Crustal tomography of the Pyrenees and surrounding regions using ambient noise correlation

Marie MACQUET

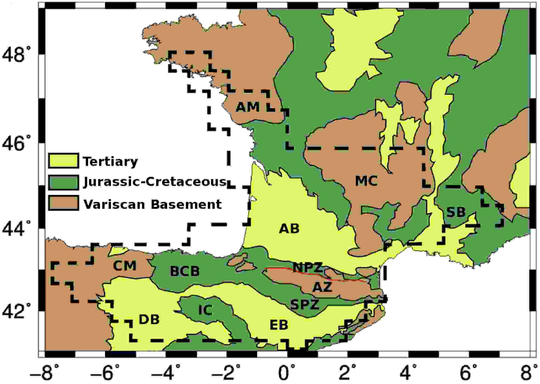
CREWES Tech talk - March 4^{th}, 2016

outline

Study Area


Greenland
Iceland
Norwegian Sea
Northwestern Passages
Hudson Bay
Canada
United States
Sweden
Norway
Denmark
United Kingdom
Ireland
Germany
Poland
France
Austria
Romania
Italy
Spain
Portugal
Greece
Tunisia
Morocco

Study Area



Sedimentary basins

- Aquitaine basin (AB)
- Ebro Basin (EB)
- Duero Basin (DB)
- Southeastern basin (SB)

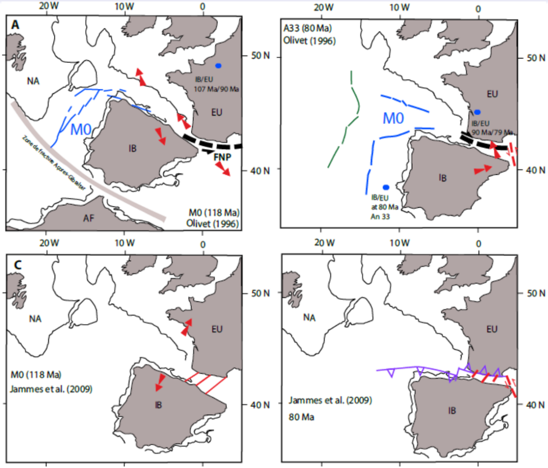
Mountain Belts

- Pyrenees (AZ)
- Massif Central (MC)
- Cantabrian mountains (CM)
- Armorican Massif (AM)

Pyrenees - Geodynamical model is still debate

Rotation of the Iberian plate

Extensional phase before collisional phase

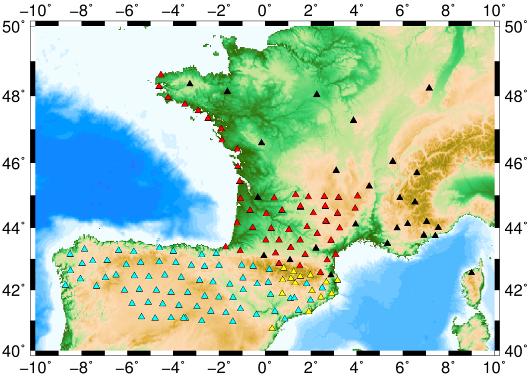


Mouthereau *et al.*, 2014

Geodynamical history can be constrain by structural geology, geochemistry, paleomagnetism, geophysical studies, as gravimetry and **seismic imaging**

Seismic arrays used

Aim : Obtain a 3-D V_S crustal model of the region

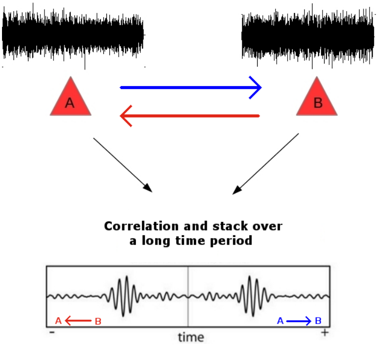


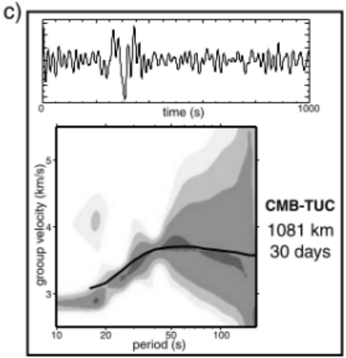
1. Permanent arrays
   - French array
   - Catalan Array
2. Temporary array PYROPE (2011-2013)
3. Temporary array IBERARRAY (2011-2013)

⇒ 158 broadband stations, average spacing of 60km.

Ambient noise correlation - Principle

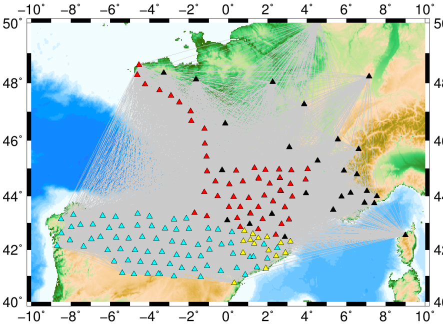
⇒ **We can reconstruct of the Green function between 2 stations by correlating the continuous signal (Weaver et Lobkis (2001) ; Shapiro and Campillo (2004))**



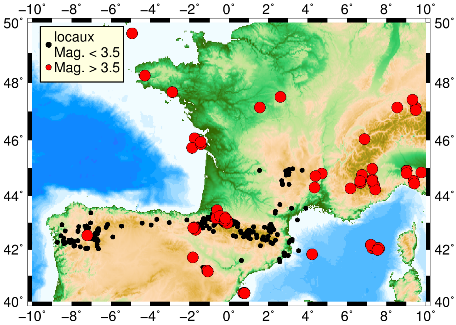


Shapiro and Canpillo (2004)

Ambient noise correlation vs "classical" method



12403 potential paths



2011-2013 :
361 EQs inside the area
69 EQs with magnitude > 3.5

Noise correlation application

"classic" processing

- deconvolution of the instrument responses
- in 3 frequency ranges :
  1. time normalization : 1-bit processing
  2. spectral normalization : whitening

Particularity of this study (February-December 2011) : Tohoku-Oki Earthquake and the many aftershocks

Noise correlation application

"classic" processing

- deconvolution of the instrument responses
- in 3 frequency ranges :
  1. time normalization : 1-bit processing
  2. spectral normalization : whitening

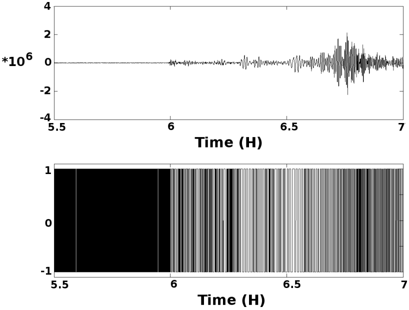
[5-30]s ; [20-40]s ; [30-55]s.

to overpass the effect of the 1-bit filtering

Noise correlation application

"classic" processing

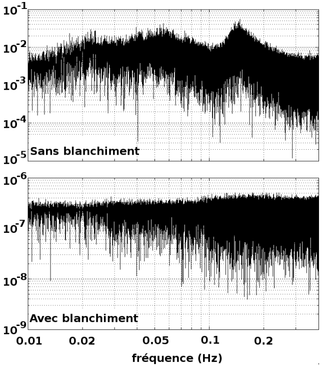
- deconvolution of the instrument responses
- in 3 frequency ranges :
  1. time normalization : 1-bit processing
  2. spectral normalization : whitening



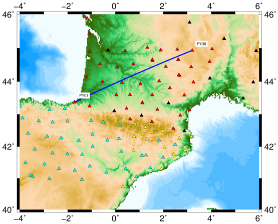
Noise correlation application

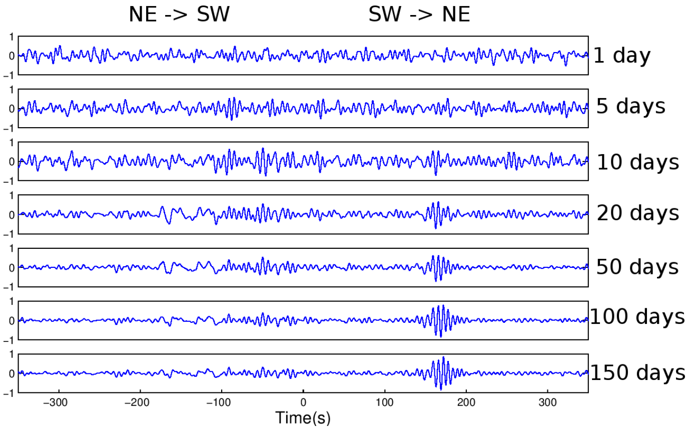
"classic" processing

- deconvolution of the instrument responses
- in 3 frequency ranges :
  1. time normalization : 1-bit processing
  2. spectral normalization : whitening



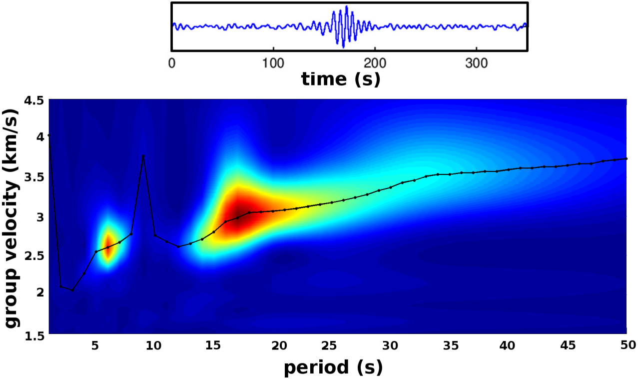
Compute and average of the daily correlation
⇒ emergence of the Green function





Dispersion curves

- ZZ correlations : emergence of the Rayleigh wave



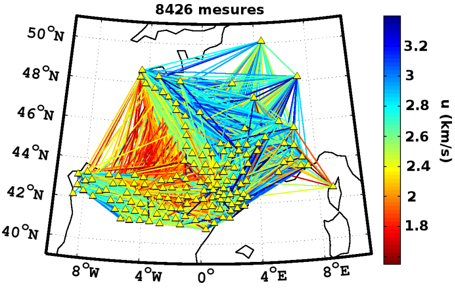
- Surface waves are dispersive : we can calculate the dispersion curve of the group velocities by FTAN

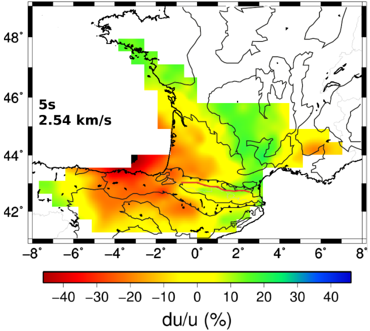
Group velocities maps

Linearized inversion - minimized the cost function

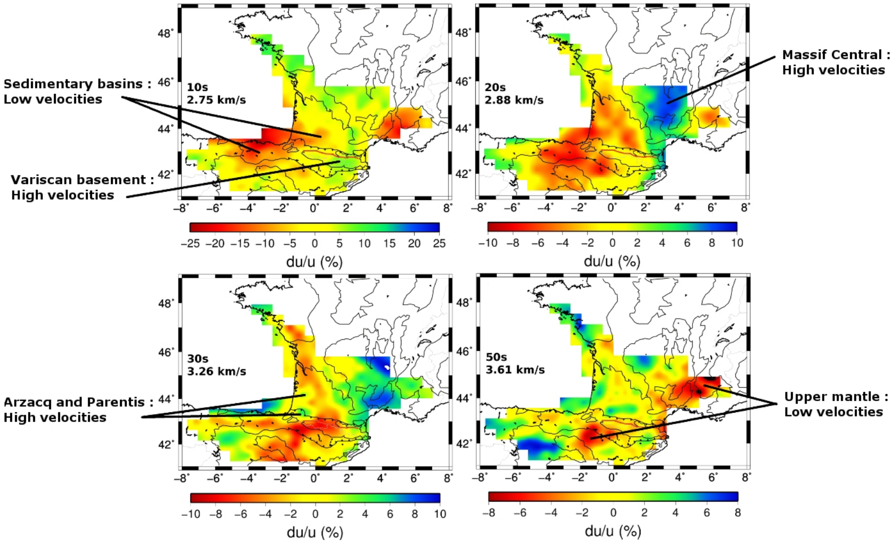
$$s(m) = (G_m - d)^T C_d^{-1} (G_m - d) + m^T Q_m$$

fit to data — smoothing





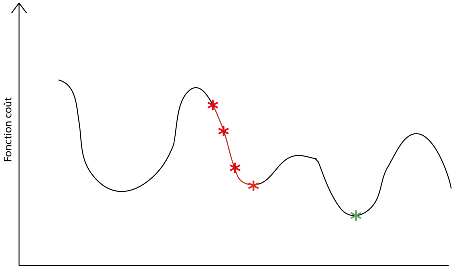
Group velocity maps - Results



Aim

Dispersion curves ($V_g(T)$) $\Rightarrow$ velocity models ($V_S(z)$)

Major problem : non uniqueness of the solution and very heterogeneous area



We need **(1)** using other inversion methods (e.g non linearized inversion) **or (2)** having a 3-D starting model, laterally heterogeneous and close to the solution, for a linearized inversion

New methodological approach

Exploration of the whole models space

Aim : get a 3-D model laterally heterogeneous, close to the solution, for a linearized inversion

- Creation of a library of 5-layers velocity models and dispersion curves associated (2 766 555 models)

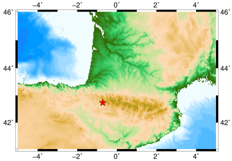
layer	thickness (km)	V_P ($km.s^{-1}$)
Top layer	0-4	2-3
Sedimentary layer	0-12	3-5.5
Upper Crust	10-26	5-6
Lower Crust	10-26	6-7
Mantle	∞	7.5-8.1

New methodological approach

Exploration of the whole models space

Aim : get a 3-D model laterally heterogeneous, close to the solution, for a linearized inversion

- Creation of a library of 5-layers velocity models and dispersion curves associated (2 766 555 models)
- For each node :

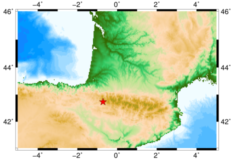


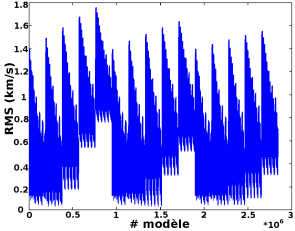
New methodological approach

Exploration of the whole models space

Aim : get a 3-D model laterally heterogeneous, close to the solution, for a linearized inversion

- Creation of a library of 5-layers velocity models and dispersion curves associated (2 766 555 models)
- For each node :
  1. calculation of *RMS* between the observed dispersion curve and the whole library





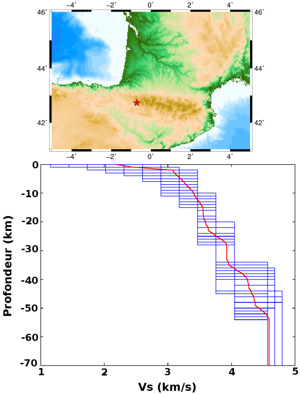
$$RMS = \sqrt{\frac{1}{N}\sum_{i=5}^{55}(u_{obs}(i) - u_{theo}(i))^2}$$

New methodological approach

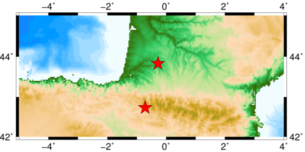
Exploration of the whole models space

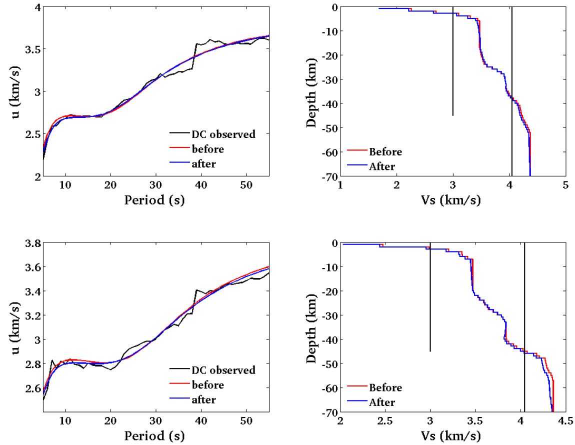
Aim : get a 3-D model laterally heterogeneous, close to the solution, for a linearized inversion

- Creation of a library of 5-layers velocity models and dispersion curves associated (2 766 555 models)
- For each node :
  1. calculation of *RMS* between the observed dispersion curve and the whole library
  2. average of the 1000 models with the best *RMS*



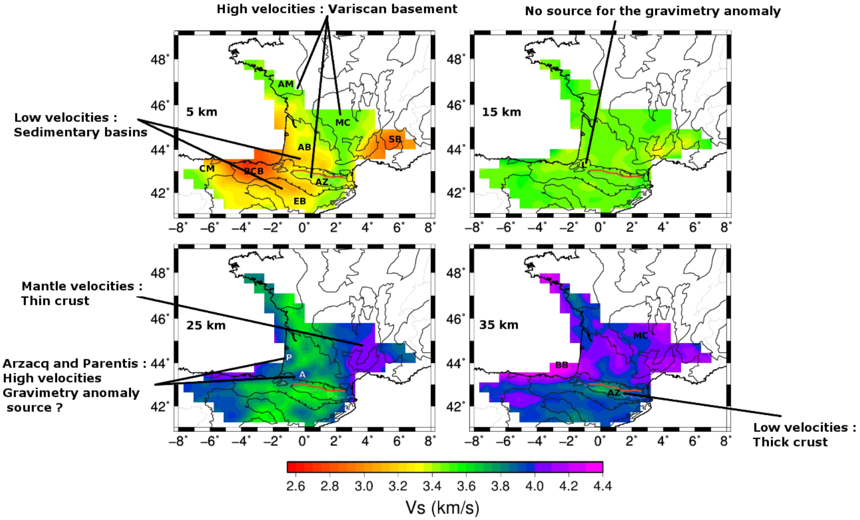
Linearized inversion (Herrmann et Ammon (2002))





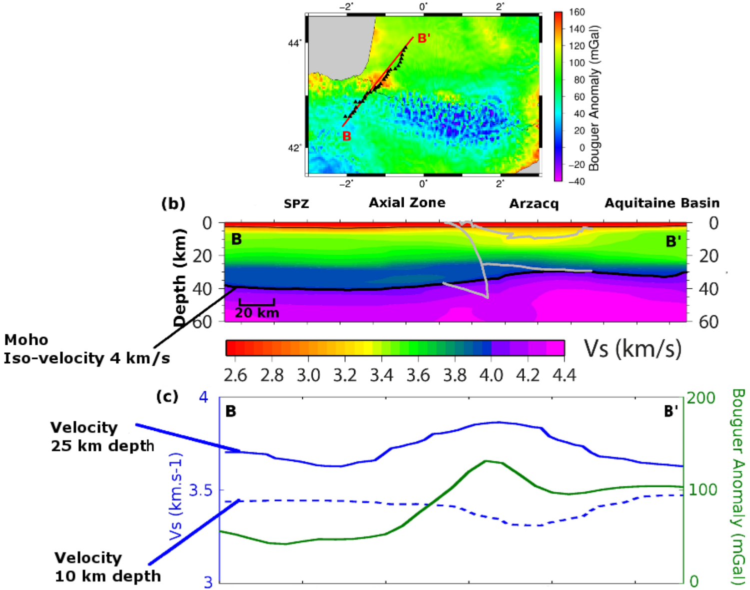
⇒ Average *RMS* decrease from 0.070 $km.s^{-1}$ to 0.052 $km.s^{-1}$

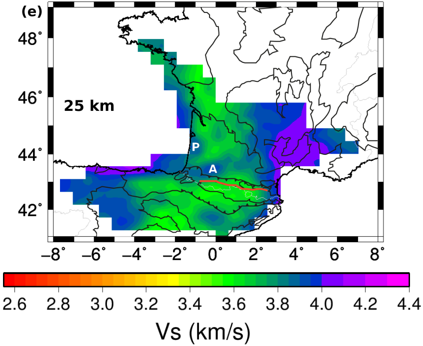
Velocity maps - results



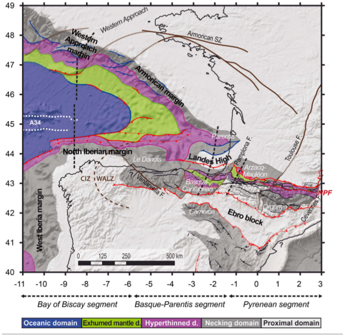
Macquet *et al*, 2014

Labourd-Mauléon Bouguer Anomaly





Macquet *et al*, 2014



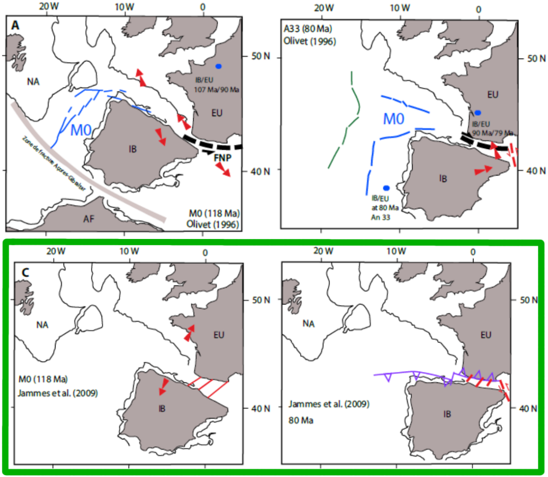
Tugend *et al*, 2014

Interpretation

Traces of the ancient hyper-extensional rifts which could have preceded the compression

Rotation of Iberian plate

Extensional phase followed by compressional phase

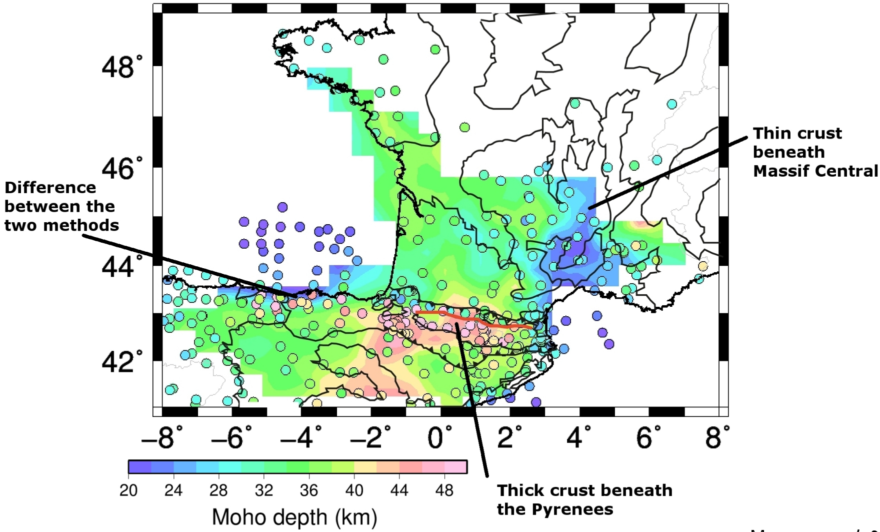


Mouthereau *et al.*, 2014

Interpretation

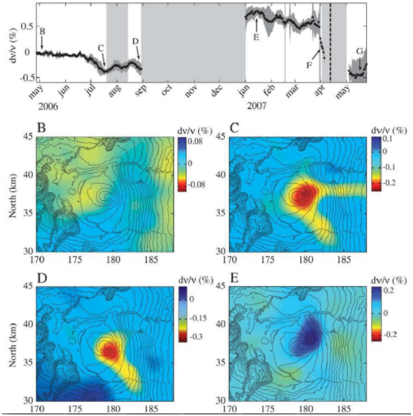
Traces of the ancient hyper-extensional rifts which could have preceded the compression

Iso-velocity 4 $km.s^{-1}$ - Crust/mantle interface



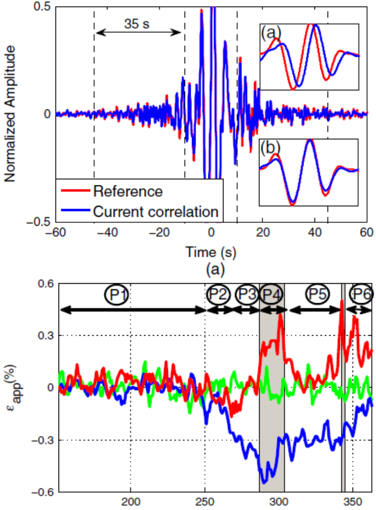
Macquet *et al*, 2014
Chevrot *et al*, 2014

Monitoring volcanoes



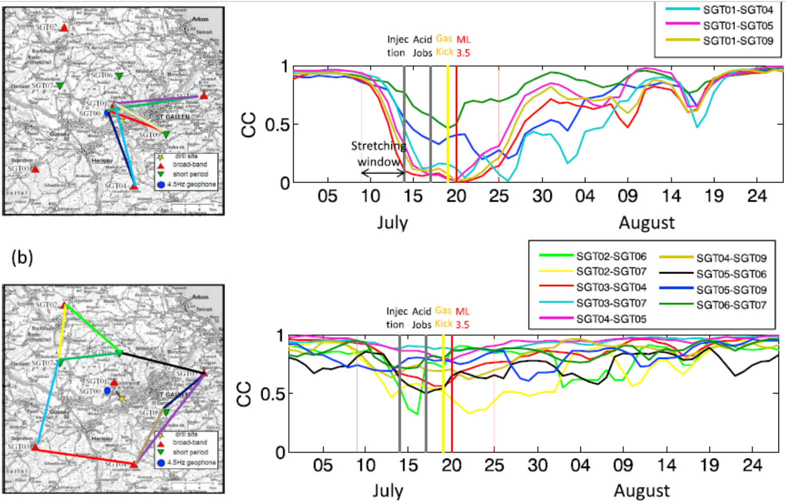
Duputel et al. (2009)

[0.1-1]Hz, [0-2]km depth



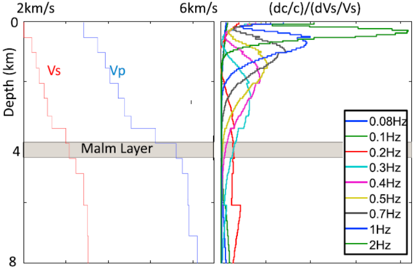
Obermann et al. (2013)

Monitoring the St. Gallen geothermal site



Obermann et al. (2015)

Monitoring the St. Gallen geothermal site



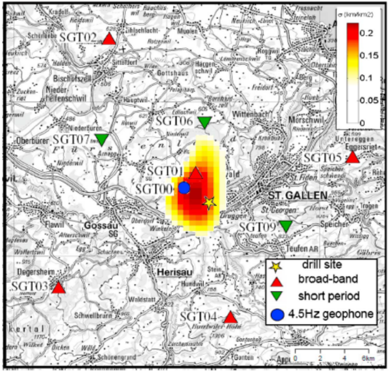


Figure 9. Scattering cross-section density changes derived by least squares inversion averaged over July 2013. The observed changes are around the injection well, indicating a causal relationship with the activities at the well.

Obermann et al. (2015)

Conclusions

- Development of a new approach for the inversion of $V_g(T)$ to $V_S(z)$
- This first 3D V_S model gives some keys to better understand the geodynamical history of the Pyrenees (it still needs to be explored...)
- The ambient noise correlation gives the possibility to image everywhere on the Earth
- Some studies show that ambient noise correlation can be used for monitoring

Acknowledgements

- Dr. Don Lawton
- CREWES staff and students
- This work was done during my Ph. D thesis, ISTerre laboratory, University of Joeseph Fourier (France), under the supervision of Dr. A. Paul and Dr. H. Pedersen.

NSERC CRSNG

CMC Containment & Monitoring Institute

UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience

CREWES

Thank you !