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DE LA RECHERCHE À L'INDUSTRIE

The PREliminary Miga Seismic Experiment - PREMISE

O. Sèbe[1], S. Gaffet[2], M. Auguste[3], F. Bayoua[4], M. Besson[5], D. Boyer[2], C. Broucke[6], S. Carré[1], A. Cavaillou[2], J.-B. Decitre[2], D. Fouquet[1], C. Lallemand[1], V. Lanticq[4], M. Laporte[1], I. Lazaro Roche[2], A. Lescoat[6], B. Miossec[1], A.-S. Morlens[1], S. Olivier[1], G. Rouillé[1], L. Sommier[1], A. Vallage[1]

1 – **CEA, DAM**, F-91297 Arpajon, France
2 – **LSBB**, Laboratoire Souterrain Bas Bruit, CNRS, 84400 Rustrel, France
3 – **I.E.M**, Les Agachons, 84480 BUOUX
4 – **FEBUS Optic**, Technopole Hélioparc, 64000 Pau, France
5 – **Ets BESSON Michel**, 127 rue des Cayssines, 46000 CAHORS
6 – **Université de Strasbourg**, CNRS, EOST, UMS830, F-67000 Strasbourg, France
7 – **SERCEL**, 16 rue de Bel Air, BP 30439, Carquefou, France

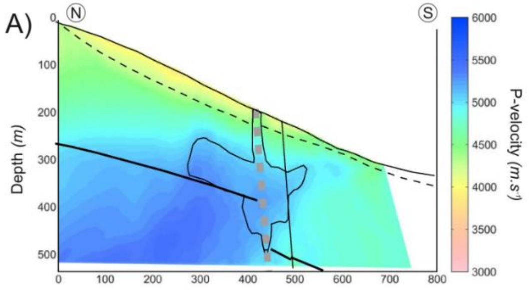
Outline

- The context and main objectives
- The experiment Design and deployment
- Example of recorded signals
- Some preliminary analyses

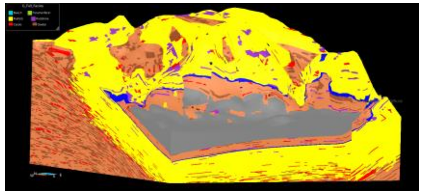
The main objectives and the general context

- **Several purpose:**
  - Analyze the **effects of the free surface** (topography) and of local **heterogeneities** on the **seismic wave field**
  - Test **High performance numerical modeling** of the seismic wave field in complex media
  - **Use of spatial properties** of the seismic wave field
    - Multi-scale 3C seismic antenna for beamforming and gradiometry
  - **Explore DAS performance** for measuring the seismic wave field
    - Comparison with classical seismometers

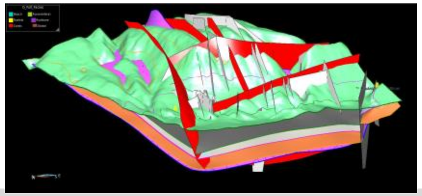
- **The selected site: the Underground low Noise Laboratory (LSBB)**
  - 3D geometry: (4km galleries)
    - underground and surface measurement
    - all around the source
  - Low noise environment: optimize SNR
  - Well know 3D geological model



Facies model

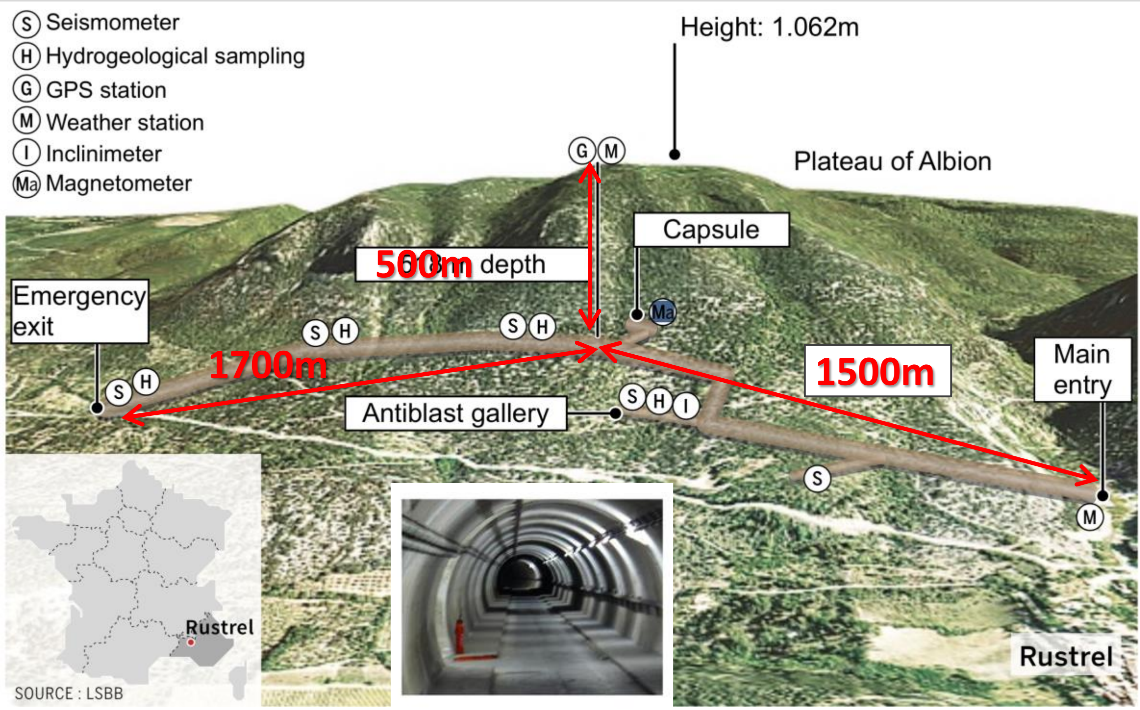


Fault & Horizons model

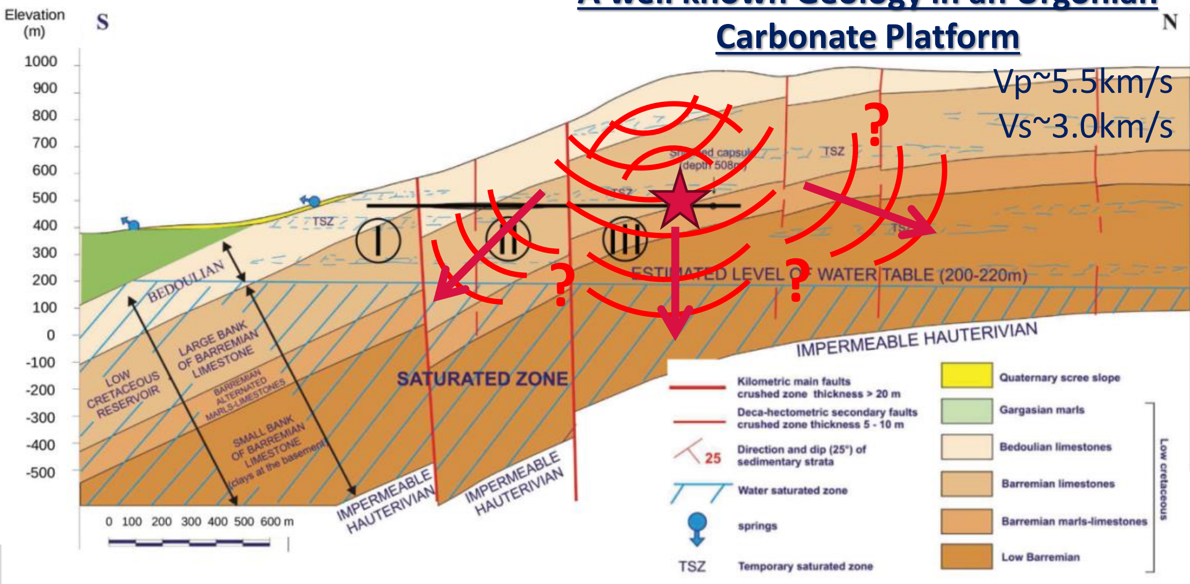


Maufroy etal. 2014, Matonti et al 2017, Tendil et al. 2018

A 3D Ground & Underground Infrastructure



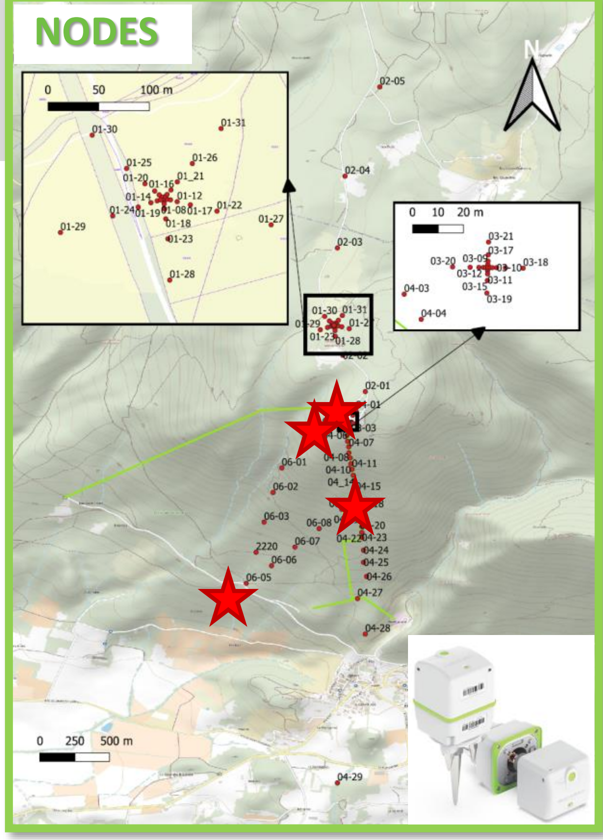
A well known Geology in an Urgonian Carbonate Platform

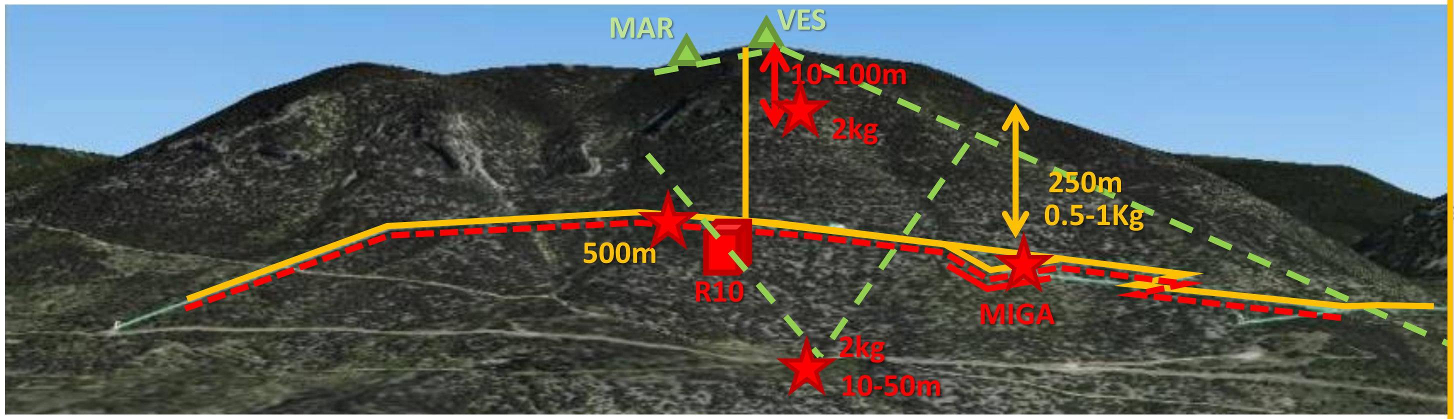


The experiment design

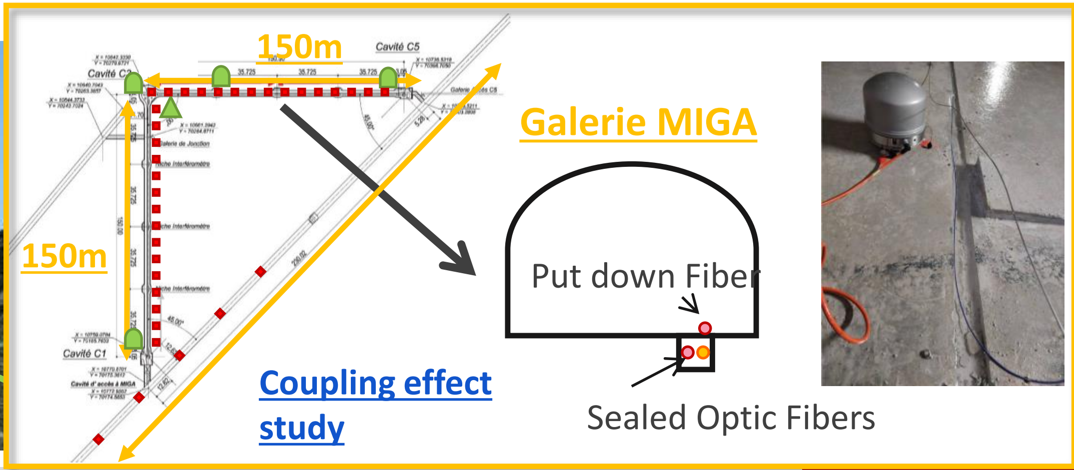
- **3D geometry**
  - Seismometer 3C - Surface: 105 « Nodes » sensors
  - Accelerometer 3C – Galleries: 200 « Sercel » Mems
  - **Optic Fiber – Galleries: >3km**
- **Several specific area**
  - MAR & VES: a multi-scale 3C seismic array
  - MIGA: Simultaneous recording by a dense seismic array of 3C seismic sensors and Optics Fibers
- **4 shot zones:**
  - Surface and galleries
  - Several depth of burial: 10m, 25m, 50m, 75m, 100m, 250m, 500m
  - Several yields: 0.5Kg, 1Kg and 2 Kg

Galleries accelerometers: DSU





DAS: seismic measurements on Optic Fibers



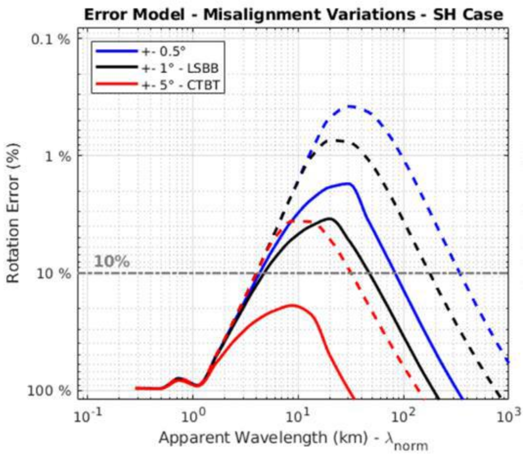
Installation constraints: Seismometers

Deal with High Frequency, 3Components, Dense and multiscale seismic antenna

- **Objectives: 3 Component array processing**
  - Beamforming, **polarization** analysis and **gradiometry**

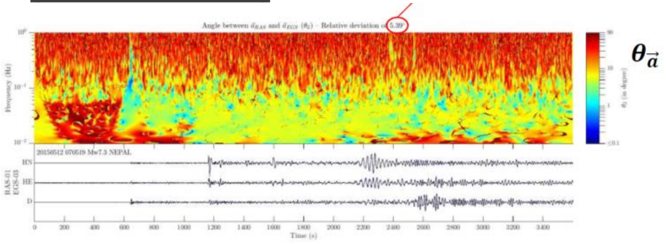
- **High quality sensor installation:**
  - Orientation precision: Δθ≤ 0.5°
  - Position precision: Δx≤2 cm (for small aperture antenna)
  - Instrument response precision: |ΔH|<1%

Gradient estimation: Array derived rotation (Rusch 2020)

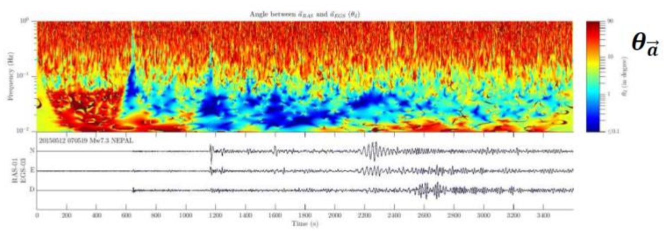


Estimation Error > 20% with Δθ~5°

Array polarization coherency (Labonne 2016)



Orientation variability ~10° (magnetic compass)

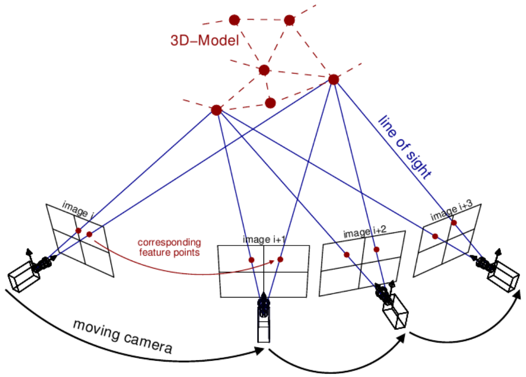


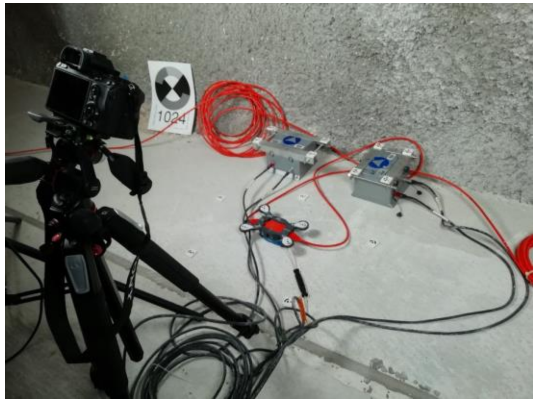
Bleu area : orientation variability < 0.5° (gyrocompass based sensor orientation)

Different installation strategies:

- **At surface:**
  - High precision GPS
  - Gyrocompass

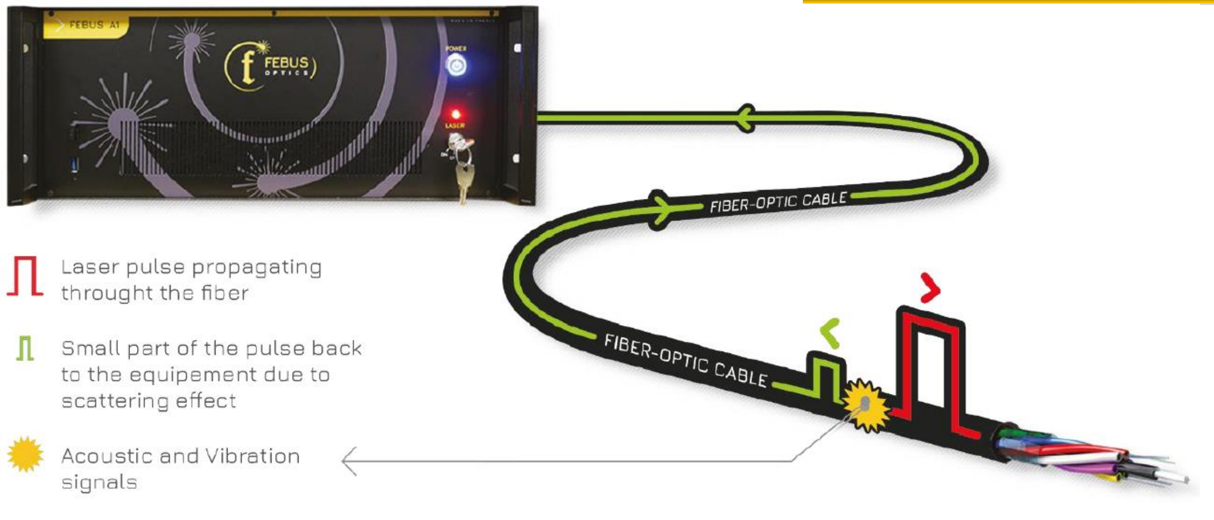
- **In the galleries**
  - Theodolite
  - Photogrammetry with gyrocompass



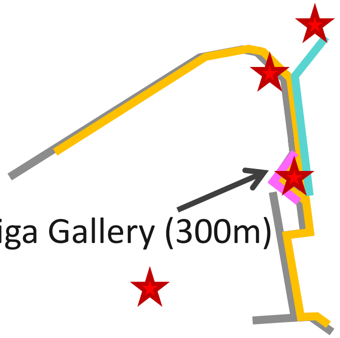


Optic Fiber installation and DAS measurement

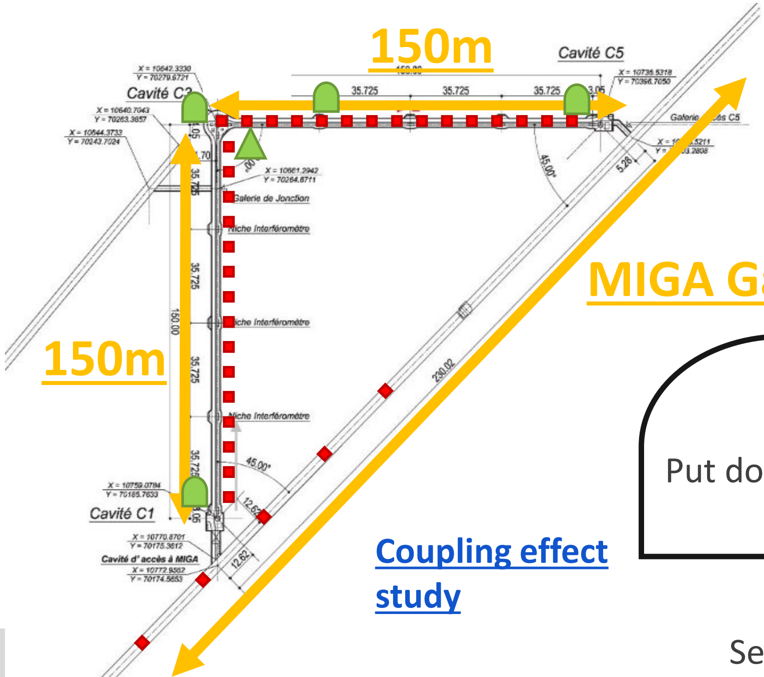
- **Purposes: interest for seismic monitoring**
  - ❑ Performance and quality of DAS measurement
  - ❑ Comparison with seismometer
  - ❑ Relevance of the **amplitude** information: ground coupling effects

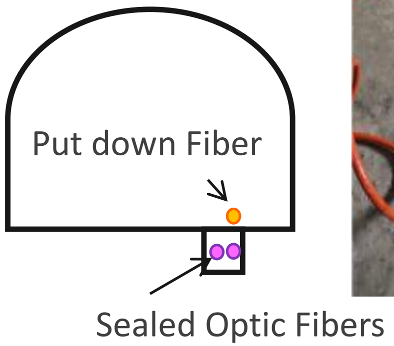


- **3 different coupling area**
  - ❑ **Weak:** placed on the ground
  - ❑ **Strong:** embedded in concrete
  - ❑ **Unknow:** communication fibers



- **Recordings parameters:**
  - ❑ Shot and background noise recording periods
  - ❑ High frequency (>kHz) and high spatial resolution (<5m)
  - ❑ Full data recording: Raw format



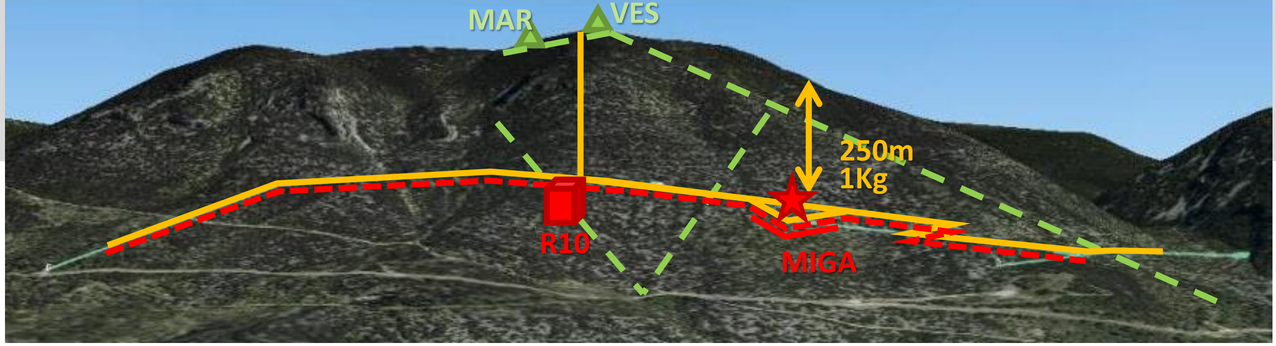


The deployment in few words

- An engaged multidisciplinary team work
- More than 39 persons involved
- 18 Laboratories and companies
- More than 300 Sensors installed
- 3.6 km of Fiber deployed
- 300m of Borehole
- 35 Kg of explosive
- 12T of sand bag
- More than 25 To of data

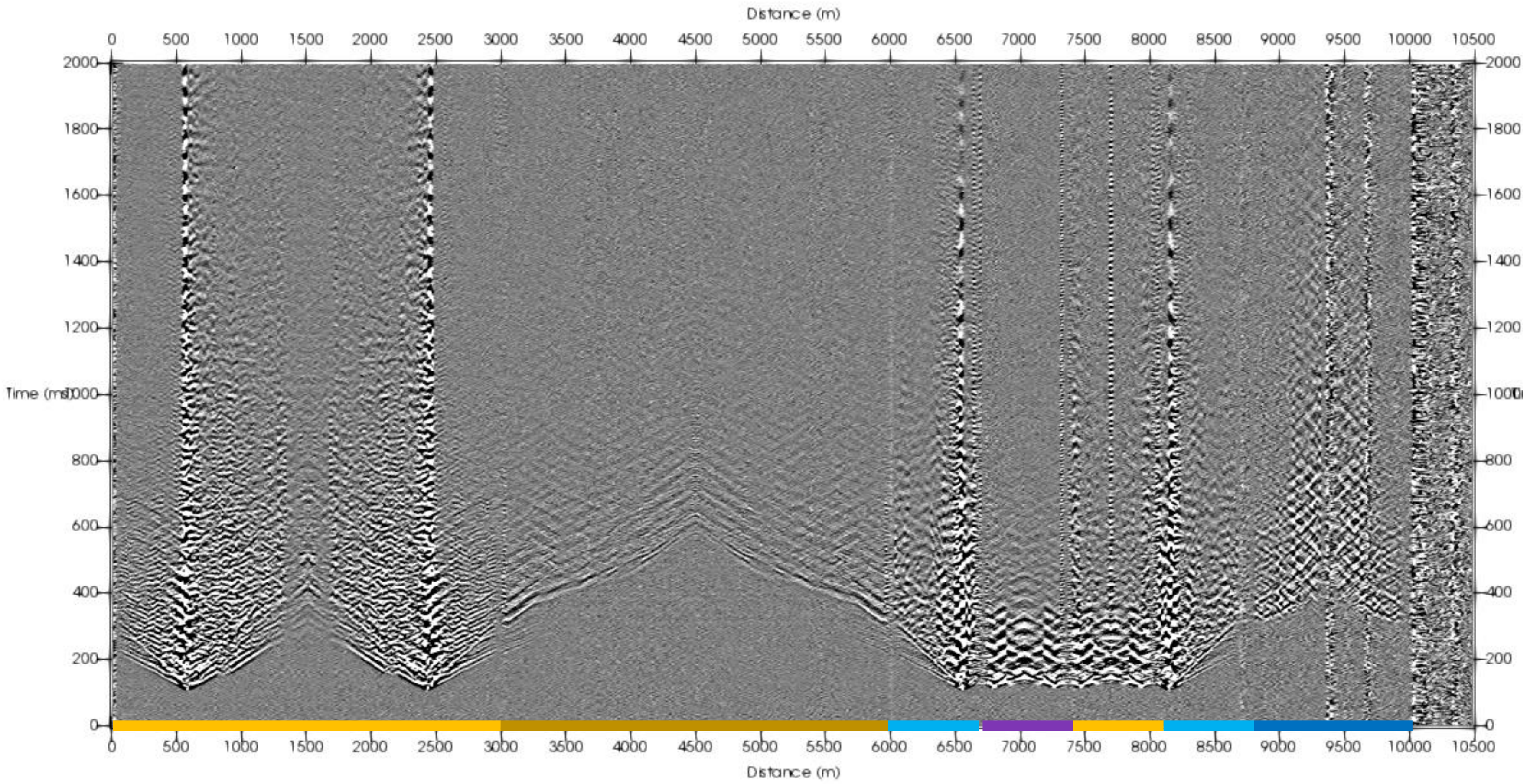
Thank you very much!!!

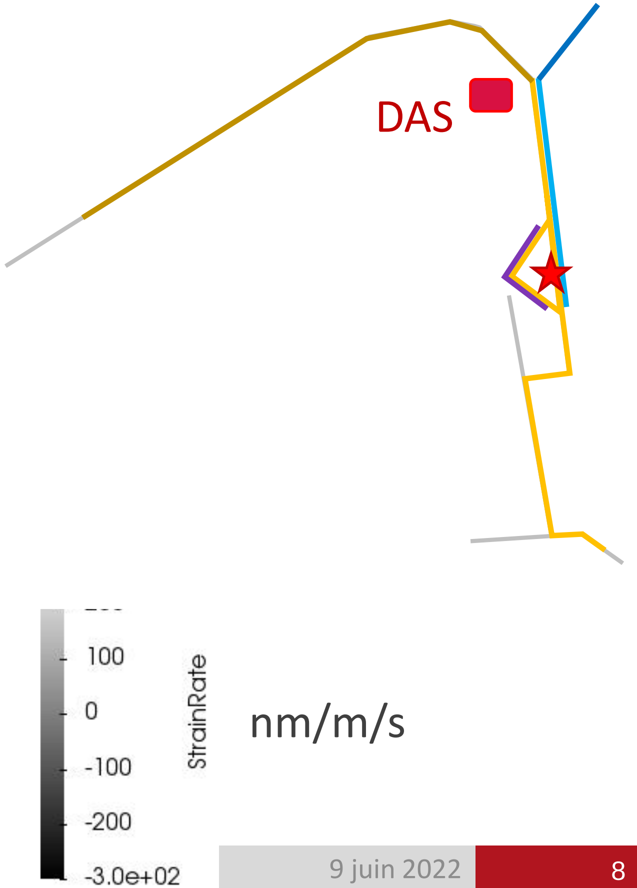
Some recorded signals



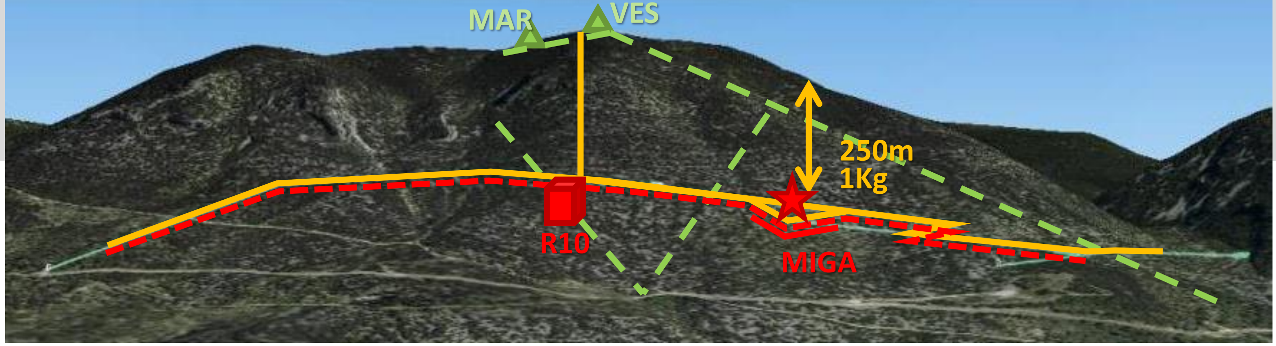
Shot n°2: 1kg, main gallery, 250m depth

- **DAS measurement : Strain Rate**
  - Gauge length of 20m



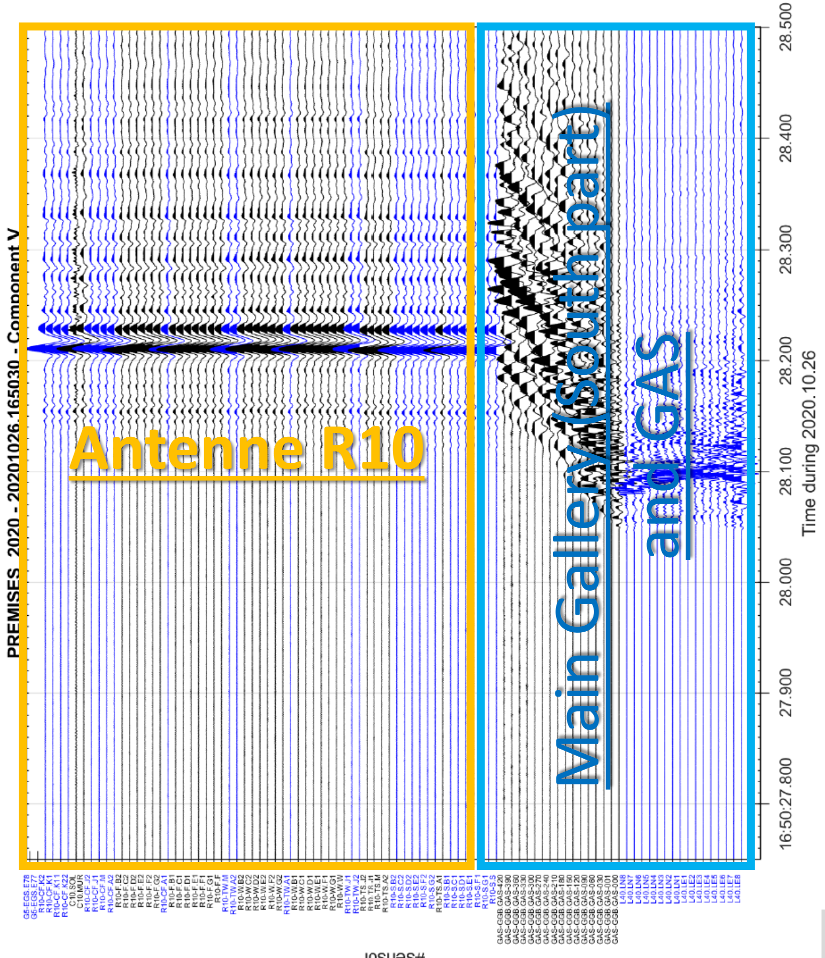


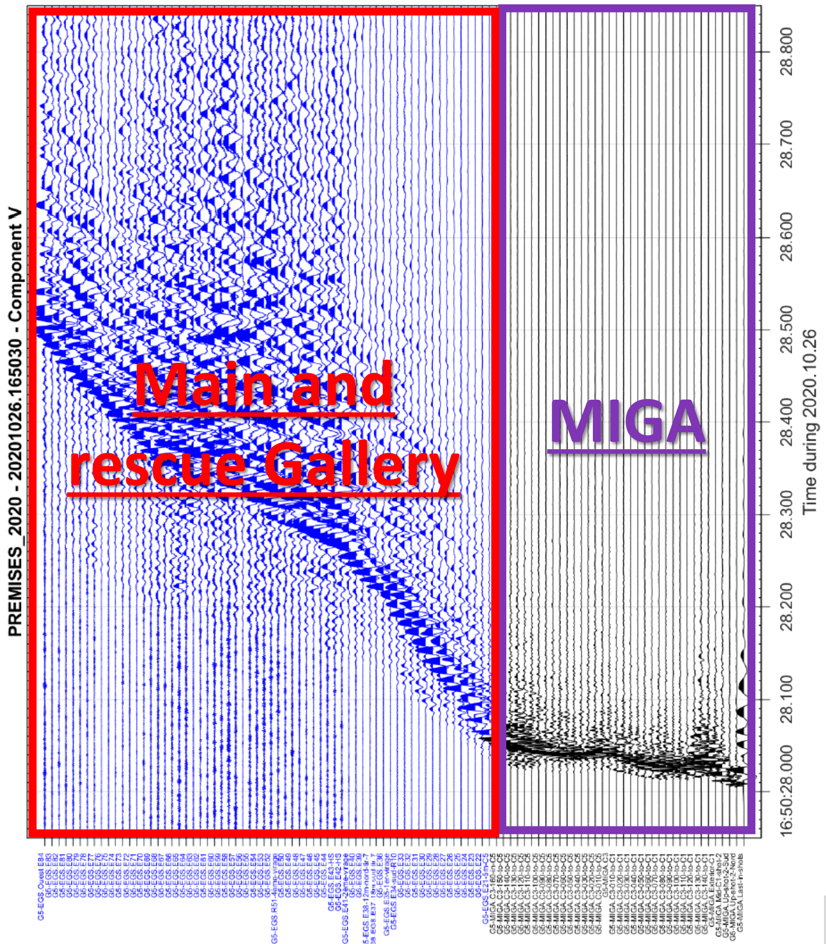
Some recorded signals

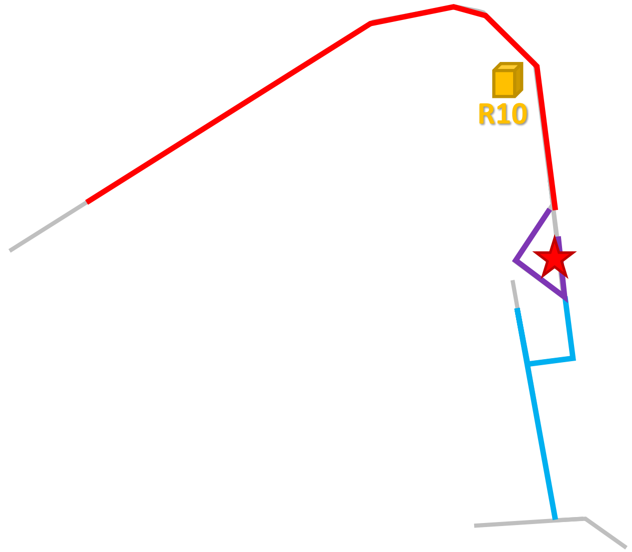


Shot n°2: 1kg, main gallery, 250m depth

- DSU measurement: 3C ground acceleration over 200 sensors



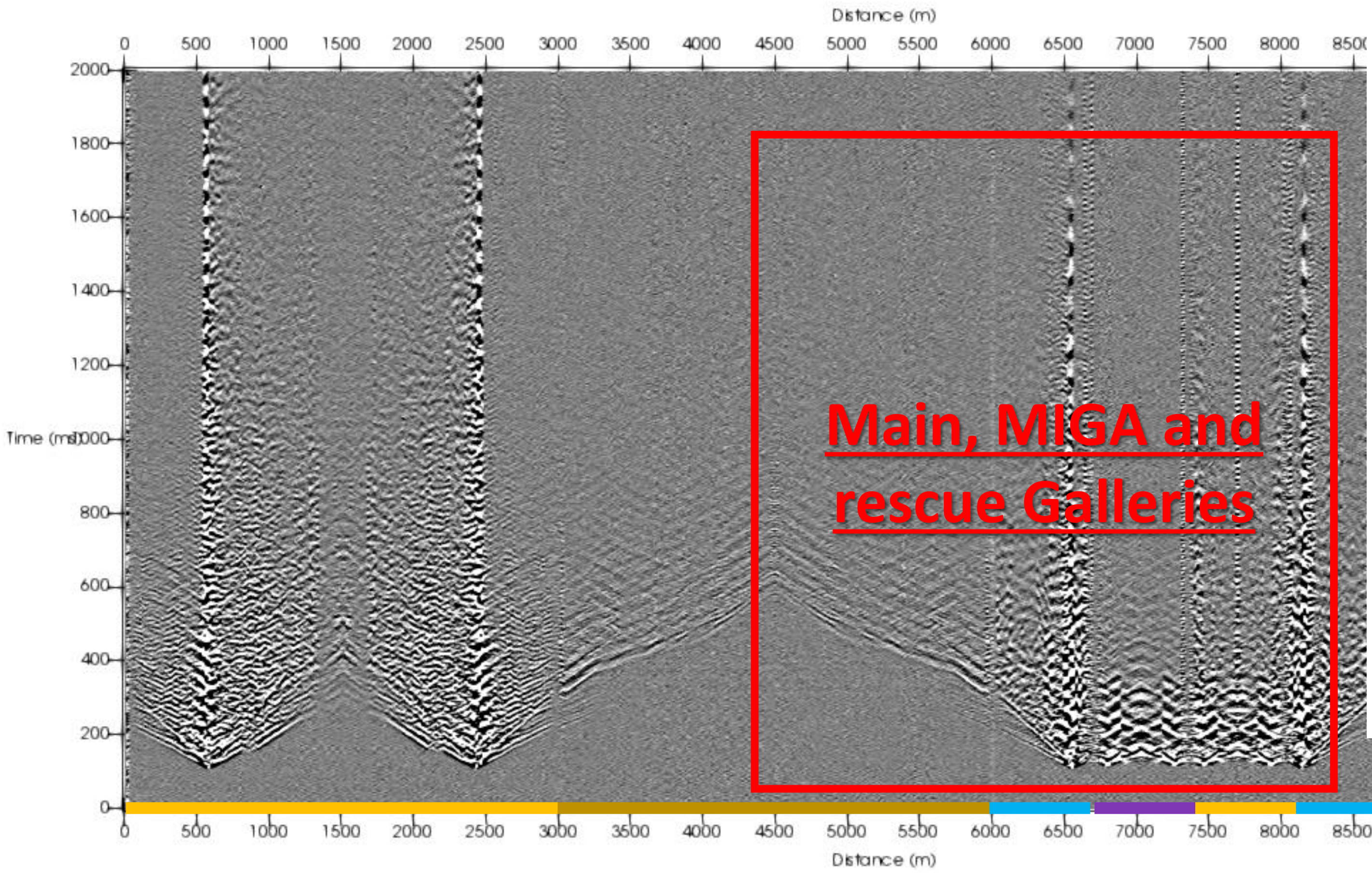


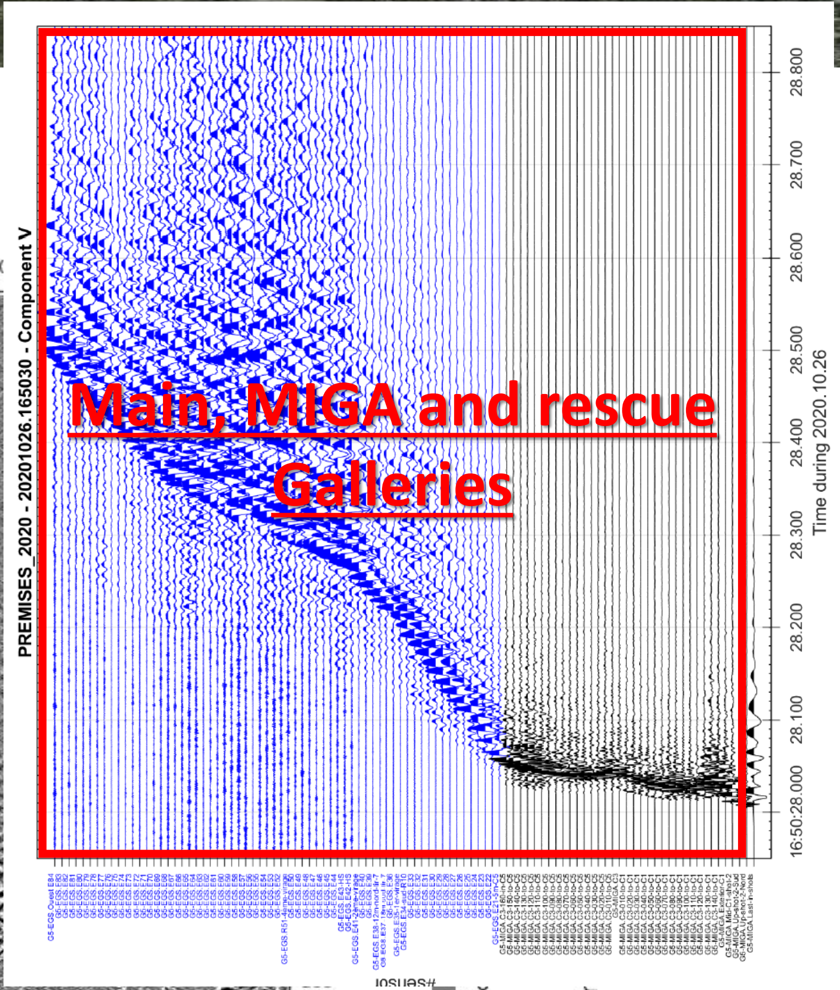


Some recorded signals

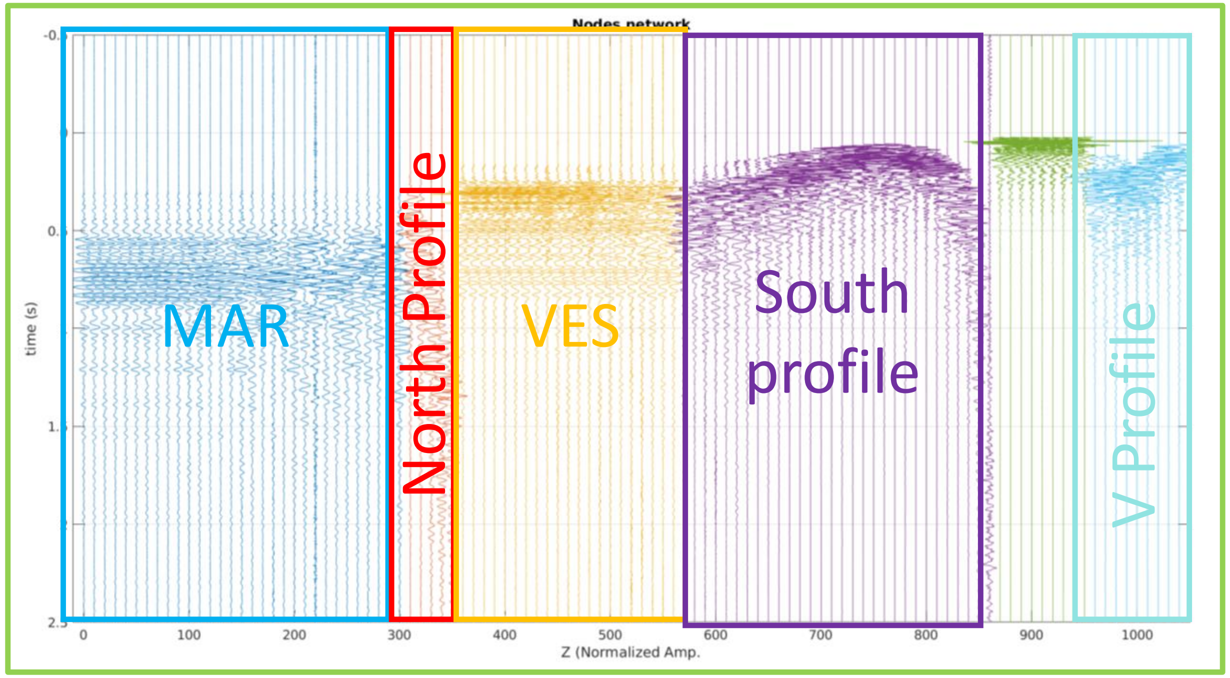
Shot n°2: 1kg, main gallery, 250m depth

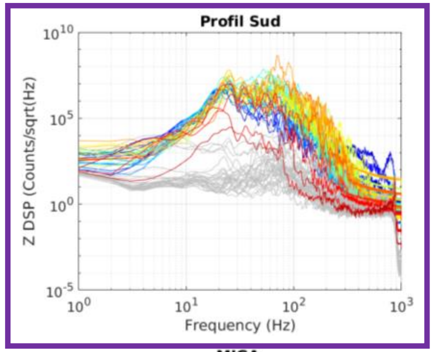
- DAS and DSU measurement direct comparison

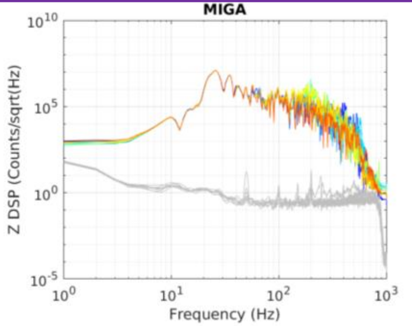


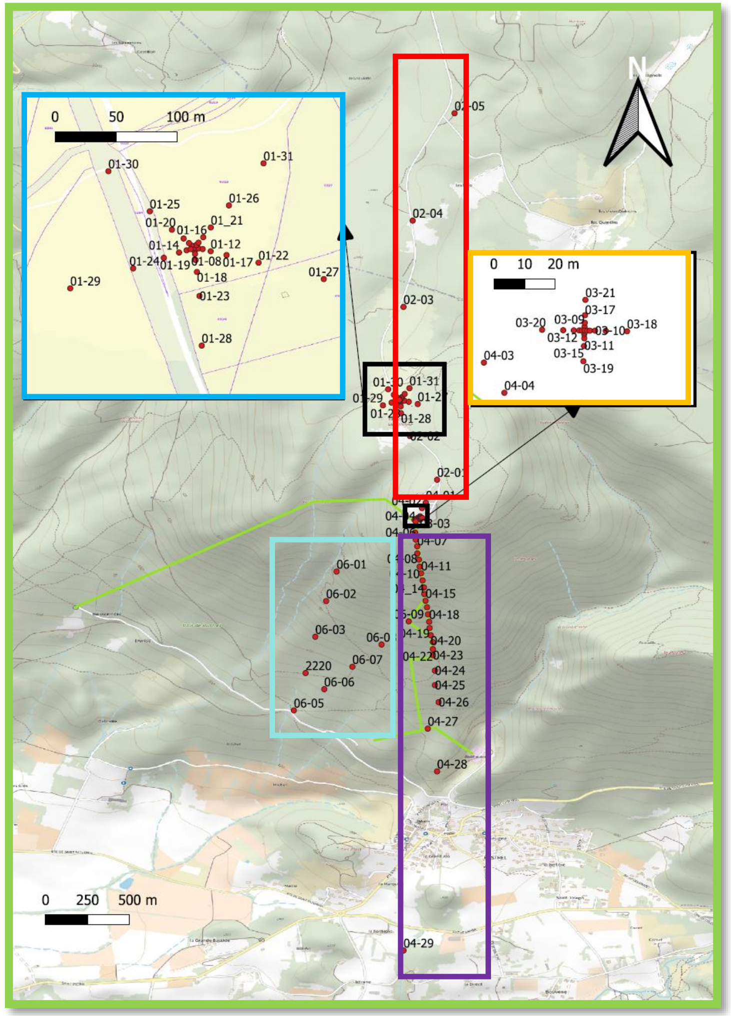


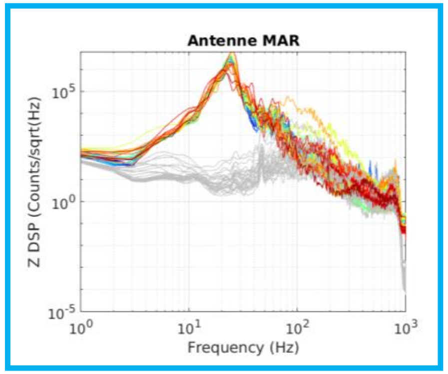
Shot n°2: 1kg, main gallery, 250m depth

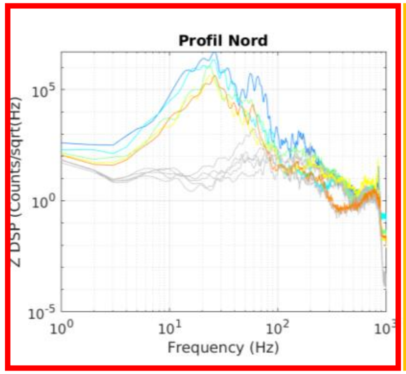


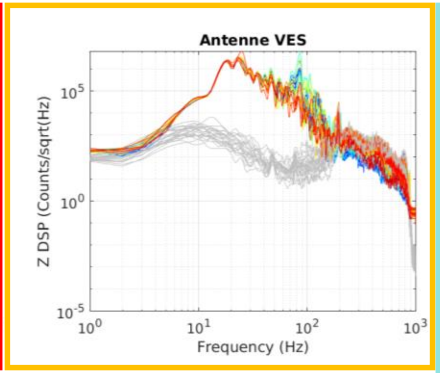


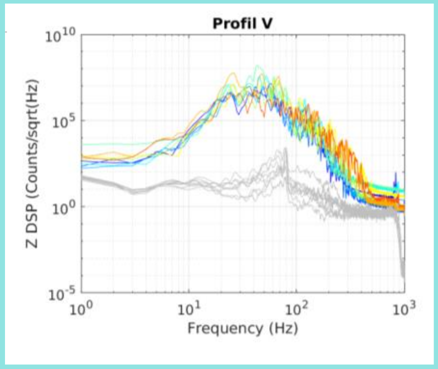








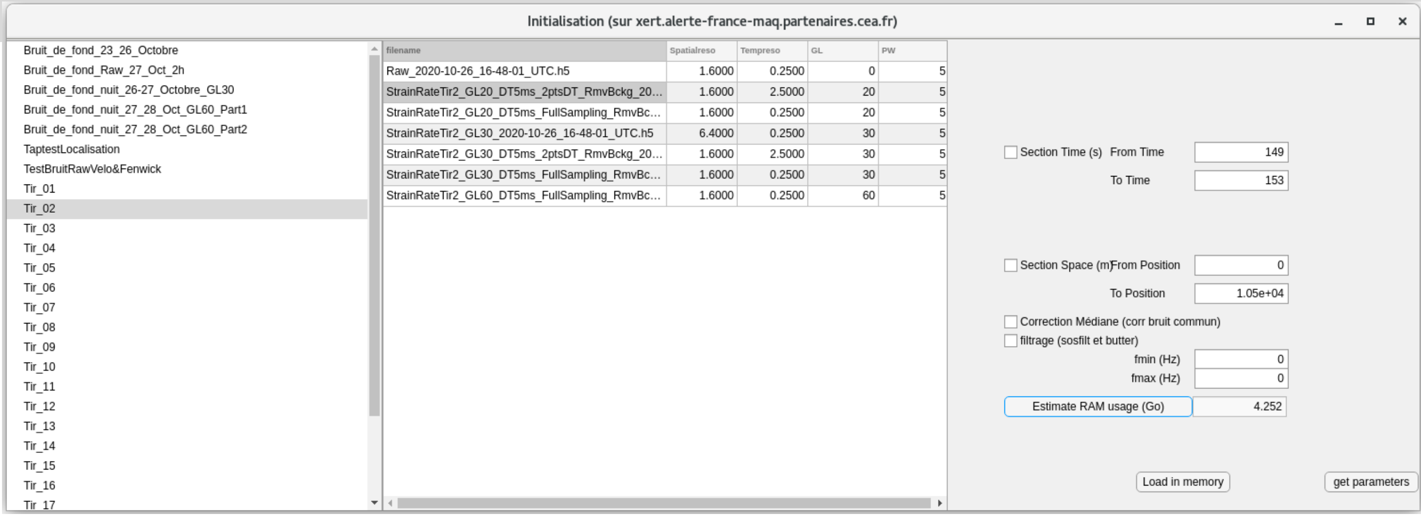


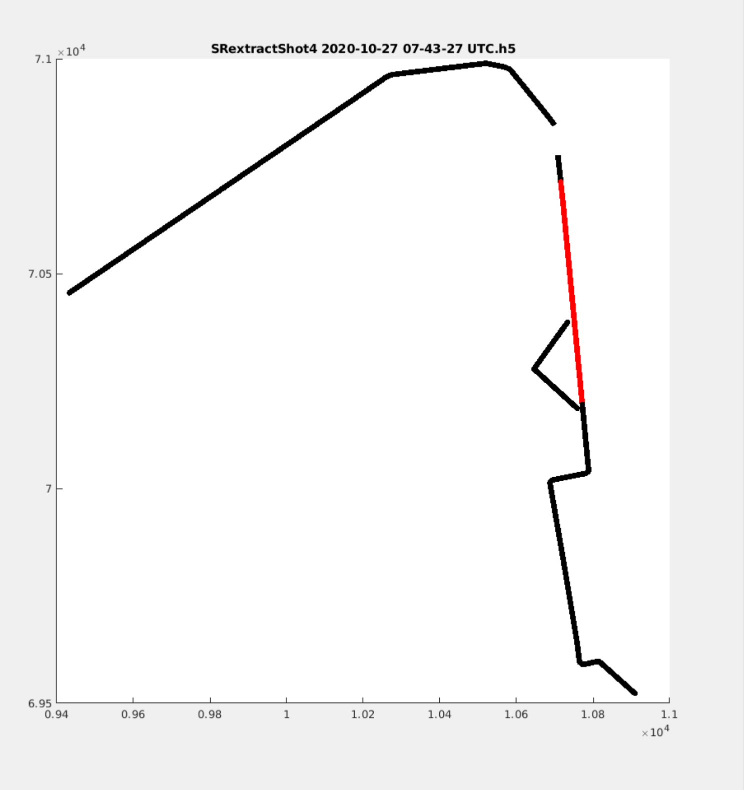


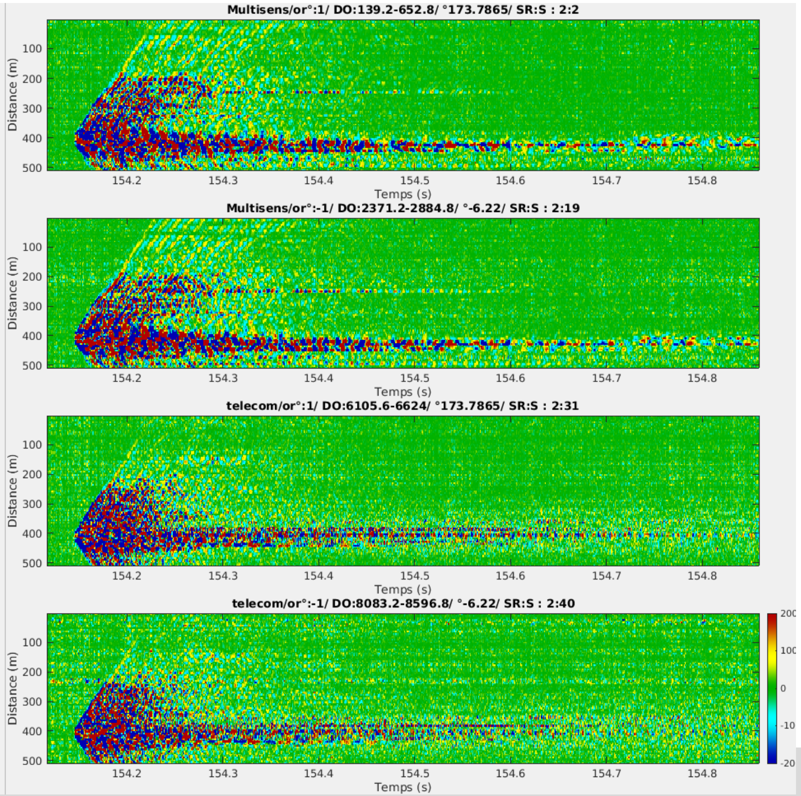
Preliminary DAS data handling

M. Peels internship

- **DAS data: about 20To**
- **Tools to access and perform some basic analyses**
  - Data extraction
  - Profile and waveform display
  - Phase peaking







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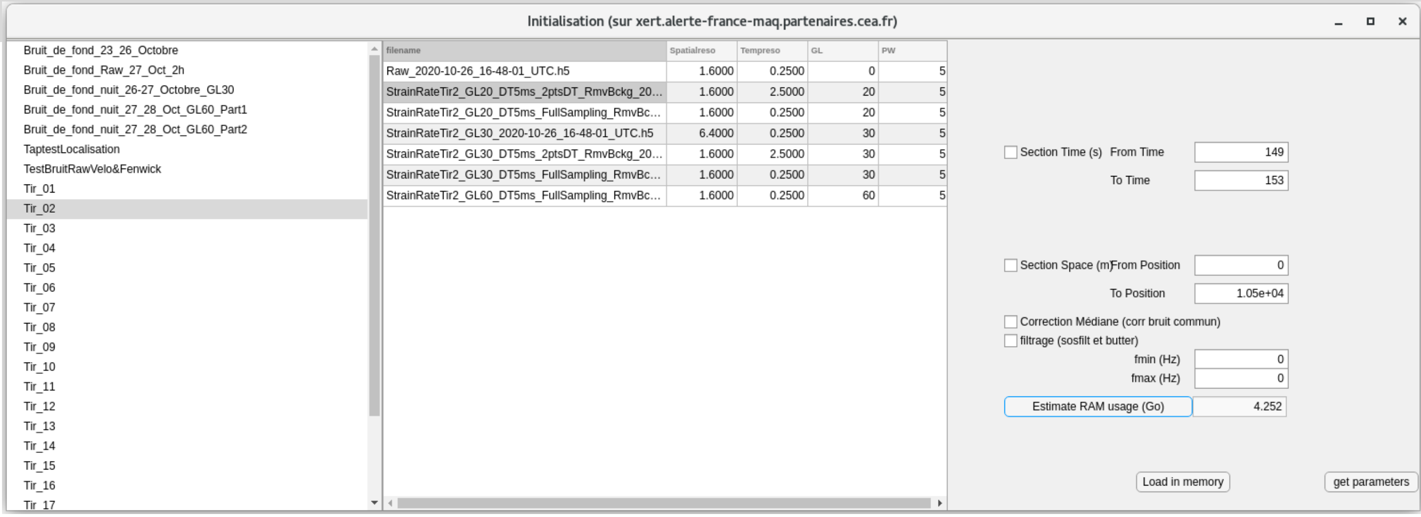

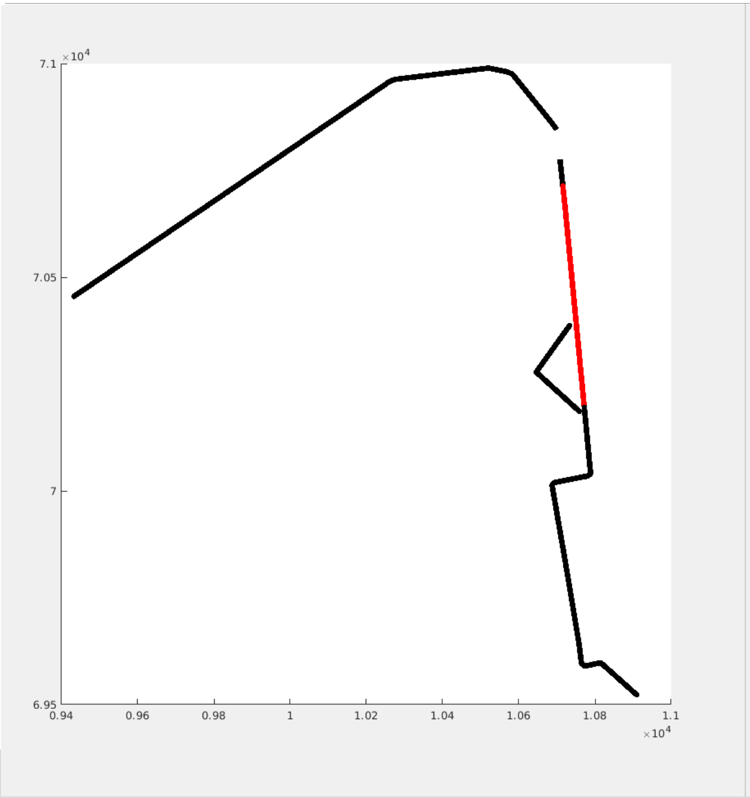

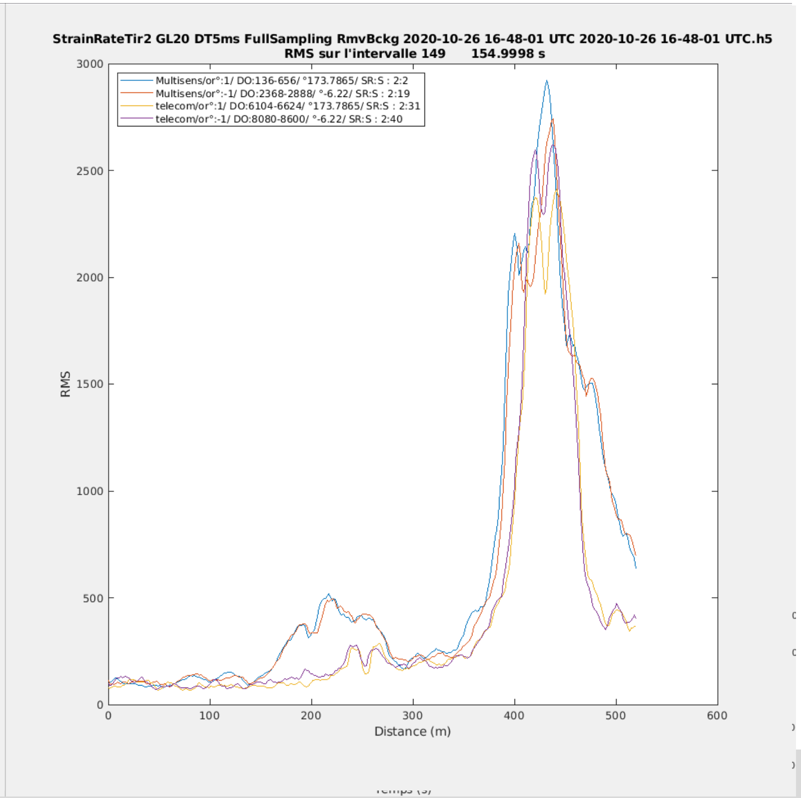

RMS Strain rate amplitude along the fiber

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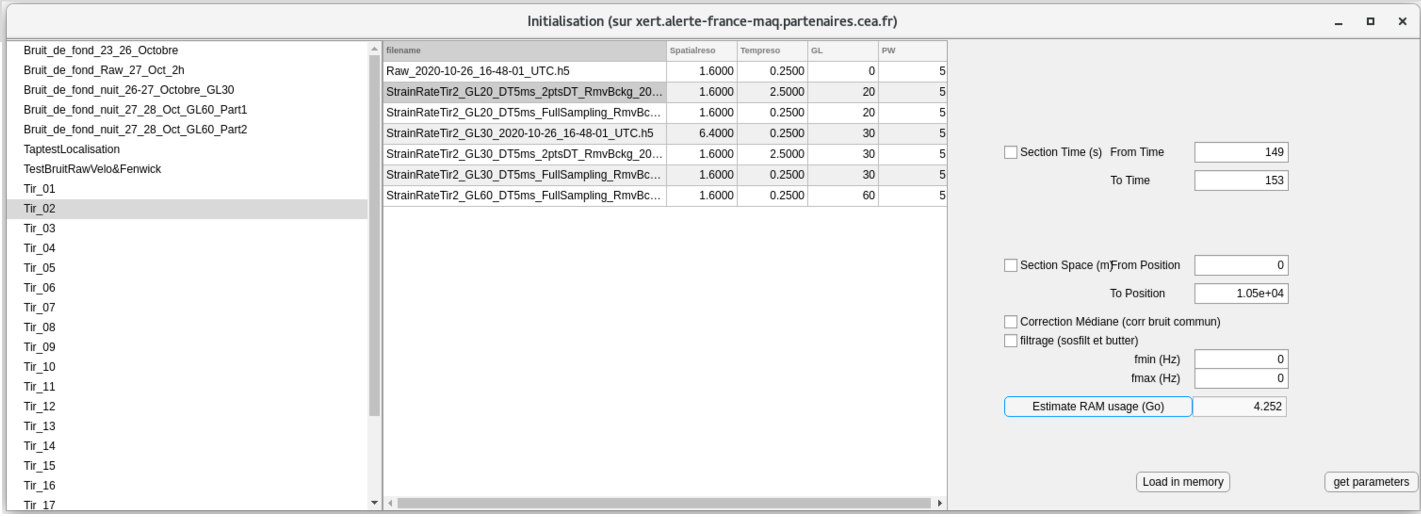

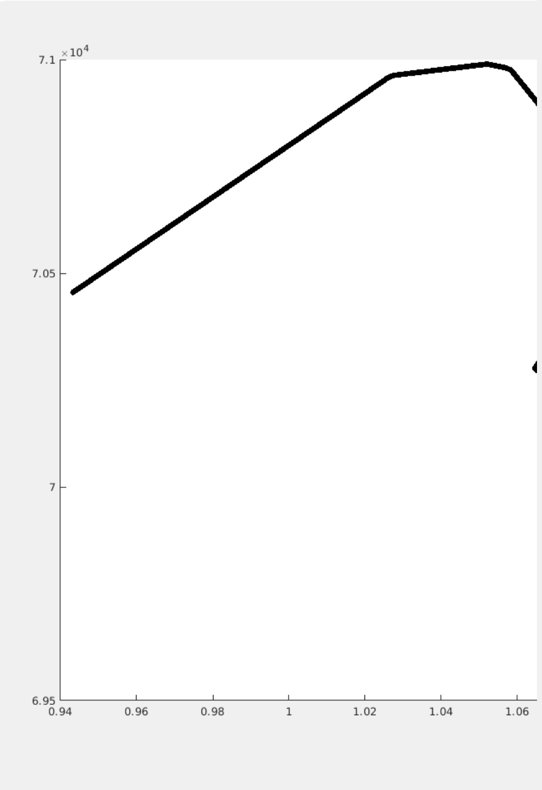

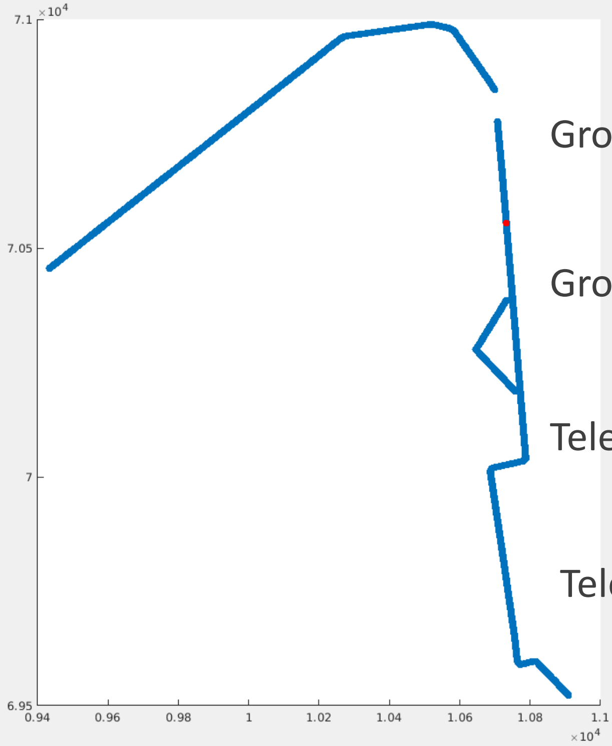

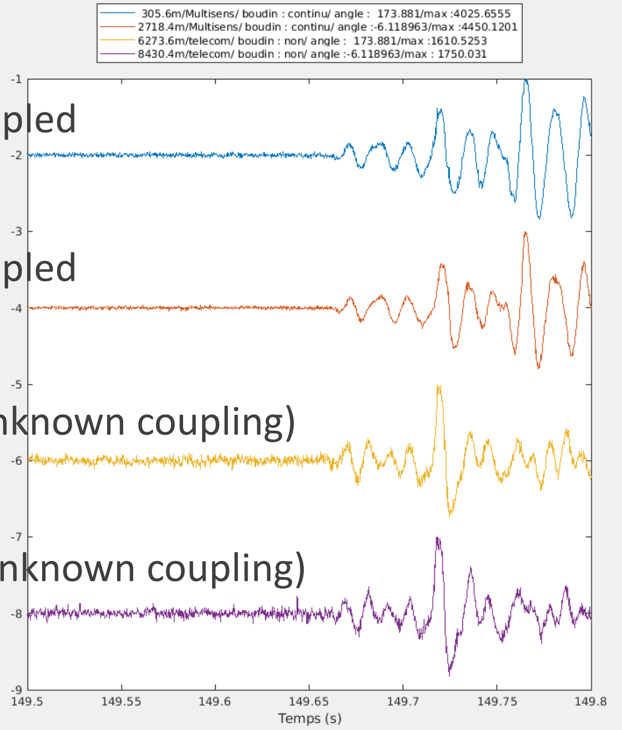

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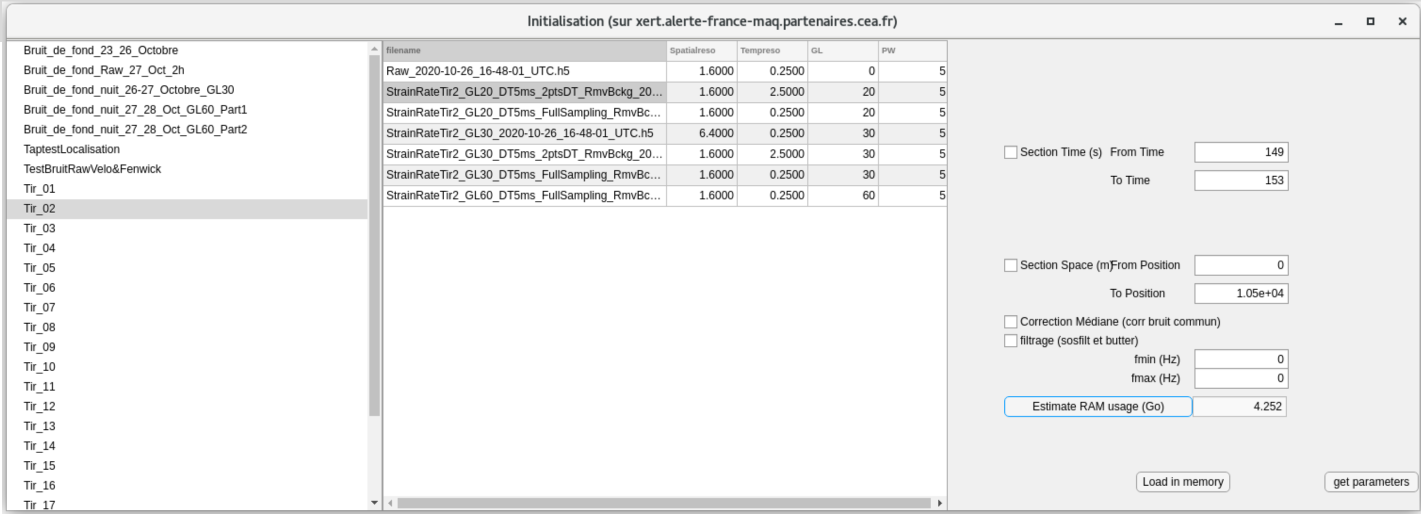

M. Peels internship

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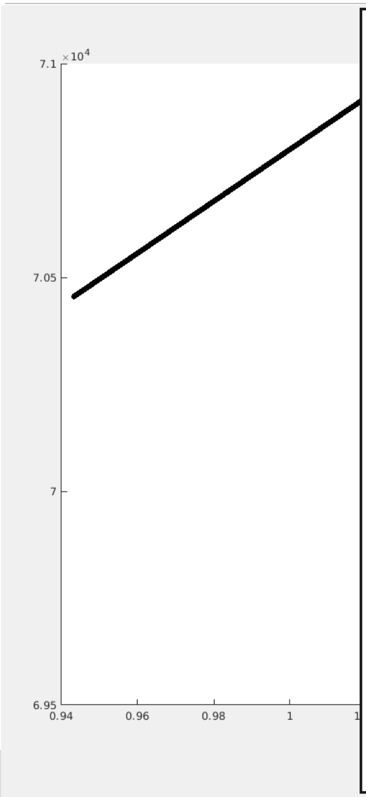
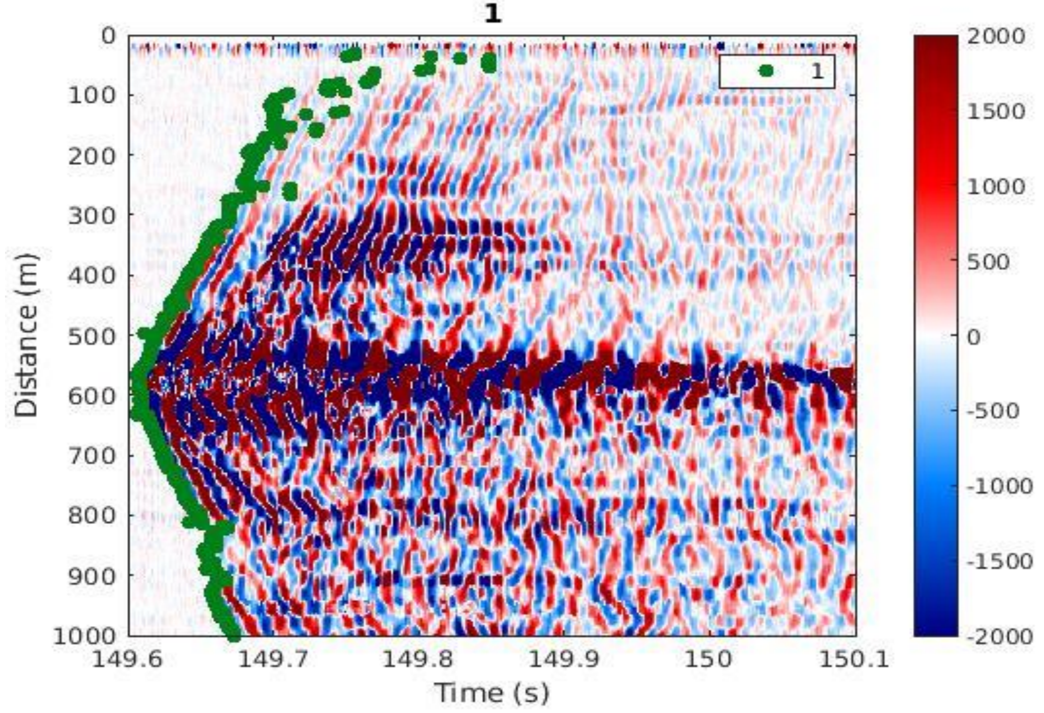
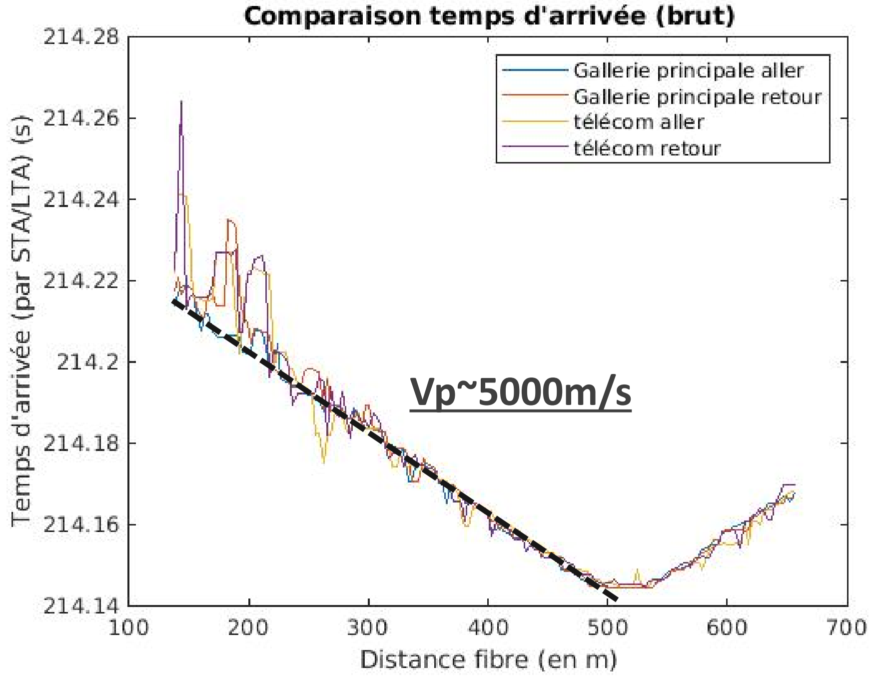


First arrival picking: LTA/STA, kurtosis





Some preliminary results on DAS data

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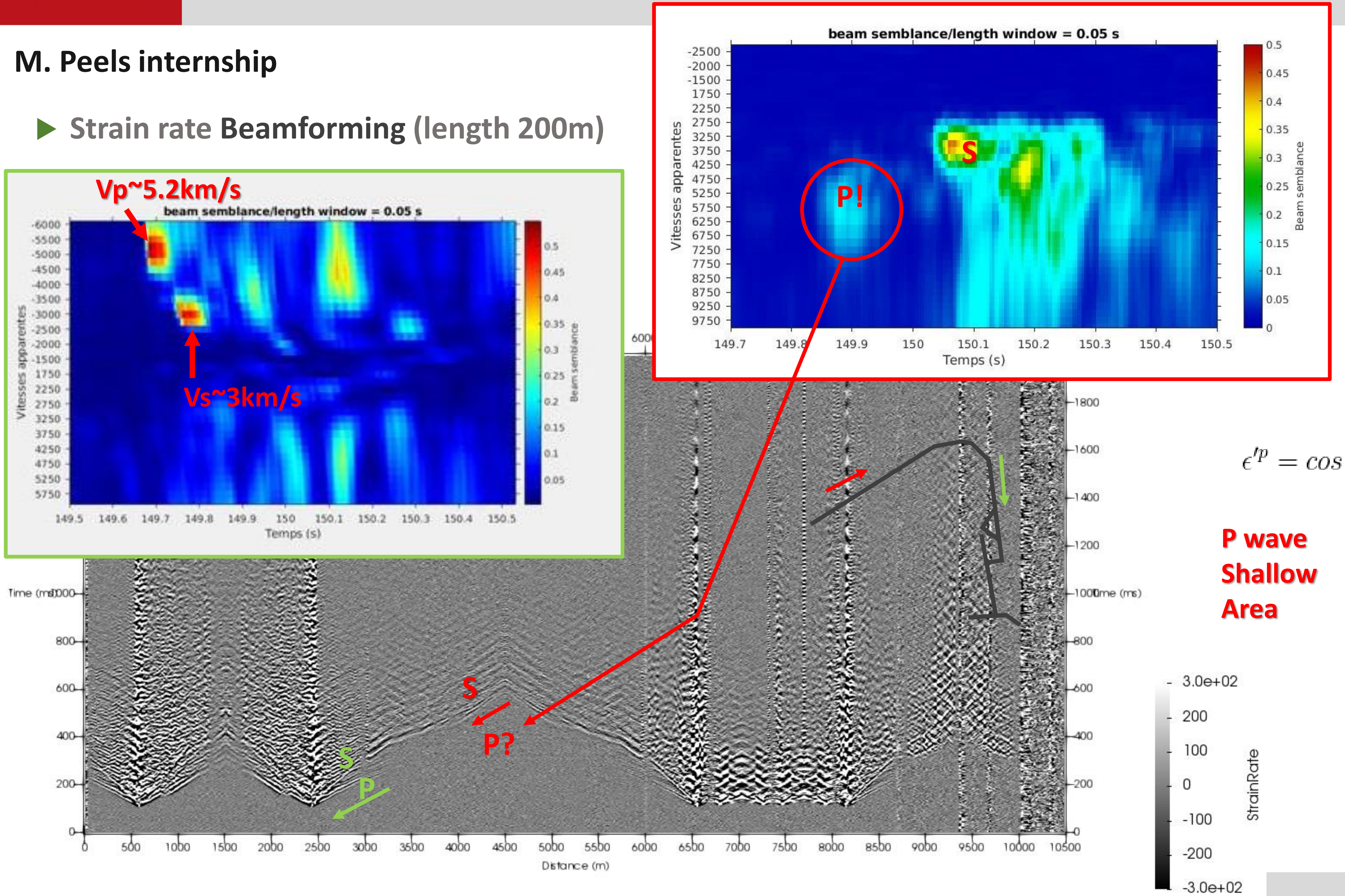
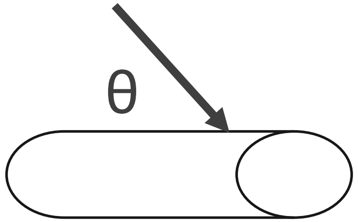
- Strain rate **Beamforming** (length 200m)



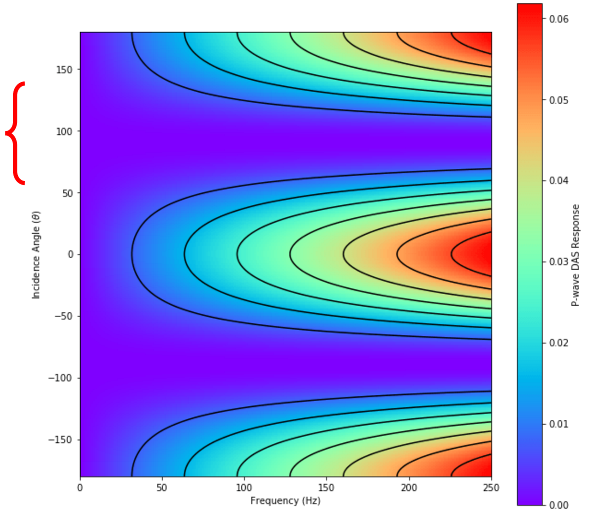
P wave detection in the shallow area
-> Stack on large number of measurement



Effective strain for P waves

$$\epsilon'^p = cos(\theta) A^p \left(\exp\left[-i\omega\cos(\theta)/v\right] - 1\right)/L_g$$

P wave Shallow Area



From https://motionsignaltechnologies.com

Source sensitivity of DAS data

M. Peels internship

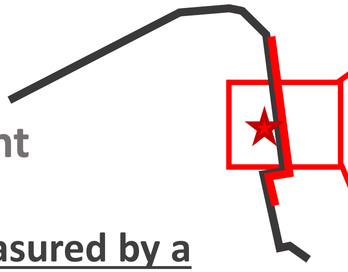
- Seismic wave field modeling: displacement

Near field

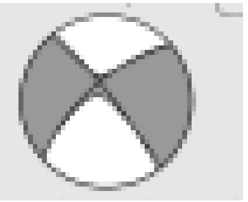
$$4\pi\rho\boldsymbol{u}(\boldsymbol{x},t) = \boldsymbol{A}^{N}\int_{r/V_P}^{r/V_S}\tau D(t-\tau)d\tau + \boldsymbol{A}^{IP}\frac{1}{V_P^2 r^2}D\left(t-\frac{r}{V_P}\right) - \boldsymbol{A}^{IS}\frac{1}{V_S^2 r^2}D\left(t-\frac{r}{V_S}\right) + \boldsymbol{A}^{FP}\frac{1}{V_P^3 r}\dot{D}\left(t-\frac{r}{V_P}\right) - \boldsymbol{A}^{FS}\frac{1}{V_S^3 r}\dot{D}\left(t-\frac{r}{V_S}\right)$$

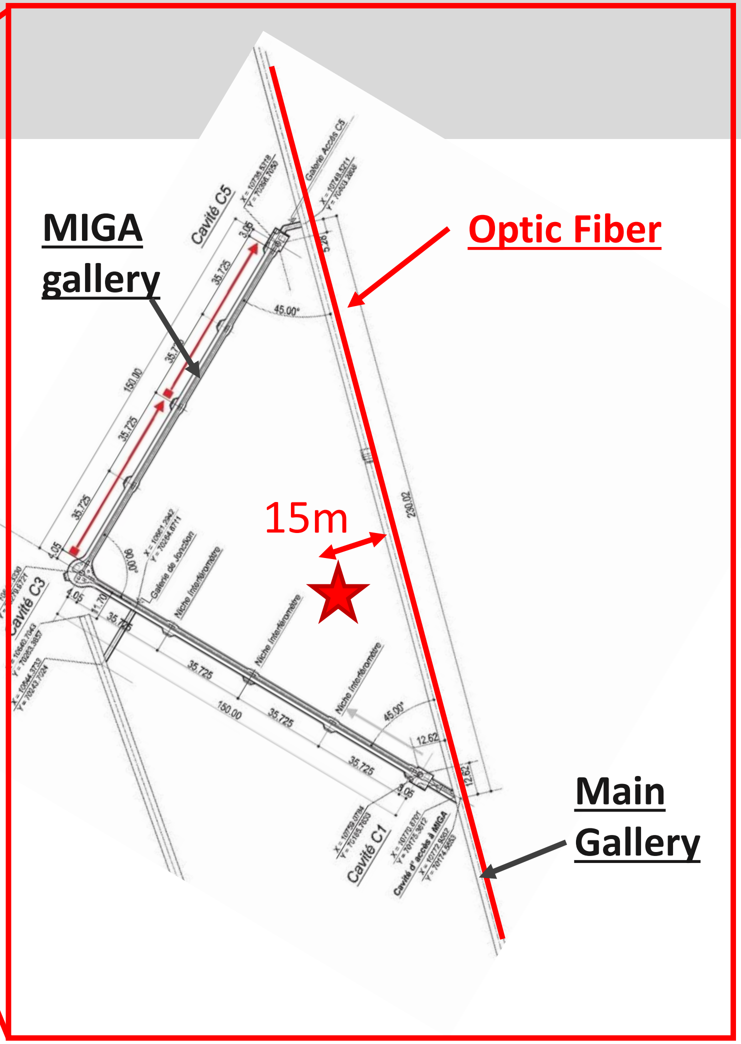
Far field

Measured by a seismometer



Source mechanism inversion

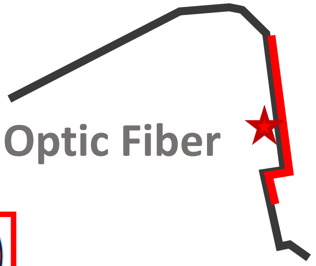




Modelling of the DAS data

M. Peels internship

- Full wave field modelling of the Strain on Optic Fiber

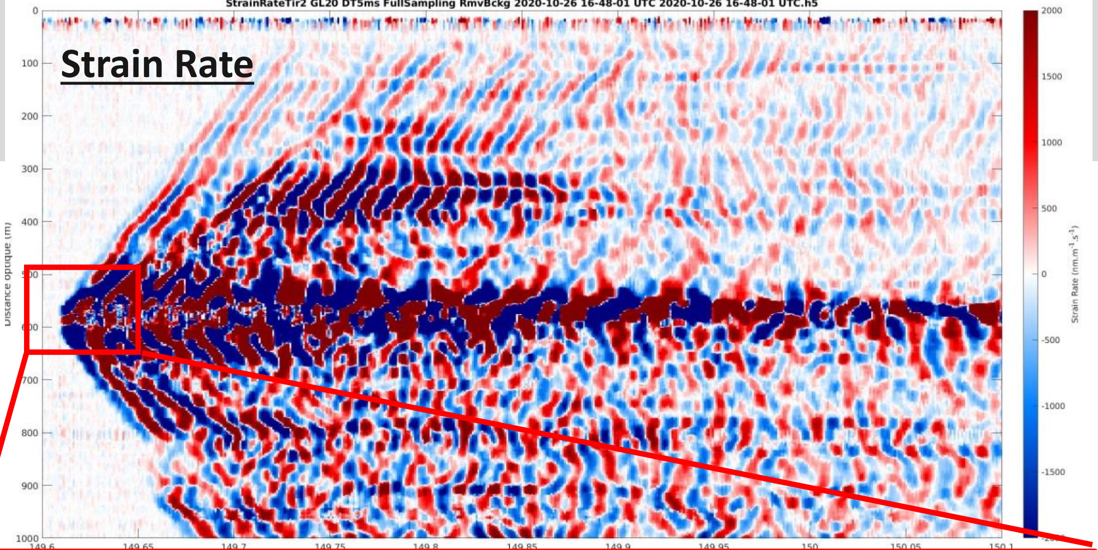


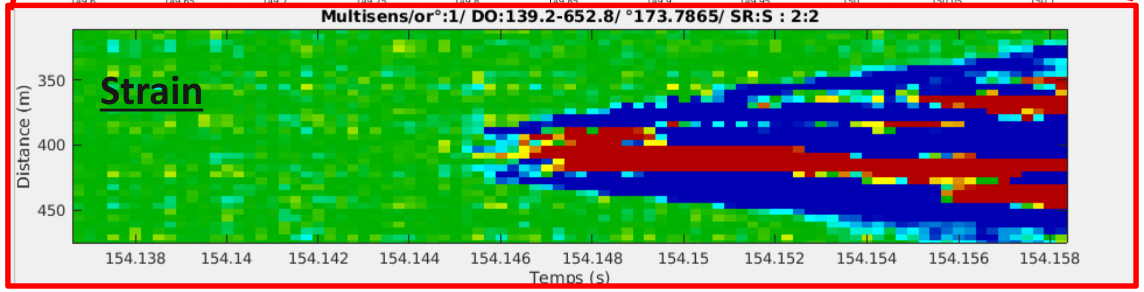
Near field

$$\varepsilon_{ii}(\boldsymbol{r},t) = \frac{1}{4\pi\rho}\frac{B^{N}}{r^{5}}\int_{r/V_P}^{r/V_S}\tau M_{jk}(t-\tau)d\tau + \frac{1}{4\pi\rho V_P^2}\frac{B^{INP}}{r^3}M_{jk}\left(t-\frac{r}{V_P}\right)$$
$$+\frac{1}{4\pi\rho V_S^2}\frac{B^{INS}}{r^3}M_{jk}\left(t-\frac{r}{V_S}\right) + \frac{1}{4\pi\rho V_P^3}\frac{B^{IFP}}{r^2}\dot{M}_{jk}\left(t-\frac{r}{V_P}\right)$$
$$+\frac{1}{4\pi\rho V_S^3}\frac{B^{IFS}}{r^2}\dot{M}_{jk}\left(t-\frac{r}{V_S}\right) + \frac{1}{4\pi\rho V_P^4}\frac{B^{FP}}{r}\ddot{M}_{jk}\left(t-\frac{r}{V_P}\right)$$
$$+\frac{1}{4\pi\rho V_S^4}\frac{B^{FS}}{r}\ddot{M}\left(t-\frac{r}{V_S}\right)$$

Far field

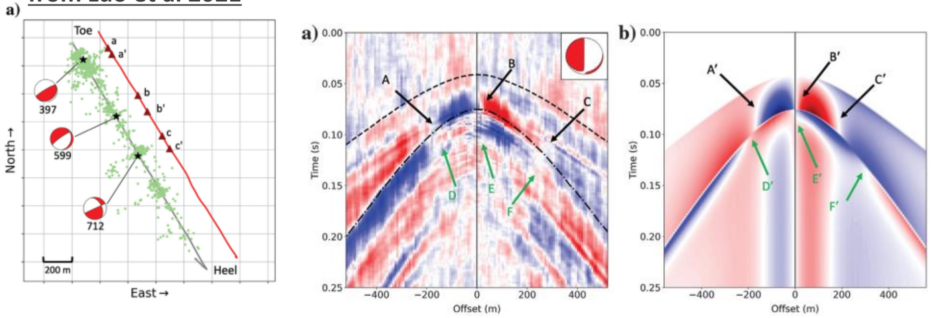
Mesured by DAS



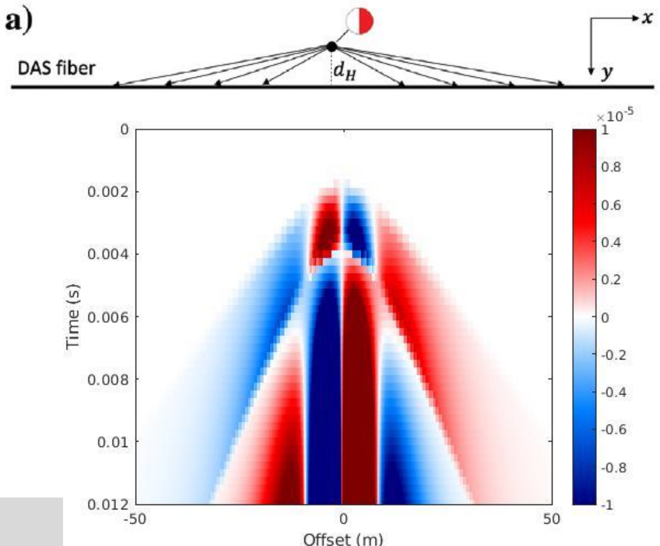


- Forward model: Double couple/isotropic source model
- In agreement with recent bibliography:

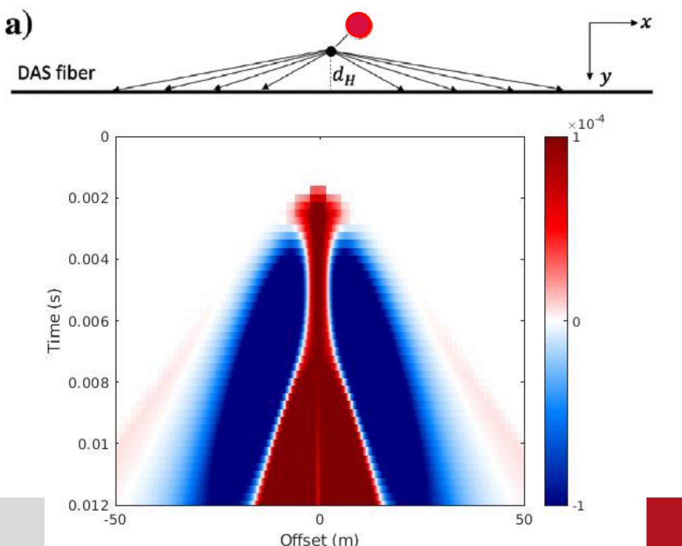
from Luo et al 2021



Fault (double couple)



Explosion (isotrope)

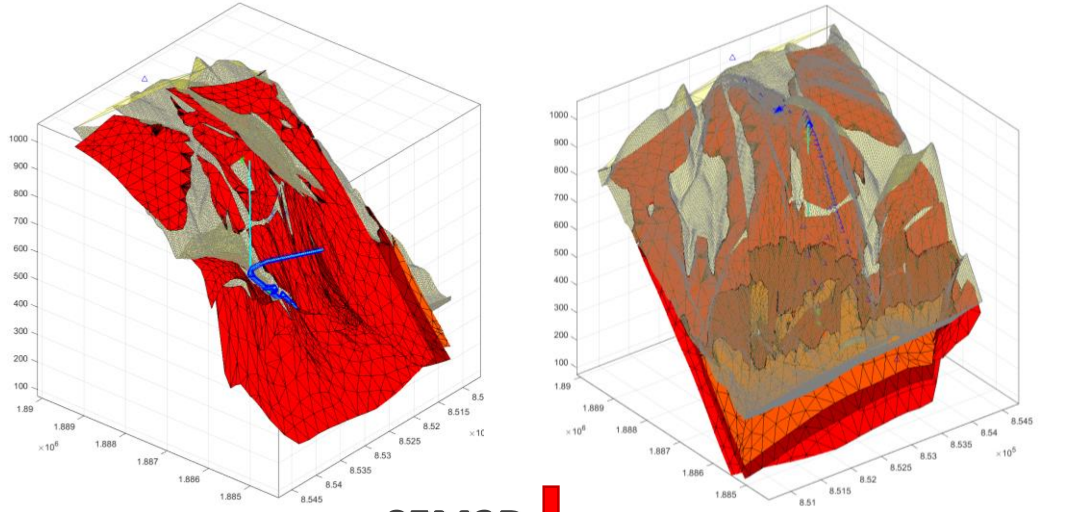


- Good agreement of the strain wave field with an isotropic source!

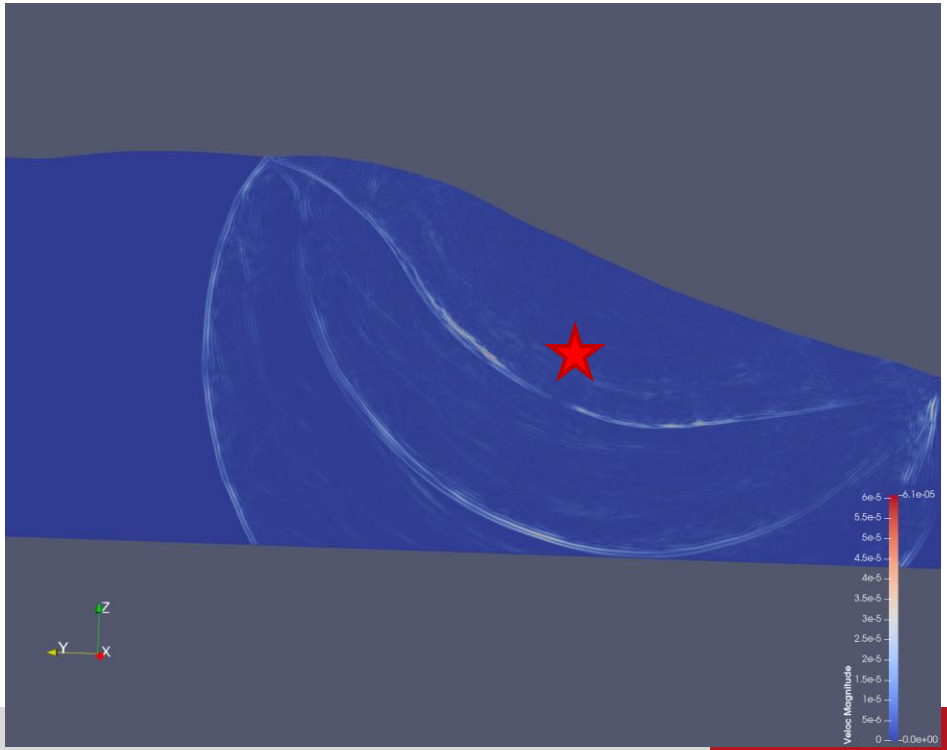
Toward a digital twin of the Premise Data

- **Goal: Generate a synthetic data base for comparison with real data**
  - Evaluate/ improve HPC seismic modeling code
  - Help to analyze data and develop processing algorithms

- **Input Model:**
  - 3D High resolution geological model (Cerege-Total-LSBB)
    - Maufroy etal. 2014, Matonti et al 2017 and Tendil et al. 2018
  - Full Premise experiment sensor geometry



SEM3D



- **The Numerical model based on Spectral Element Method (SEM3D)**
  - Frequency band: 100, 200, 400Hz
  - Mesh : **133 Millions of elements of 5 or 7 order.**
  - Processing time: 13h toward 2days on 8192 cores

- **Output waveform: Displacement, velocity, acceleration, and gradients**
  - 1579 Optic Fiber position and 299 seismometers
  - 4Go of data for 1.5s of simulated waveform

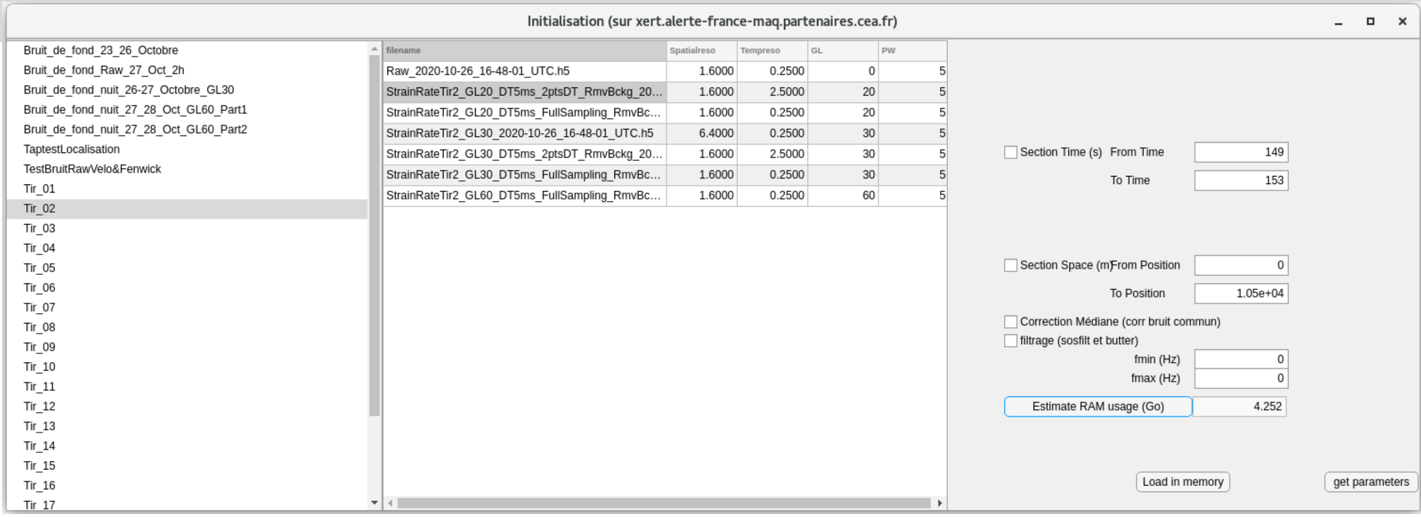
- **Perspectives and future woks**
  - Comparison of Synthetic with real waveform
  - Extraction of the Source/structure signature from dense seismic data
    - (Array processing, gradiometry etc…)
  - Usefulness of DAS signal amplitude and noise performance

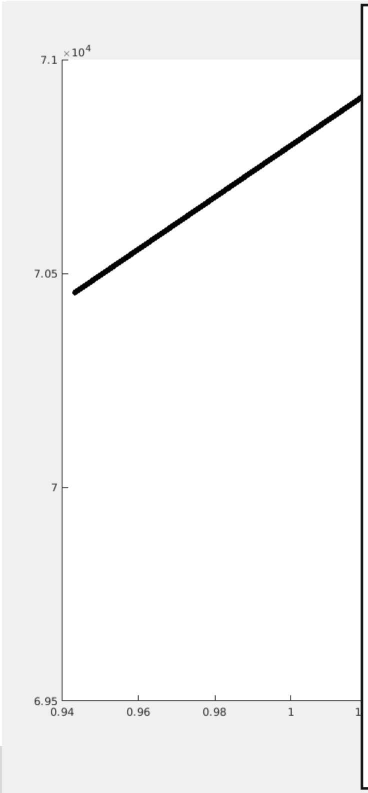
- **Thank you for your attention…**

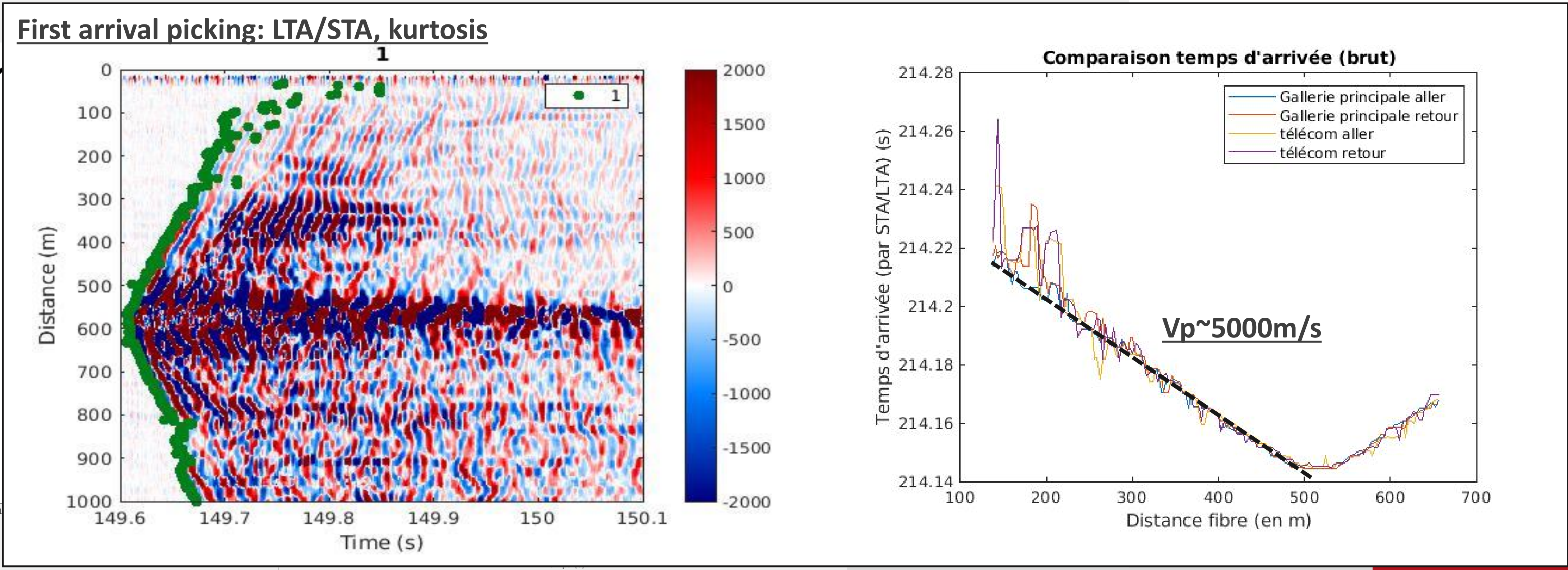
Preliminary DAS data handling

M. Peels internship

- DAS data: about 20To
- Tools to access and perform some basic analyses
  - Data extraction
  - Profile and waveform display
  - Phase peaking







Toward a digital twin of the Premise Data

- **Goal: Generate a synthetic data base for comparison with real data**
  - Evaluate/ improve HPC seismic modeling code
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- **Input Model:**
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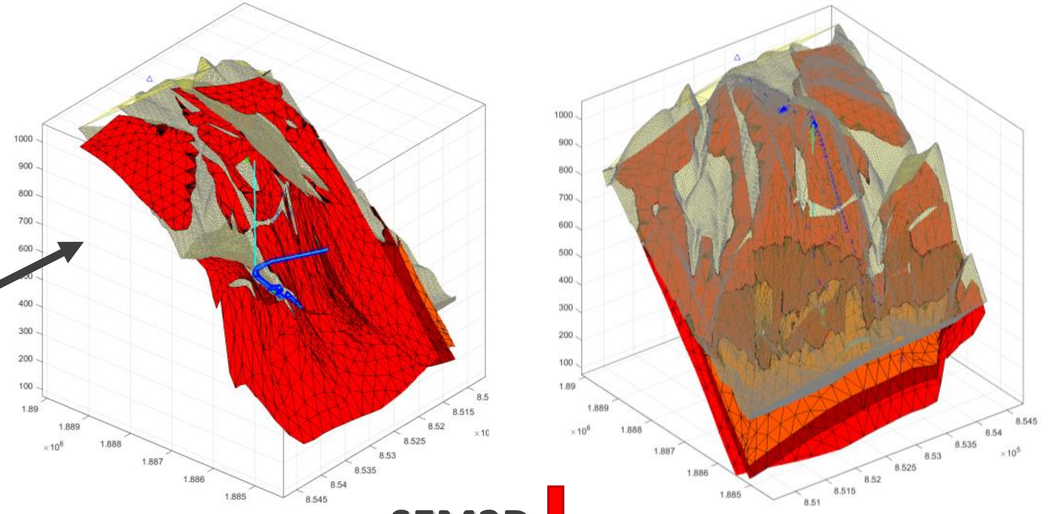
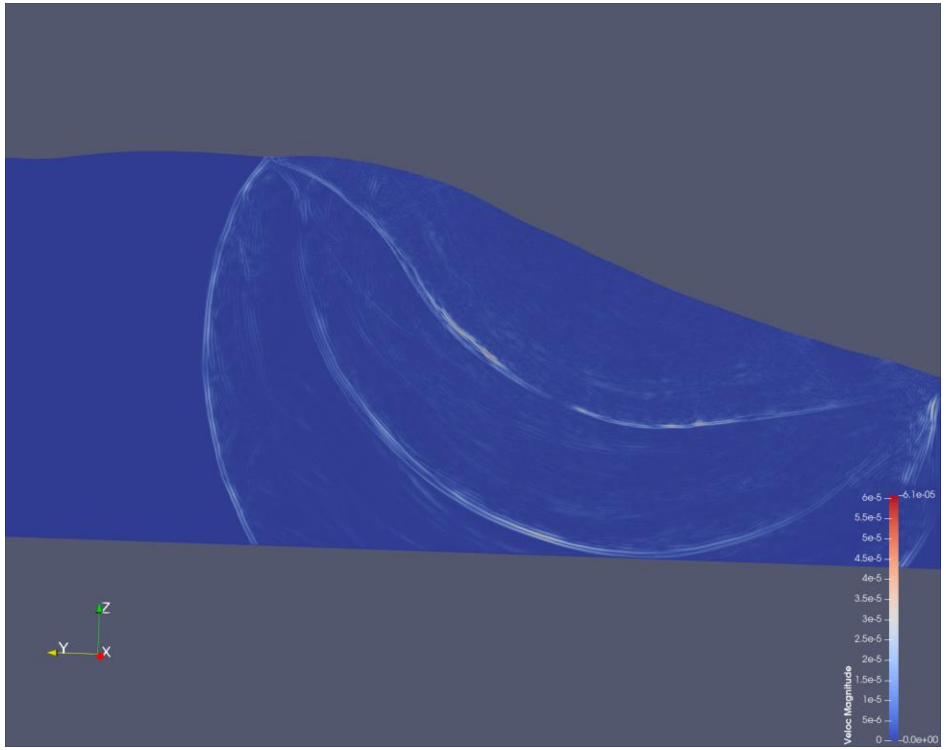


SEM3D



- **The Numerical model based on Spectral Element Method (SEM3D)**
  - Explosive source model: Denny-Johson 1Kg
  - Frequency band: 100, 200, 400Hz
  - Mesh : **133 Millions of elements of 5 or 7 order.**
  - 8.5 to 28.7 billions of integrating point
  - Processing time: 13h toward 2days on 8192 cores

- **Output waveform: Displacement, velocity, acceleration, and gradients**
  - 1579 Optic Fiber position and 299 seismometers
  - 4Go of data/simulation
  - Simulated waveform duration: 1.5s

- **Perspectives and future woks**
  - Comparison of Synthetic with real waveform
  - Extraction of the Source/structure signature from dense seismic data
    - (Array processing, gradiometry etc…)
  - Usefulness of DAS signal amplitude and noise performance