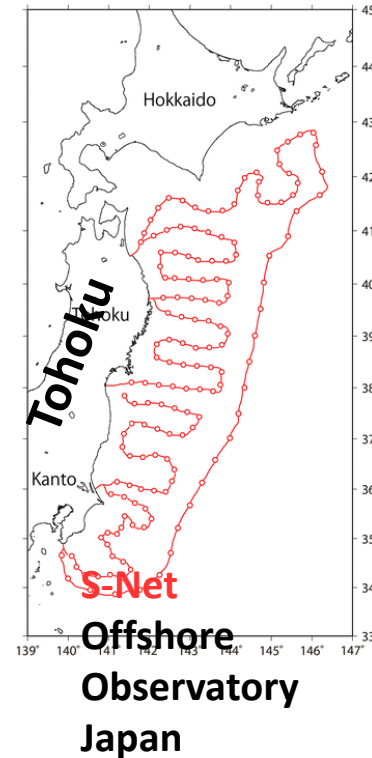
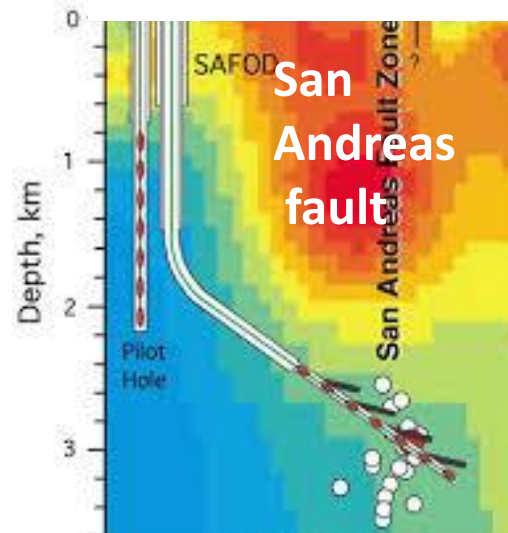


# Instrumentation optique de haute résolution en extrémité de fibre longue pour monitoring géophysique en temps réel en environnement difficile

Pascal BERNARD, IPGP  
Guy PLANTIER, ESEO-Angers

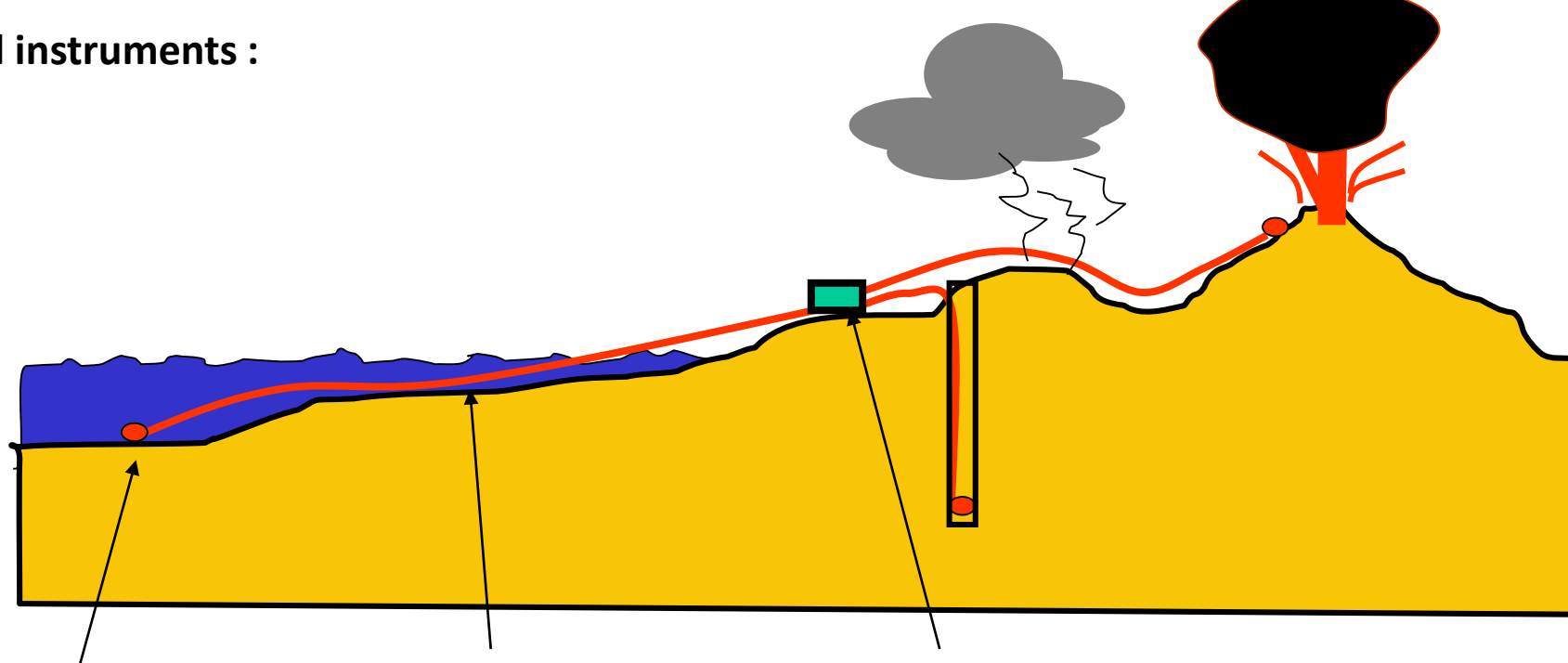
IPGP/OVSG : P. Bernard, C. Brunet, R. Moretti, S. Deroussi,  
A. Peltier, M. Assaoui, R. Daniel ...

ESEO : G. Plantier, M. Feuilloy, R. Feron,  
Ph. Ménard, A. Sourice, G. Savaton



volcanoes, deep boreholes, far offshore, large landslides...  
→ difficult or dangerous access, expensive repairs,  
high temperature, lightning strikes, ...

## Optical instruments :



**SENSOR :**

Opto-mechanical,  
no electronics

**LONG OPTICAL FIBER**

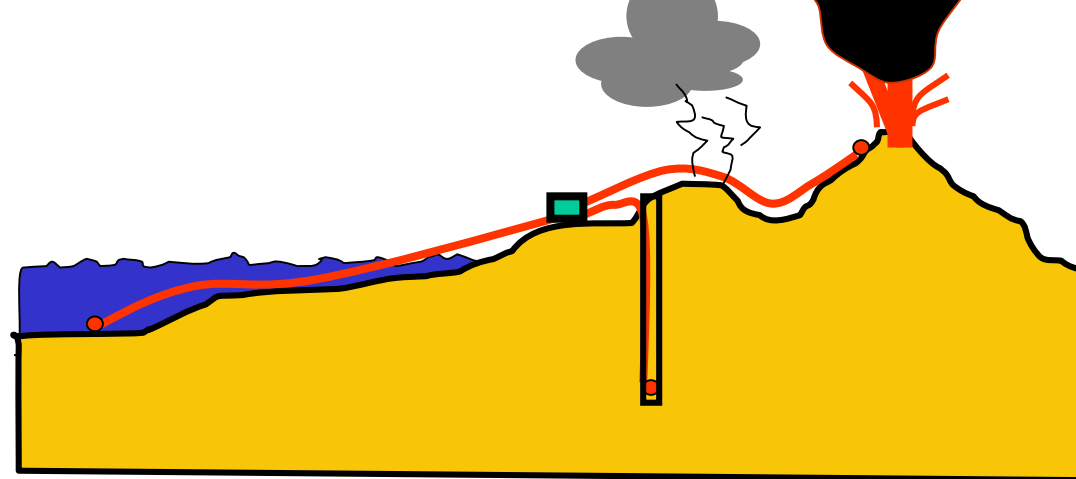
up to 50 km

**CONTROL/ACQUISITION :**

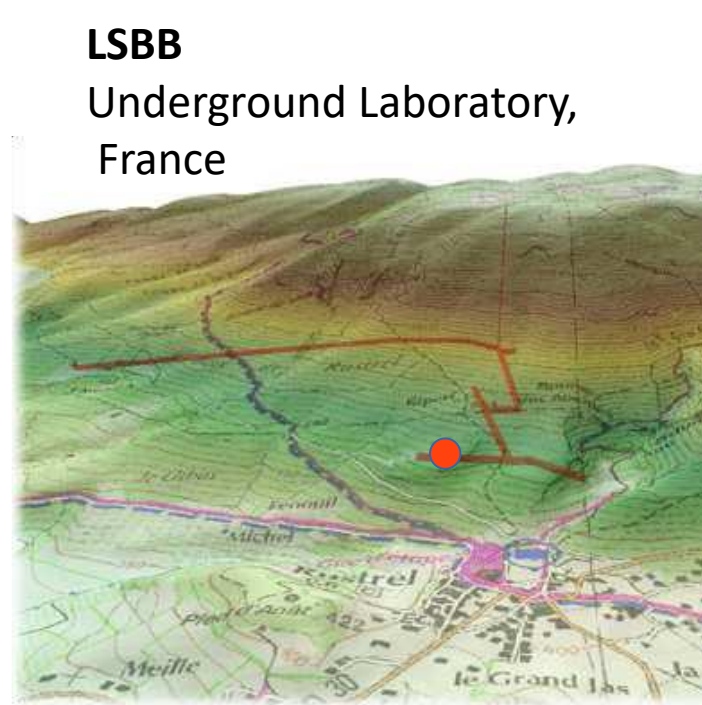
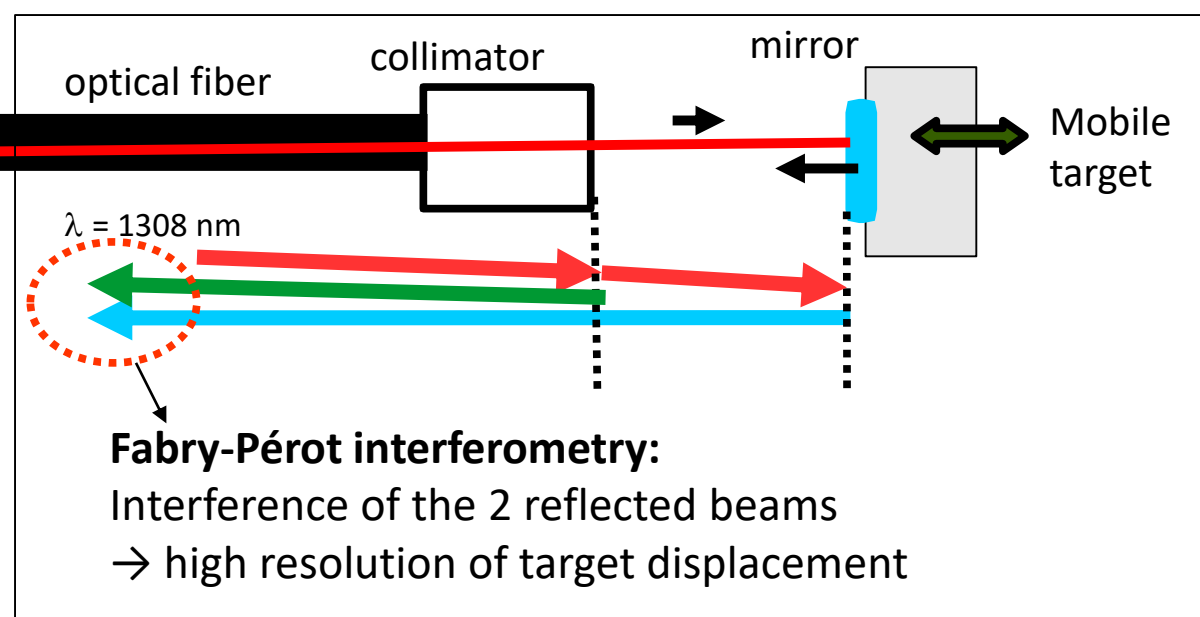
Remote installation

for natural hazard monitoring in harsh environment:  
far offshore, deep borehole, mountain/volcanoes,...

## Optical instruments :



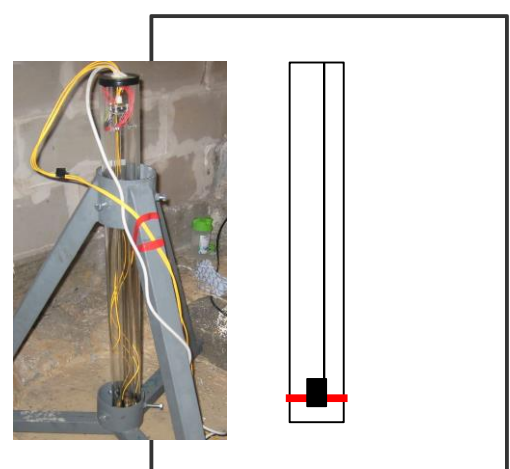
- + optical fiber tens of km long
- + stability with time (no electronic drift at the sensor)
- + fiber and sensor insensitive to EM perturbations (lightning, telluric currents, industrial environment, high voltage power lines...)
- + sensor less sensitive to high temperature (no electronic component) nor very low temperature
- + sensor simple, small, and robust: no maintenance
- + laser interferometry allows for very high resolution



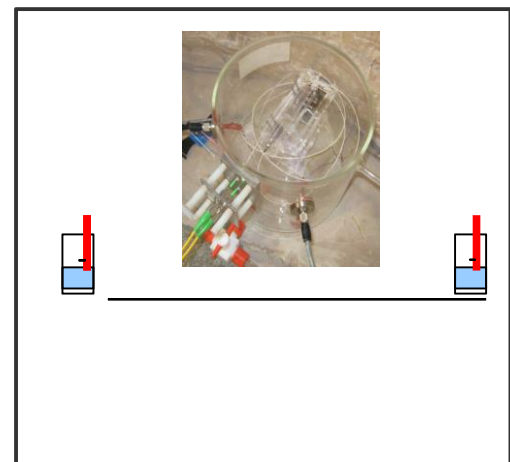
**ANR** project « **LINES** » 2009-2012

**GMontpellier**  
**IPGP**  
**ESEO-Angers**  
**LOSE-Toulouse**  
**LSBB**

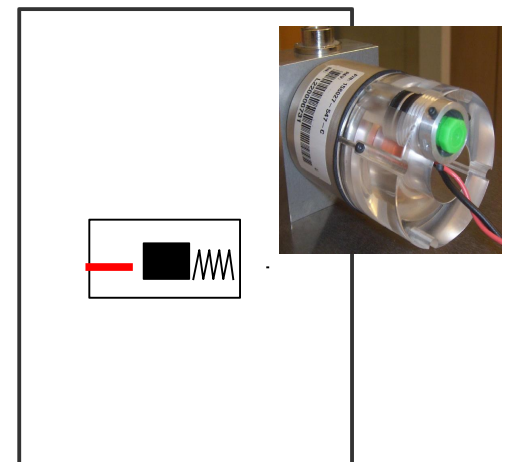
Borehole  
Tiltmeter 1 m



Long base  
Hydrostatic tiltmeter  
150 m

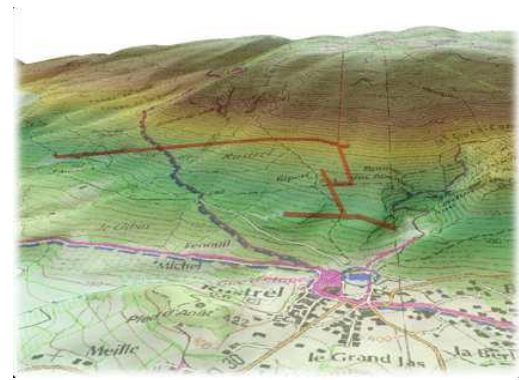


**Geophone 2 Hz**

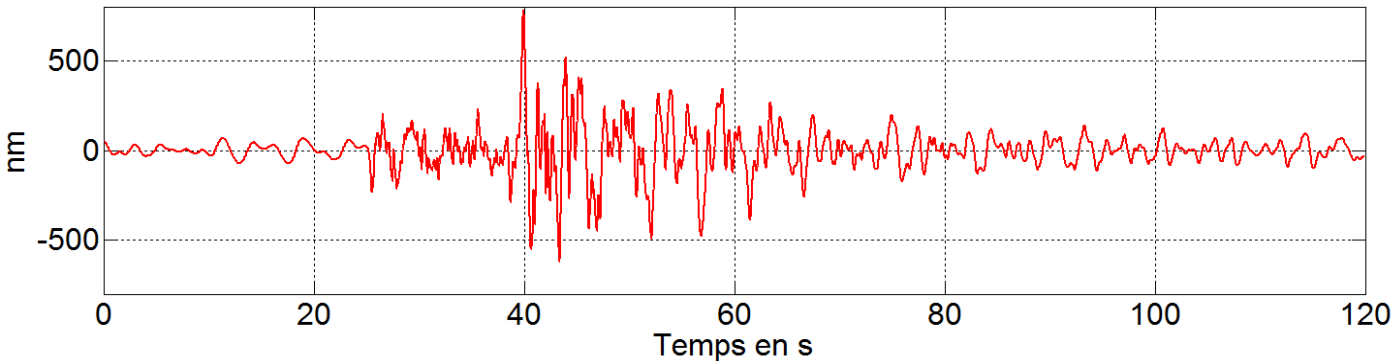


**Test of the optical seismometer**  
**2 Hz geophone, 1 component**  
**3 km optic fiber**

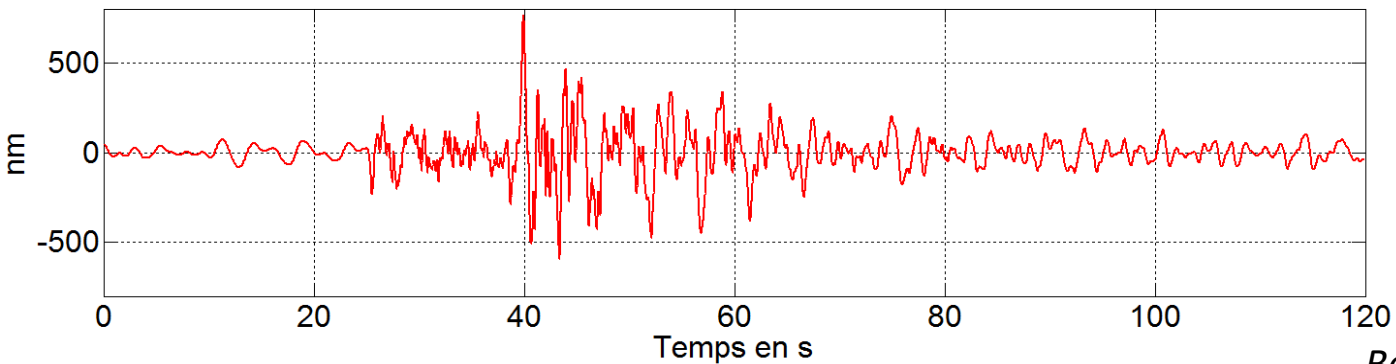
Rustrel, LSSB Laboratory,  
Southern France  
2009-2012



**earthquake M=4, d=100 km - 0.1-20 Hz**

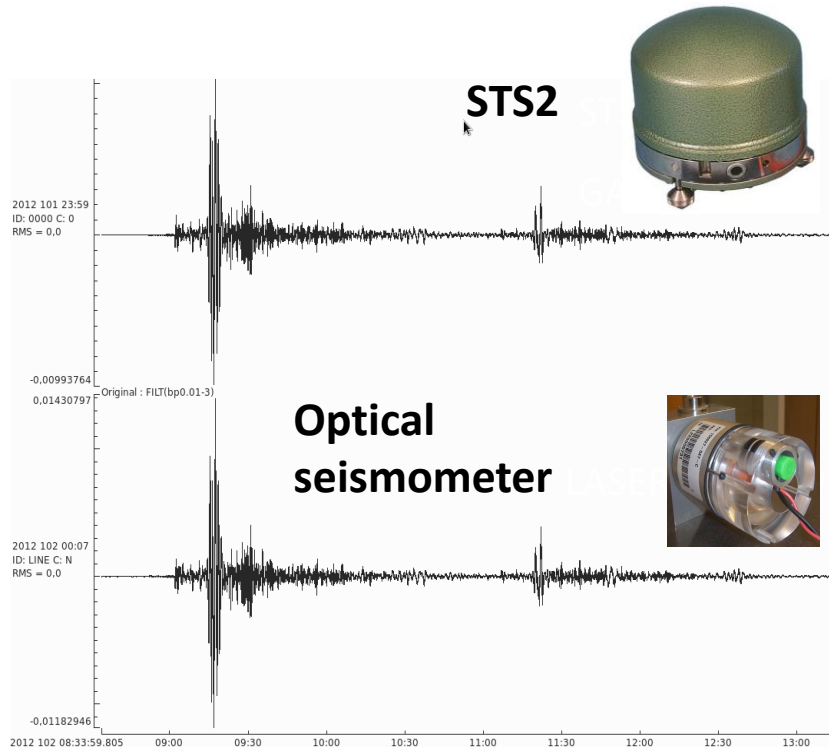


**STS2**



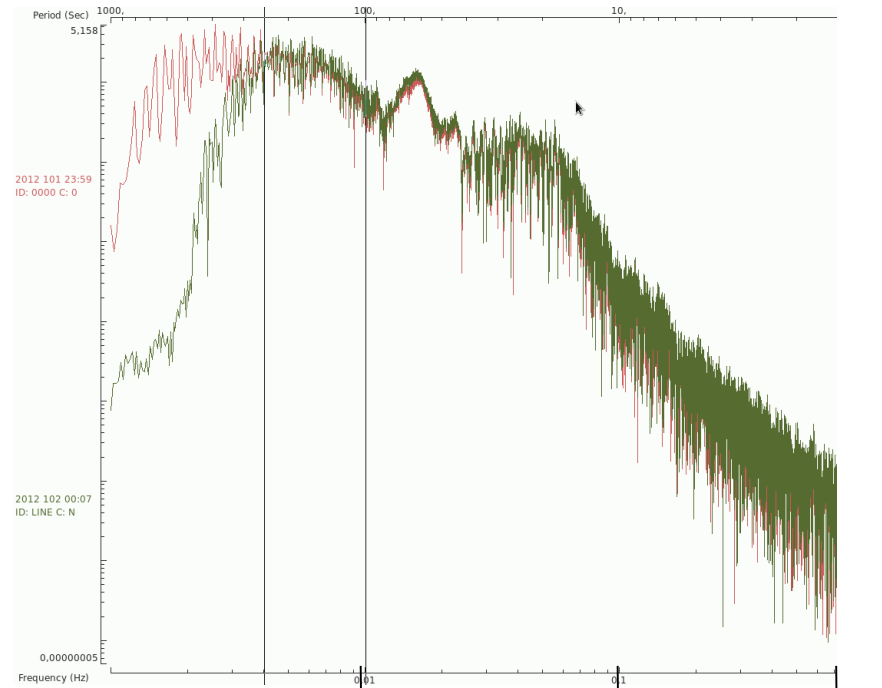
**Optical  
seismometer**

# N displacement (m) for the 2012 Sumatra M=8.7 earthquake at LSBB



4 hours

Long period surface waves



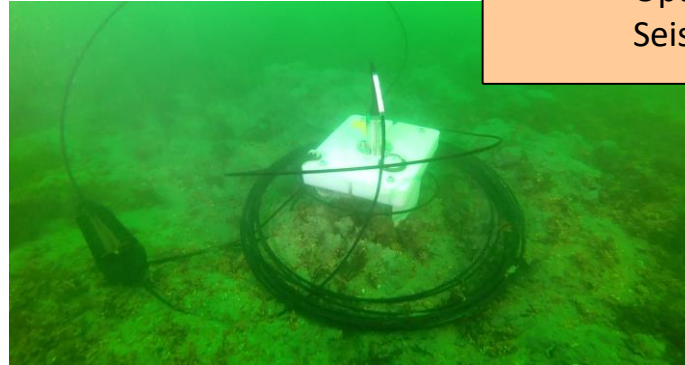
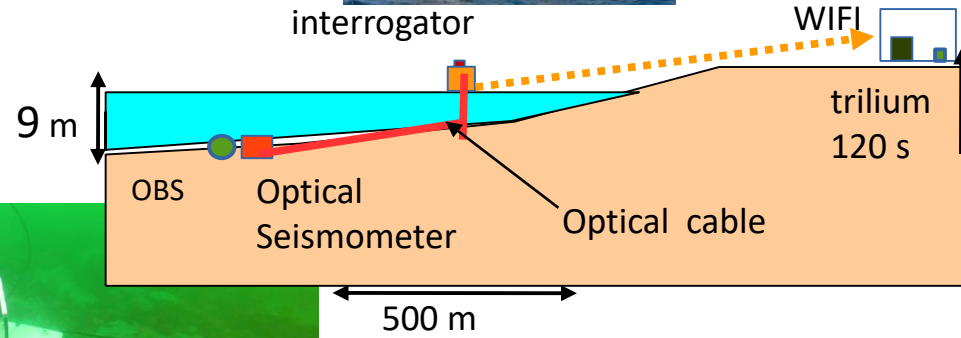
0.01 0.1 1 Hz

250 s  
with a 2 Hz geophone !

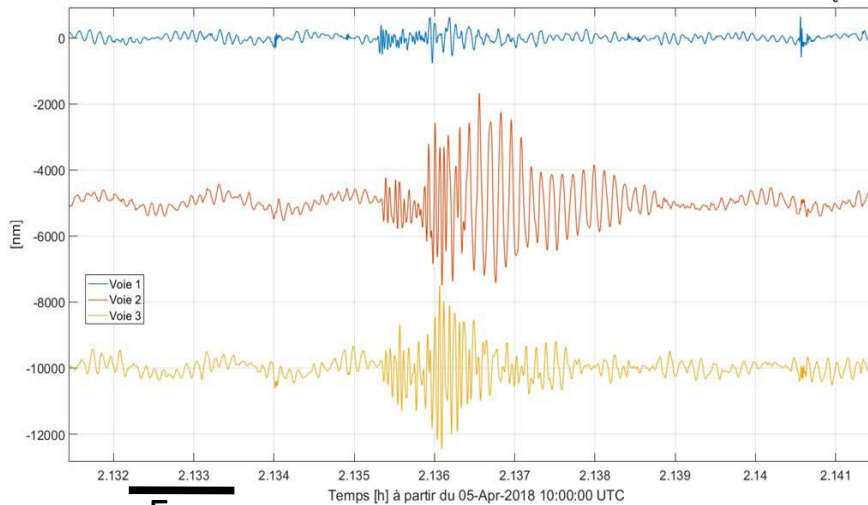


# Test of Optical seismometer Offshore 2 Hz, 3 component geophone

Lanveoc, Sea Test Base, Brittany,  
March-November 2018  
SATT-Ouest Valo



Signaux Sismo Marin au cours des 2 explosions de déminage à Brest le 05 Avril 2018 entre 11h30 UTC et 12h30 UTC -  $F_e = 100.0$  Hz



Mine clearing blast

IPGP design

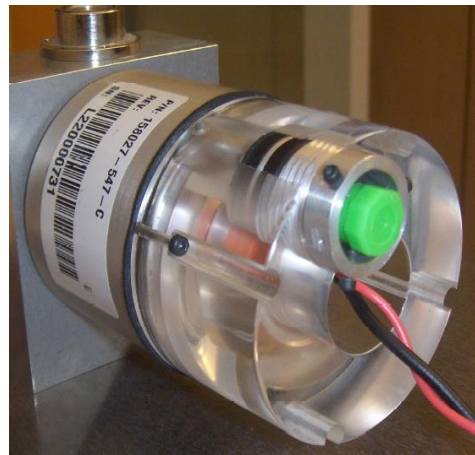
Bernard et al., SRL, 2019

Sensor :

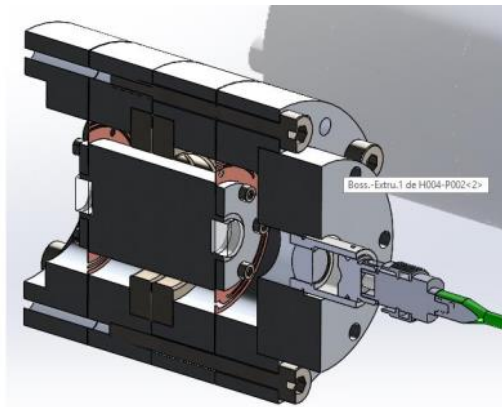
No levelling

→ omnidirectional

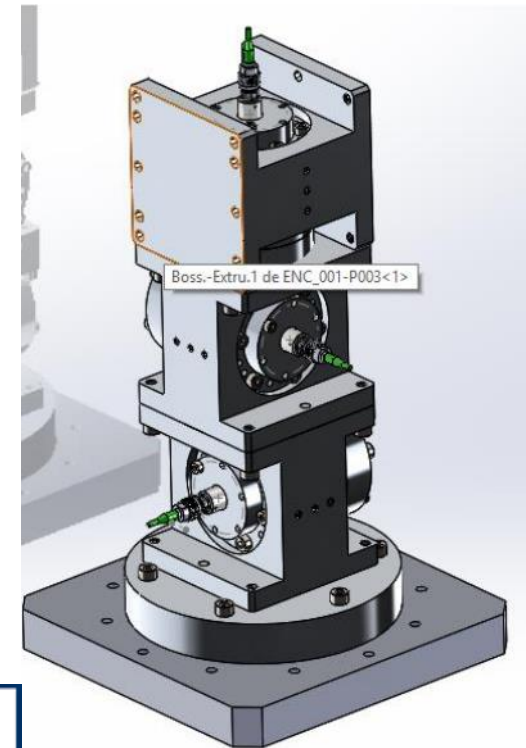
→ requires to shift the resonance from 2 Hz → 10 Hz



Customized  
Sercel 2 Hz geophone



HIPERSIS ANR project:  
seismometer 10 Hz



3 component





# Optical seismometer

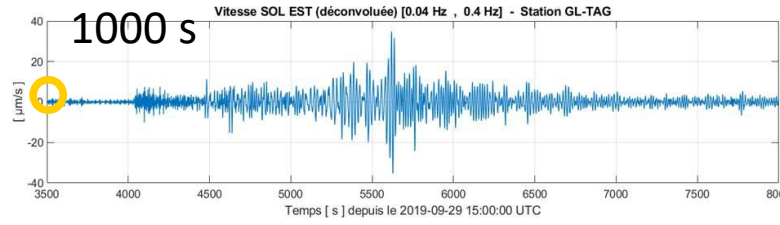
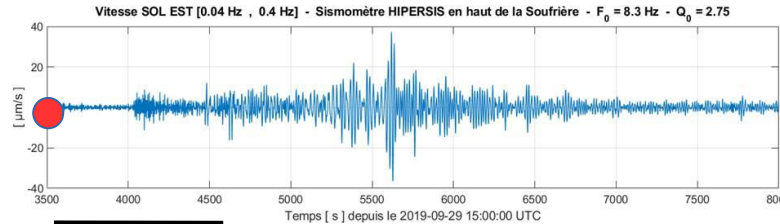
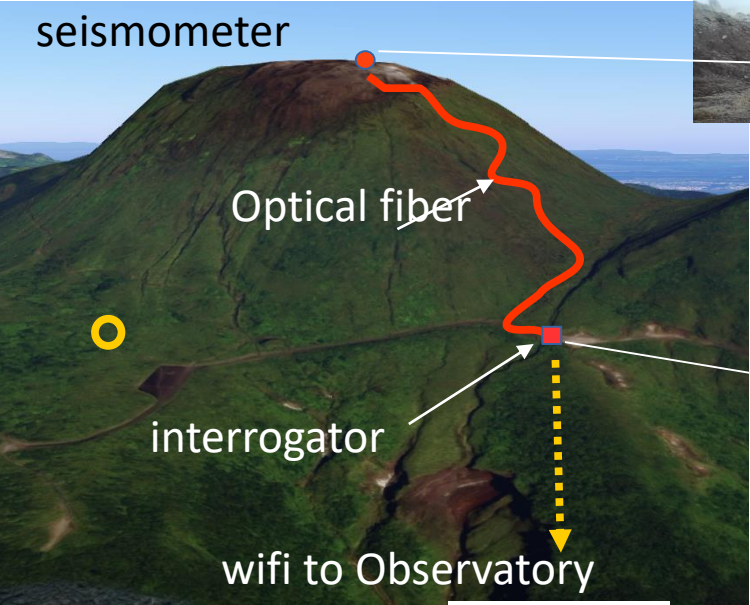
10 Hz, 3 comp, Fiber 1.75 km long  
 La Soufrière Volcano, Guadeloupe  
 since 21 September 2019



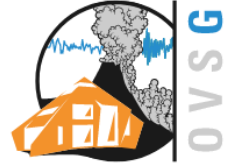
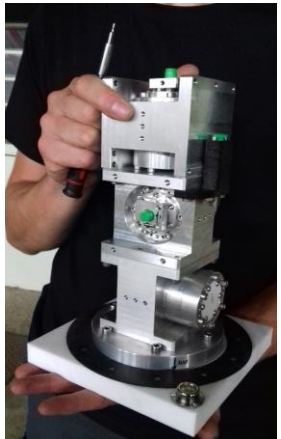
HIPERSIS



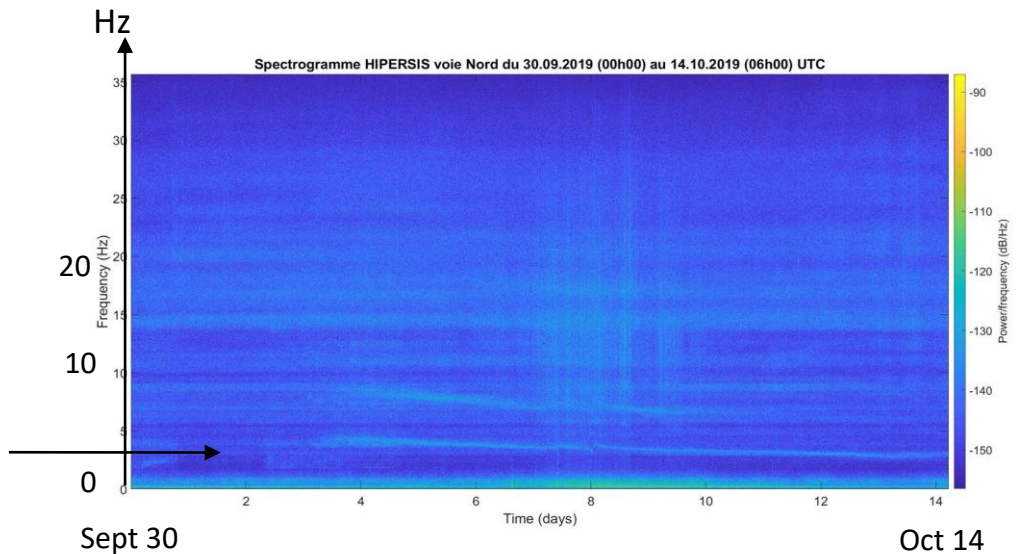
## Optical seismometer



M=6.8, Chile 29<sup>th</sup> sept. 2019  
 signal → period up to 30 s !

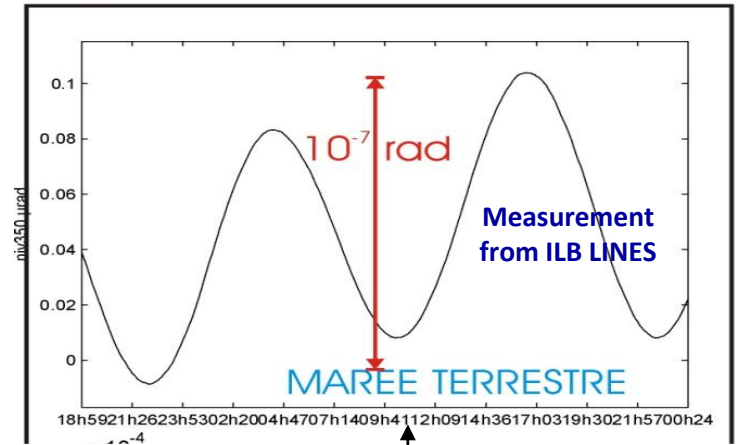
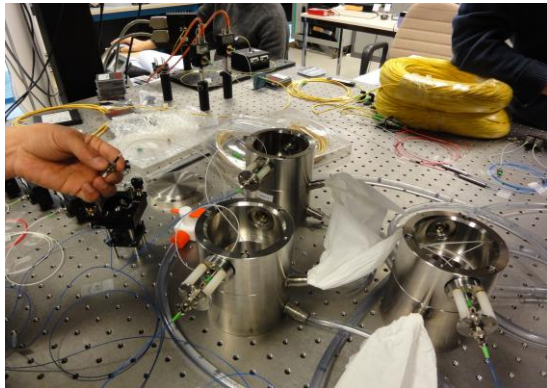
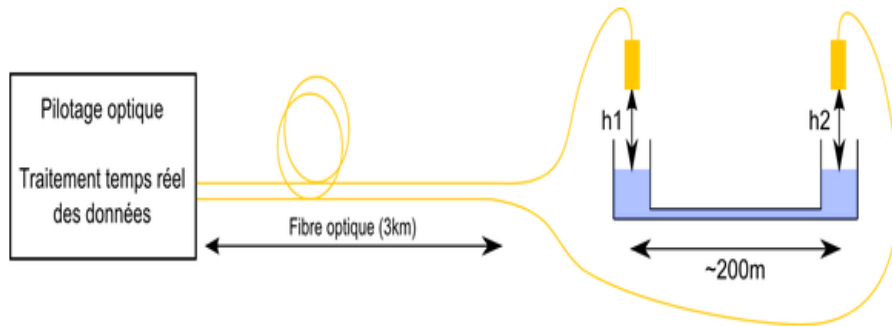


~ 3 to 4 Hz  
 resonance

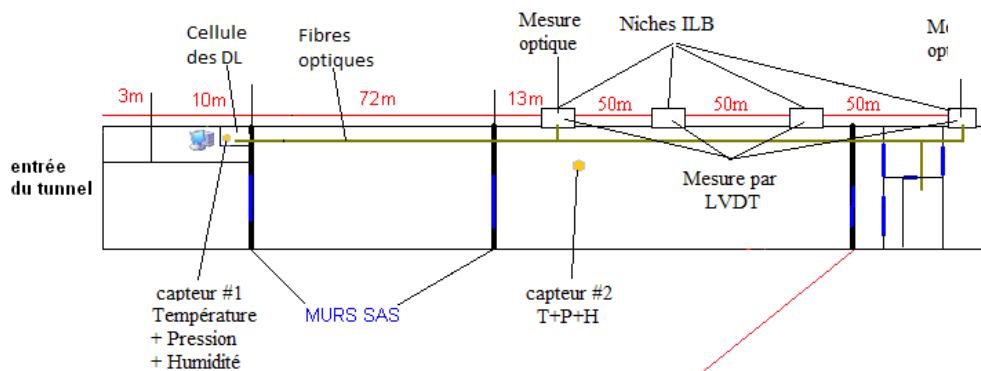
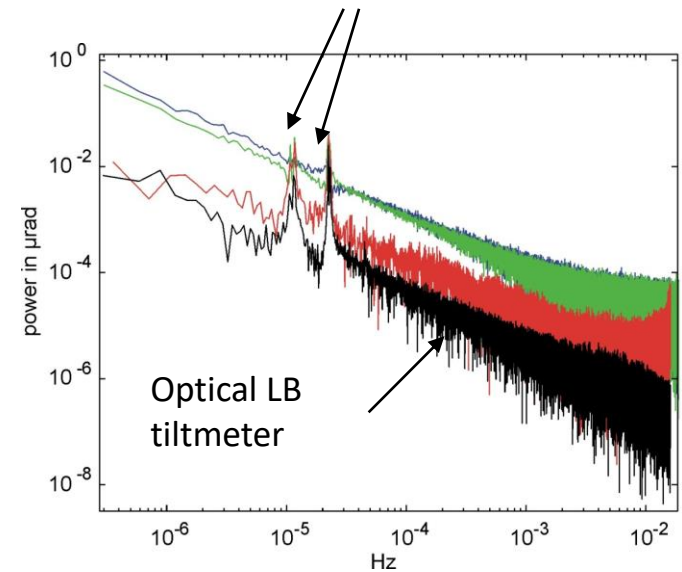


# long base optical tiltmeter

## ENS – F. Boudin



Earth tides



## design du pressiomètre optique sous-marin

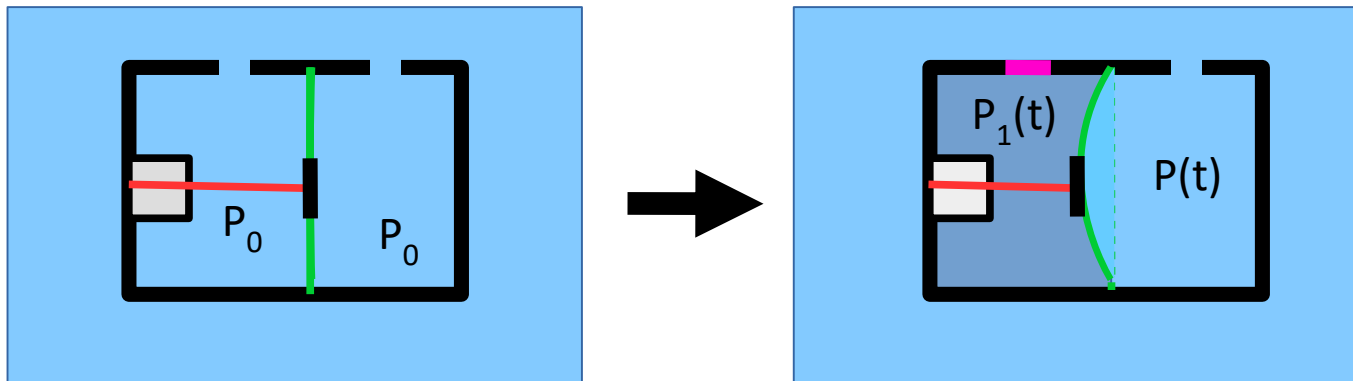
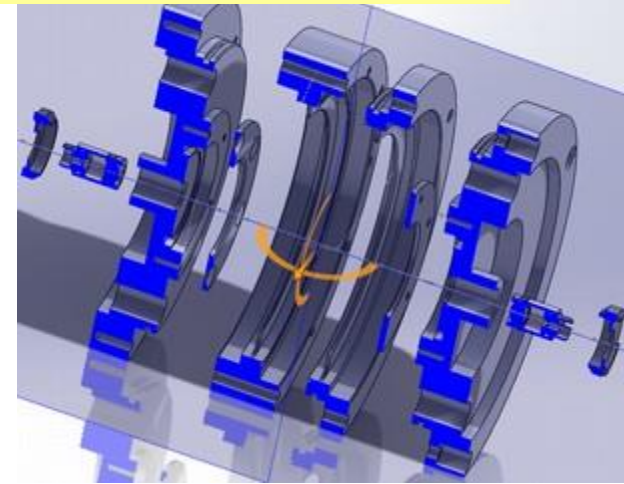
pression différentielle entre deux compartiments séparés par une membrane déformable

membranes en cours de test et de modélisation:

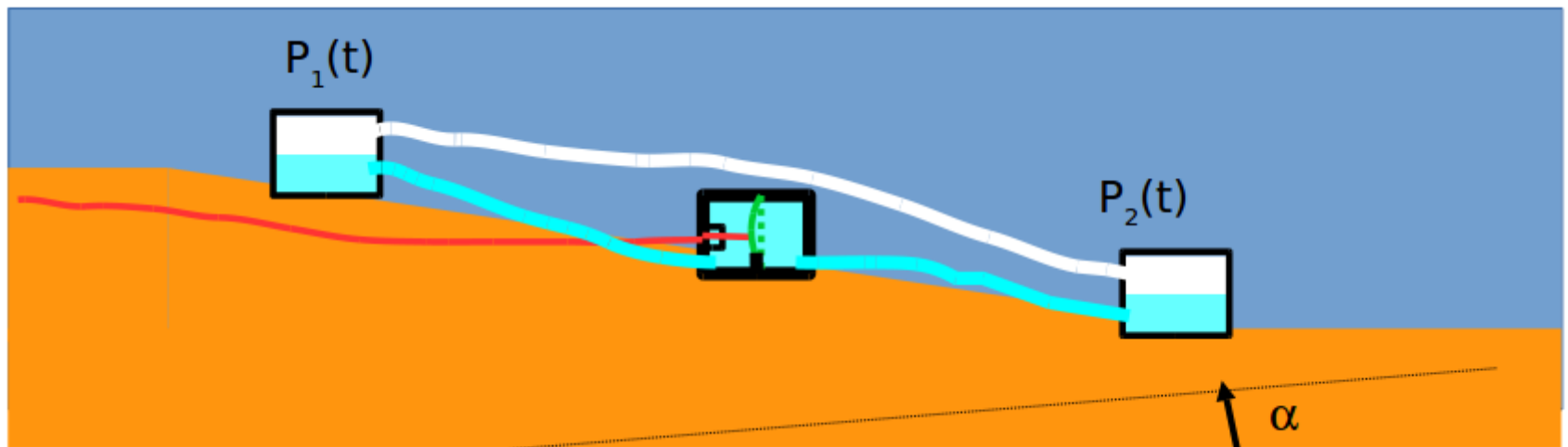
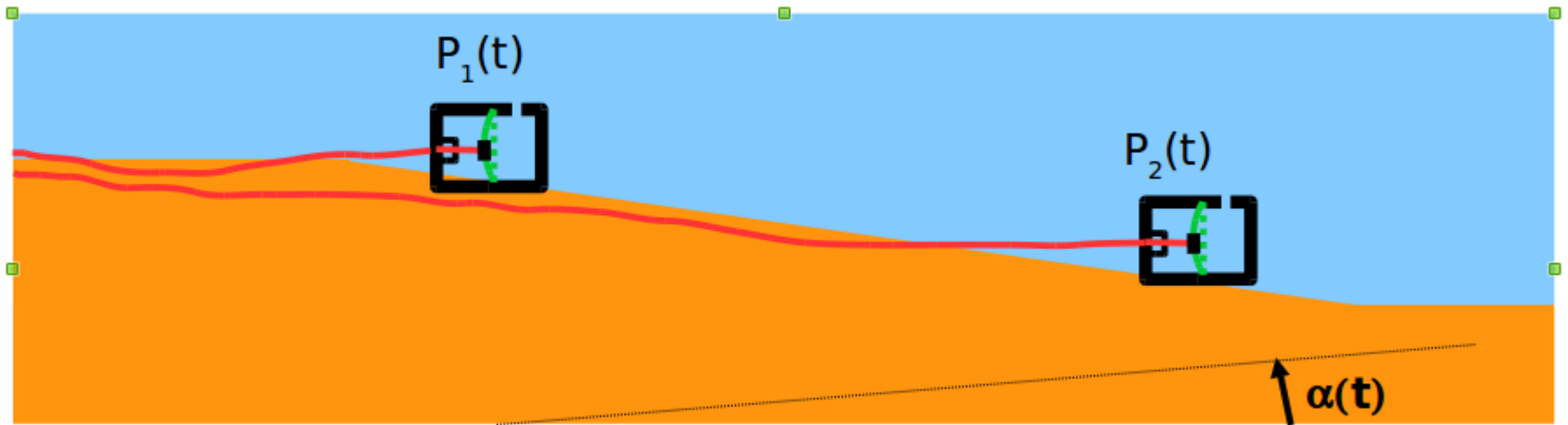
Sensibilité nominale :

$d=1 \mu\text{m}$  pour  $0.1 \text{ mm}$  d'eau de  $\Delta P$   
soit  $d=1 \text{ nm}$  pour  $\alpha=10^{-9}$  et  $L=100 \text{ m}$

- problème de l'équilibrage après installation  
pour travailler en faible déformation de la membrane



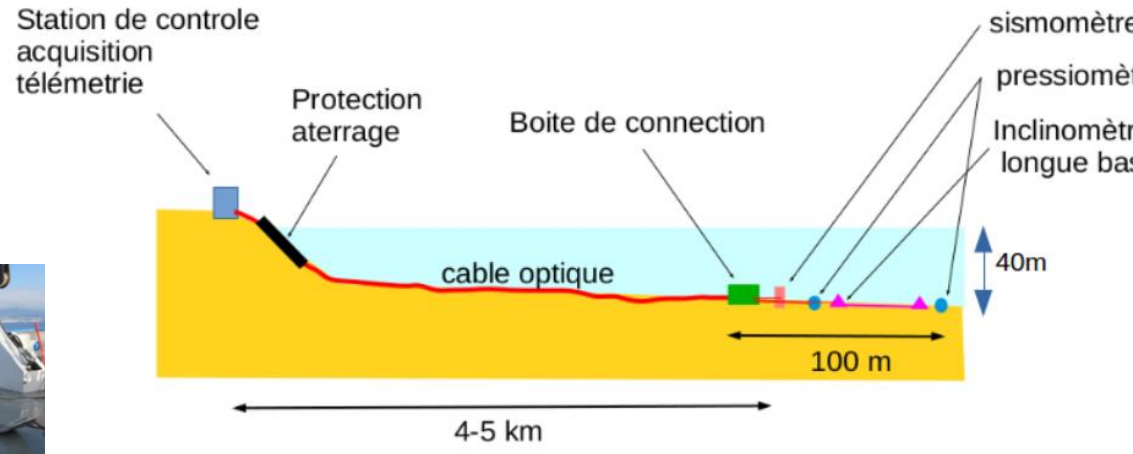
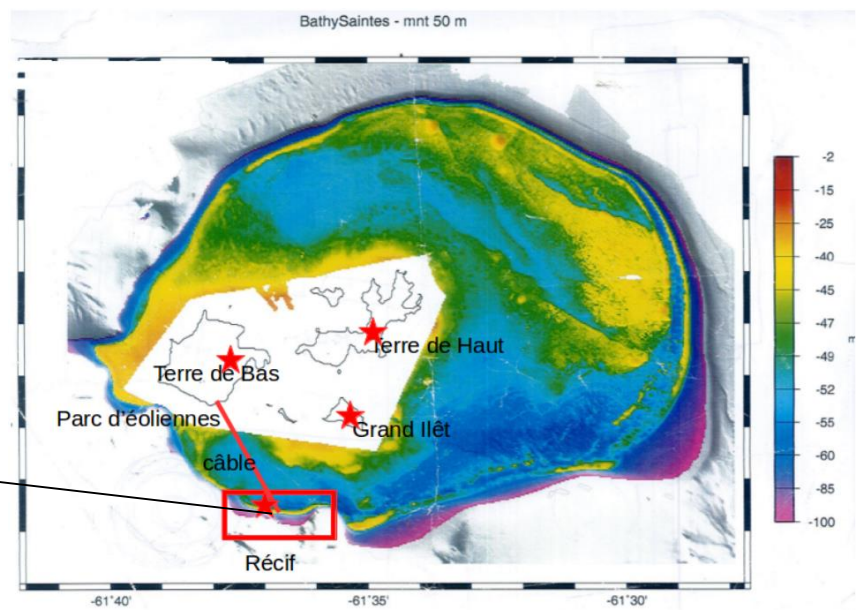
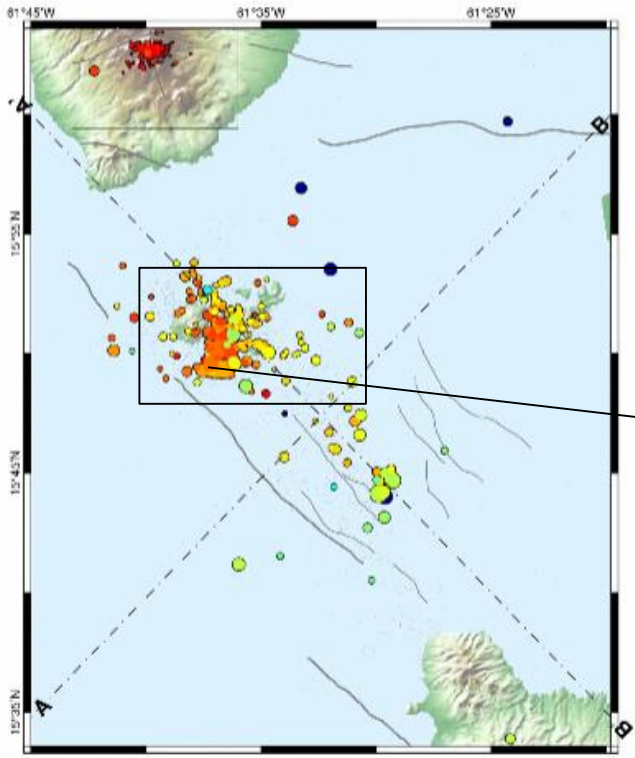
# Design for ocean bottom installations





# Microseismicity of Les Saintes islands - PREST interreg offshore installation of optical seismometer, pressiometer, and tiltmeter June 2020

Les Saintes (1 year)  
© IGP-UVSQ, 2017



# Qualification in pilot sites prone to volcanic and seismic hazard

## Volcano - 2020-2022

### La Soufrière de Guadeloupe

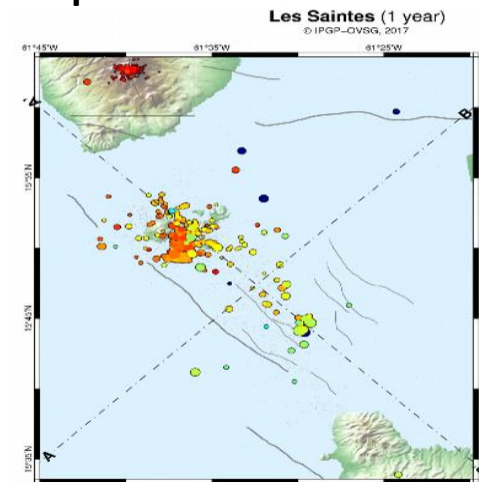
seismometer antenna  
strainmeter, tiltmeter,  
microphone, ....



## Offshore seismicity- 2021-2022

### Les Saintes, Guadeloupe

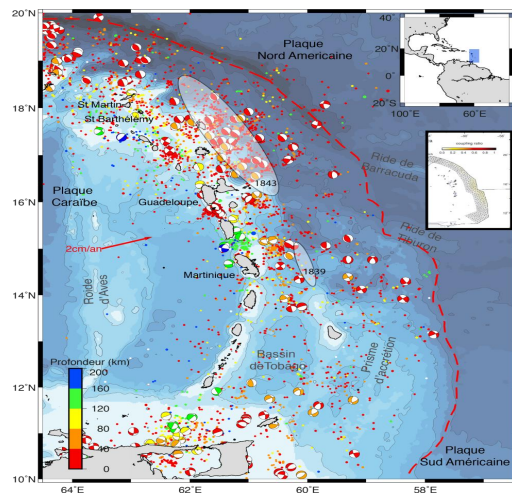
hydrophones  
seismometer  
antenna/DAS



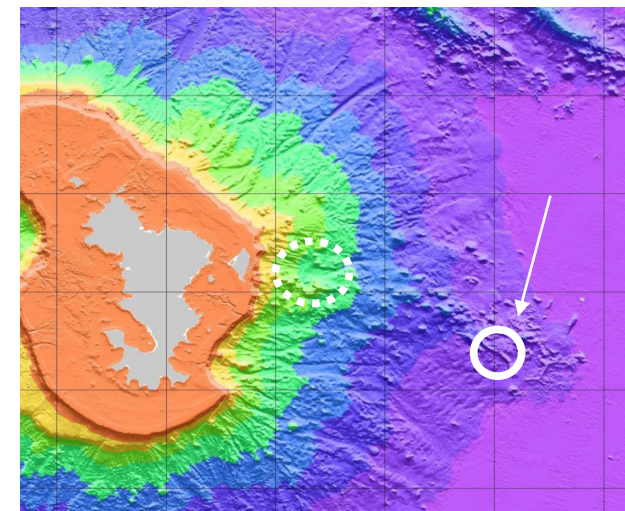
## Far Offshore 2021+ coll. IFREMER

### Lesser Antilles

### Coupling & Mega-earthquakes



### Mayotte : New born Submarine Volcano

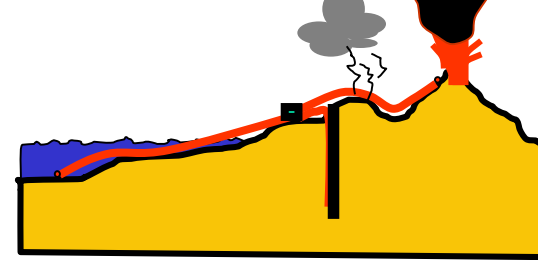


+ other earthquake and volcano targets : Japan, Chile, Italy, Greece, Turkey,...



# CONCLUSION

## Innovative optical Geophysical sensors



### SENSOR



- no electronics
- no power need
- resistant high and low T
- insensitive to EM
- robust, no maintenance

### OPTICAL CABLE

- 50 km - more?
- insensitive to EM

### INTERROGATOR



- resolution 0.03 nm
- 1.5 W / channel



### HIGH RESOLUTION OPTICAL INSTRUMENTS

- **seismometers (ESEO-IPGP)**  
*Bernard et al., SRL, 2019*
- **borehole tiltmeter (GM)**
- **long base tiltmeter (ENS)**
- **pressiometer (ENS)**
- **strainmeter**
- **hydrophone**
- **microphone**
- **pressiometer, T**
- **geochemical sensors.**
- etc...



#### Antilles (IPGP Observatory):

- La Soufrière Volcano, Guadeloupe
- Les Saintes seismicity – offshore
- subduction far offshore (*IFREMER*)

#### Mayotte (IPGP Observatory) :

- new-born submarine volcano (2018) (*IFREMER*)

#### La Réunion Volcano (IPGP Observatory)

#### Other volcanic and seismic regions (Italy, Japan, Chile, Greece, Antarctic...)

#### Marine Biology; oceanography

Marine mammals, physical parameters.

#### Geo-industries:

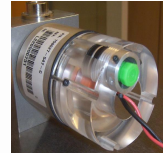
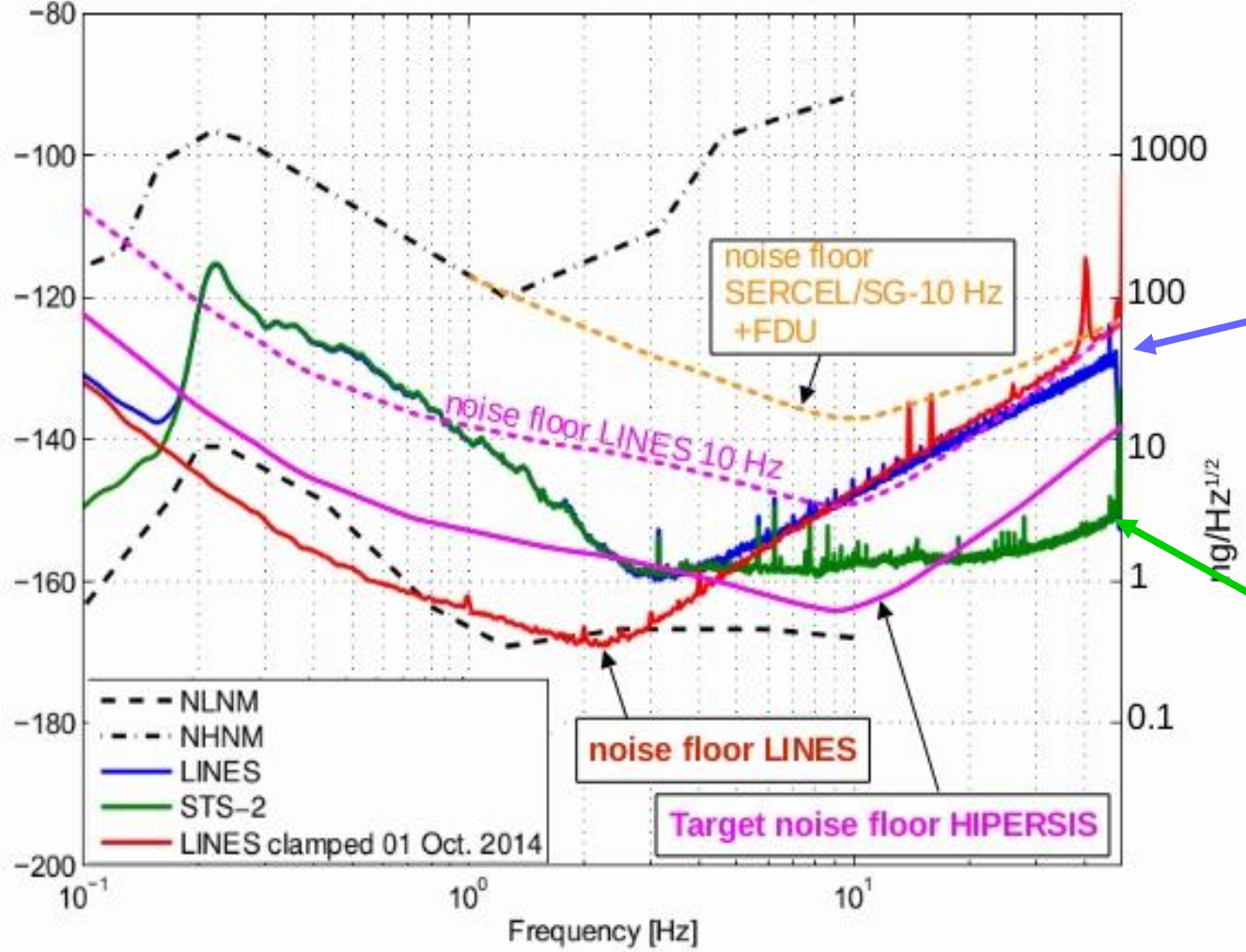
geothermy, mining (*INERIS*), oil/gas production, storage

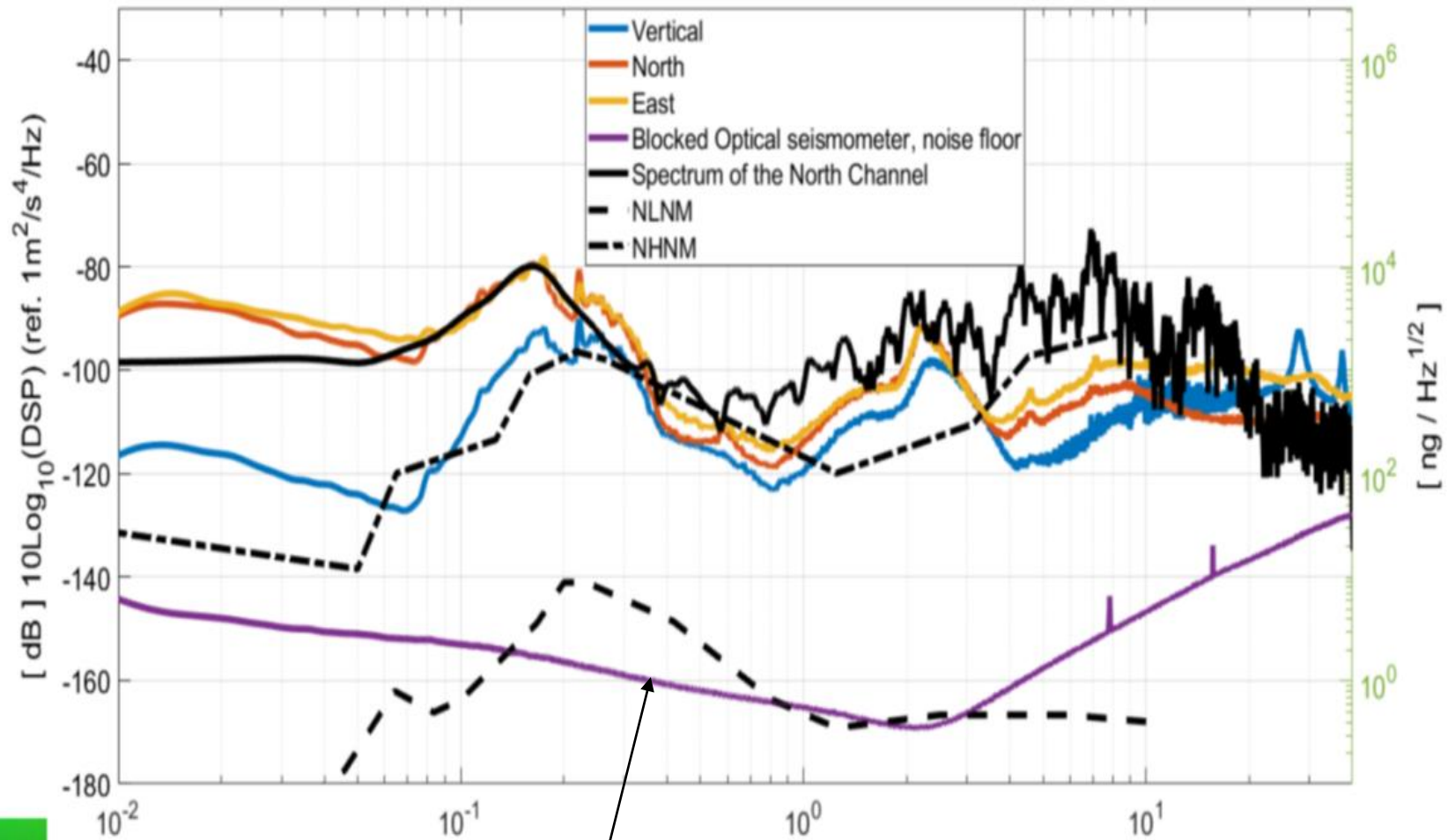
#### Building industry sector:

offshore wind farms, bridges, dams ...

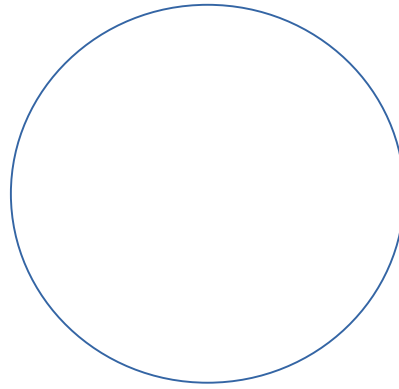


Acceleration Power Spectral Density obtained on July 8, 2014 in Rustrel

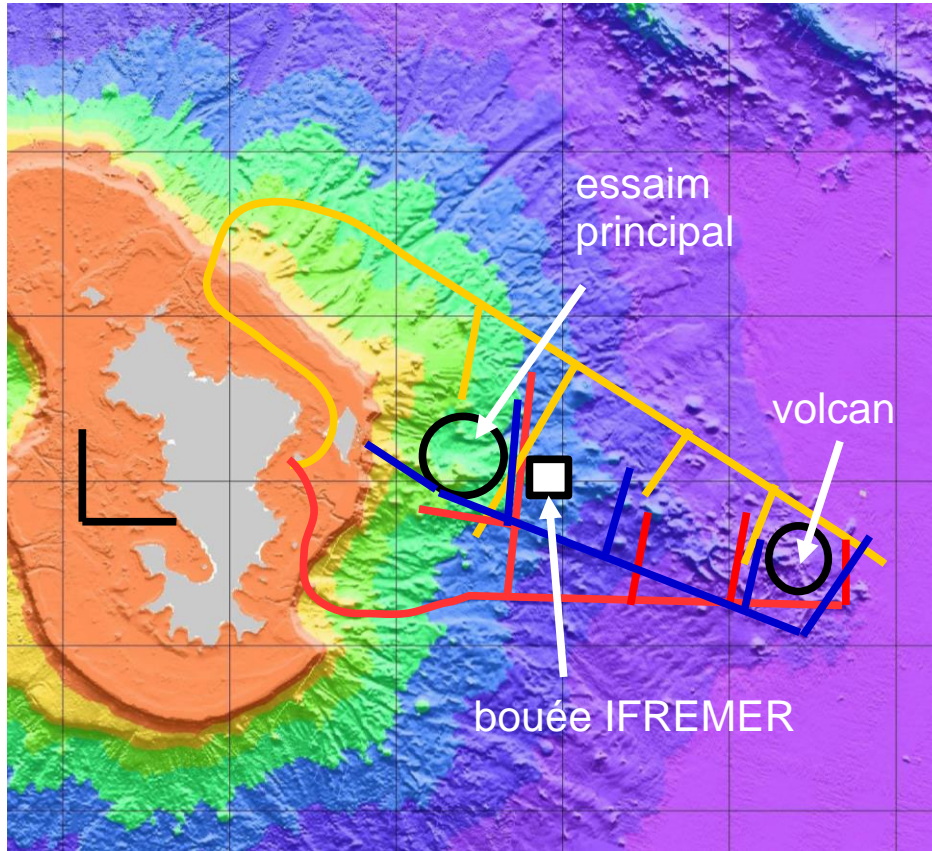




Noise floor of the optical interrogator



# Elements de reflexion pour un Observatoire sous-marin temps-réel à Mayotte



## Cablage instruments fond de mer

### 4 possibilités:

#### 1. Aterrage :

- telecom nord
- telecom sud
- telecom petite terre ?

#### 2. Bouée IFREMER

### Capteurs : association

→ **électriques (commerciaux)**

→ **optiques**

- sismomètres
- extensomètres
- inclinomètres
- hydrophones
- pressiomètres
- chimie ? ...

**+ système DAS (sur aterrage)**

### Sur la bouée :

Capteurs optiques pour longues distances

50 km

- Cable sous-marin : 25 ke/km  
100-200 km
- Temps bateau cablier : 50 ke/jour
- Aterrage ?
- instrument : 50-200 ke par sites



# LOFHIG

## Generic work on the opto-electronic system

- Real time algorithm adaptative deconvolution (linear), AI (non linear correction)
  - New optical architecture and modulation for long distances > 50 km
- Design custom system for merging DAS techniques and our optical arrays



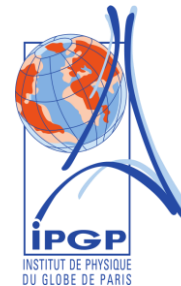
## Improving the optical seismometer of HIPERSIS

- miniaturization for deep borehole applications
  - long period seismometer
  - strong motion accelerometer



## Design and construction of new sensors - TRL 3 to 6

- Hydrophones
- Strainmeters
- Tiltmeters
- Pressimeters
- Gradio-gravimeters
- Geochemistry, ...
- ...etc...



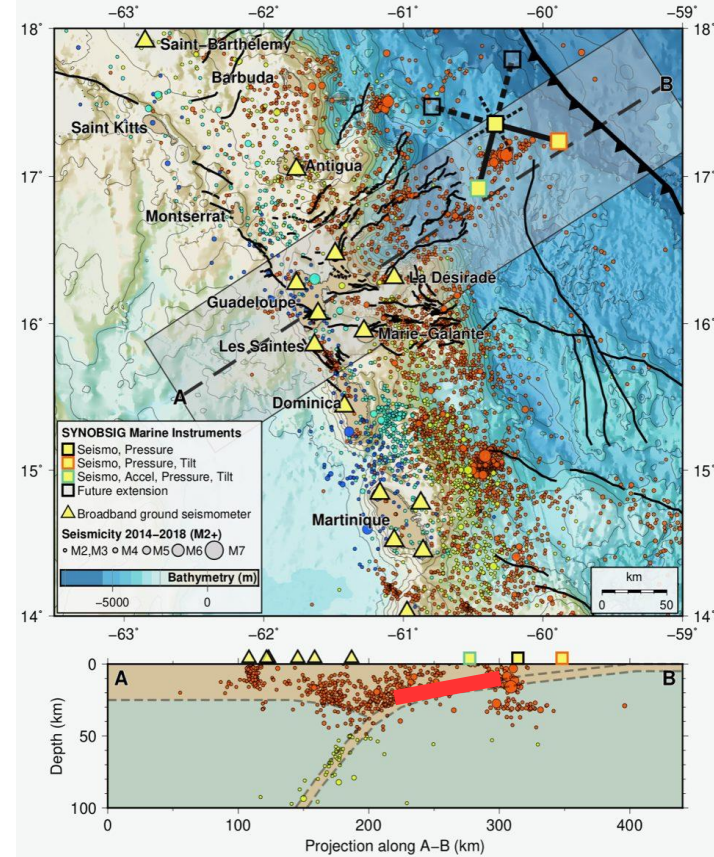
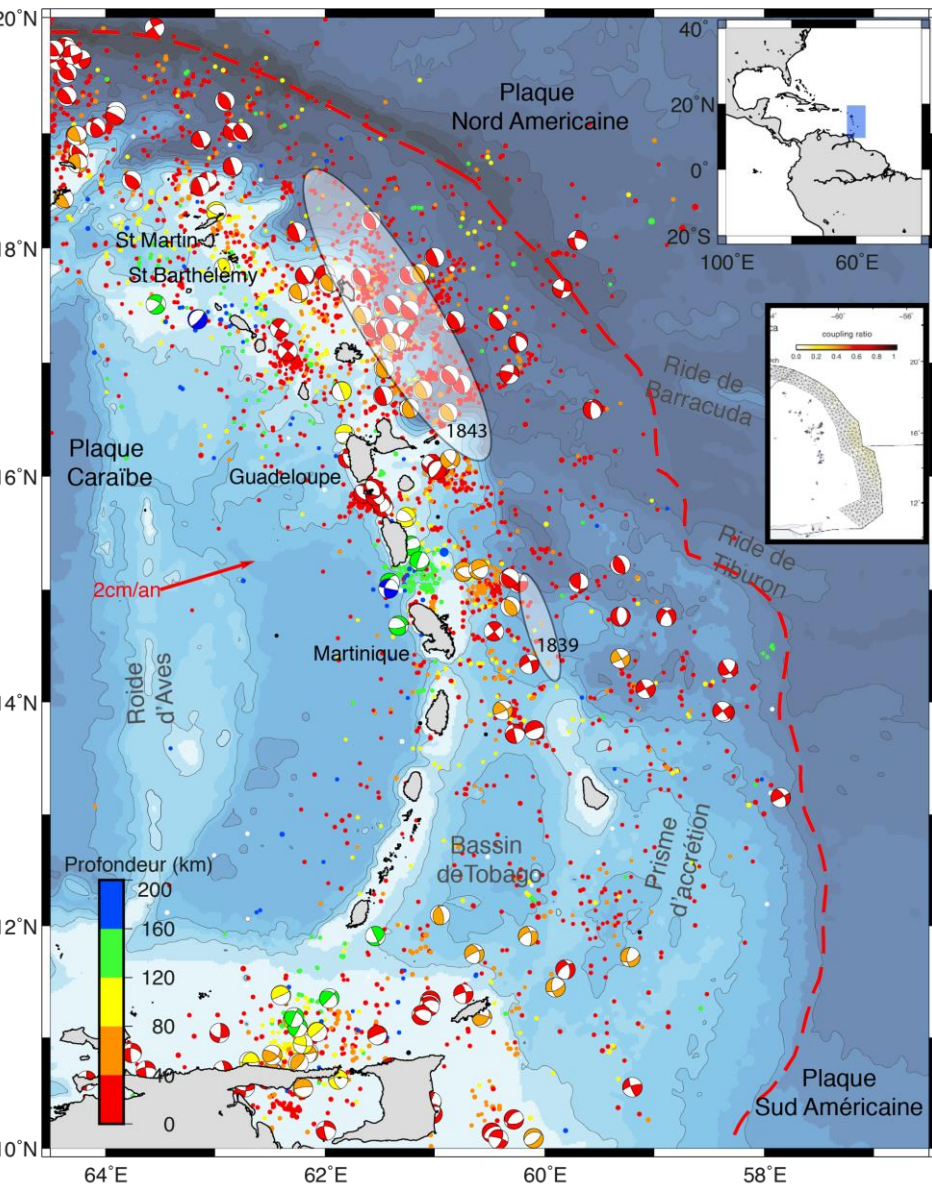
## Intellectual Property – Possible patents

ESEO, IPGP, ENS

SATT-Ouest, Valorisation CNRS, Valorisation CNRS



# Future optical instrumentation offshore ?



## Offshore Seismological targets in Caribbean:

- with landing cables  
5 km → 50 km → ?200 km
- with cable on buoys  
IPGP-ESEO-IFREMER

## **IPGP**

- Concept and design of new instruments
- Comparison with commercial instruments
- Installation in pilot sites
- Integration to observatories for real time monitoring
- Data analysis and interpretation
- Modeling of dynamic processes

## **ESEO**

- seismometers : self-calibration systems
- opto-electronics, laser Diode, (P, T), long distance
- fusion of DAS with the optical seismometer
- digital and analog hardwares (DSP, FPGA)
- embedded artificial intelligence

## **ENS :**

- construction of tiltmeters and gravimeters