Seismic Signal processing for stations in LSBB

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Introduction

- **LSBB**:
  - Laboratoire Souterraine a Bas Bruit
  - Low Noise Inter-Disciplinary Underground Science and Technology

• A network of six three-dimensional seismological antennas.

• The seismometers record **three component signlas**: two horizontal components (north-south (N), east-west (E)) and a vertical component (Z).

• **125 points per second** for each direction are recorded in each station.

All the **stations** : **RAS, GAS, VES, GGB, MGS** and **EGS**, are synchronized by a GPS system.

Goal

Question: **How can we extract information about the geology of the site of the laboratory?**

Drilling

Detect a big explosion, or an earthquake, and do ray analysis.

Use noise signals recorded for long periods of time.

H/V ratio

$$H / V \quad \frac{FFT(Horizontal)}{FFT(Vertical)}$$

It was shown by Japanese scientist that the **H/V ratio can be used to identify the fundamental frequency of soft soils**, observing that the vertical component of Rayleigh wave motion almost systematically vanishes in the vicinity of the fundamental S wave resonant frequency.

The H/V ratio is based on three main hypotheses:

1. The ambient noise is generated by surface waves and multiply reflected and refracted shear waves trapped in the considered soils.
2. The sources of noise at the surface do not influence the noise at the bottom of the soil.
3. vertical amplification of the noise at the surface can be associated with propagation effects within the soil itself.

The site response may be characterized by the spectral ratio of the vertical to horizontal components of the noise recorded at the surface.

H/V ratio

Outline of the procedure to find the H/V ratio:

- The data is then analyzed by one hour segments. Each hour segment is divided into windows 130s (2^14 points), with 50 % overlap.

- The data is filtered between 0.2 Hz and 40 Hz.

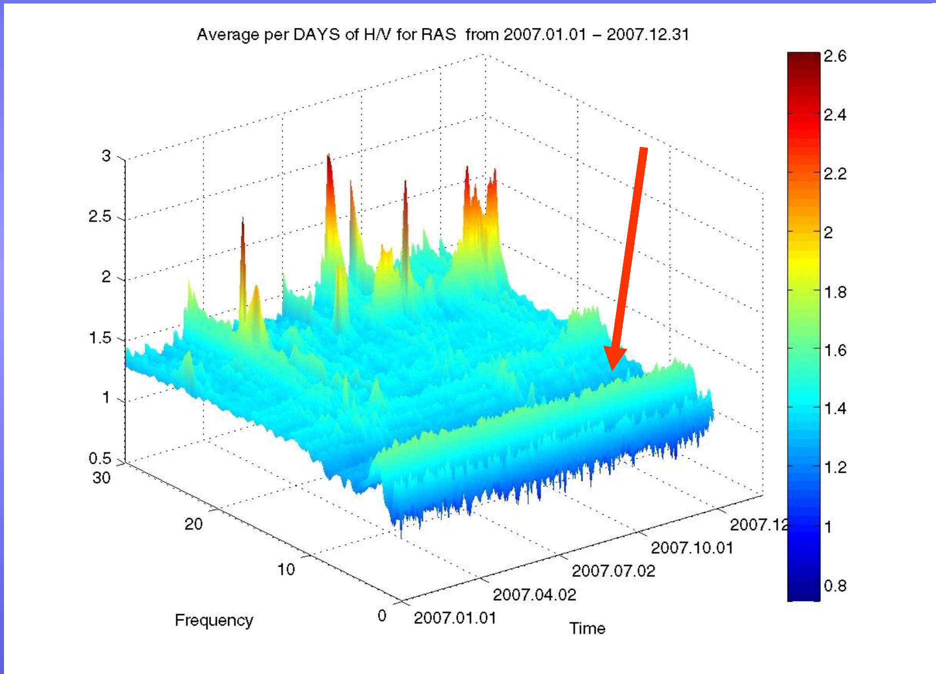
- Three components (z(t), n(t), e(t)) are detrended and the mean is removed.

- The H/V ratio is found for all the windows within an hour segment calculating:

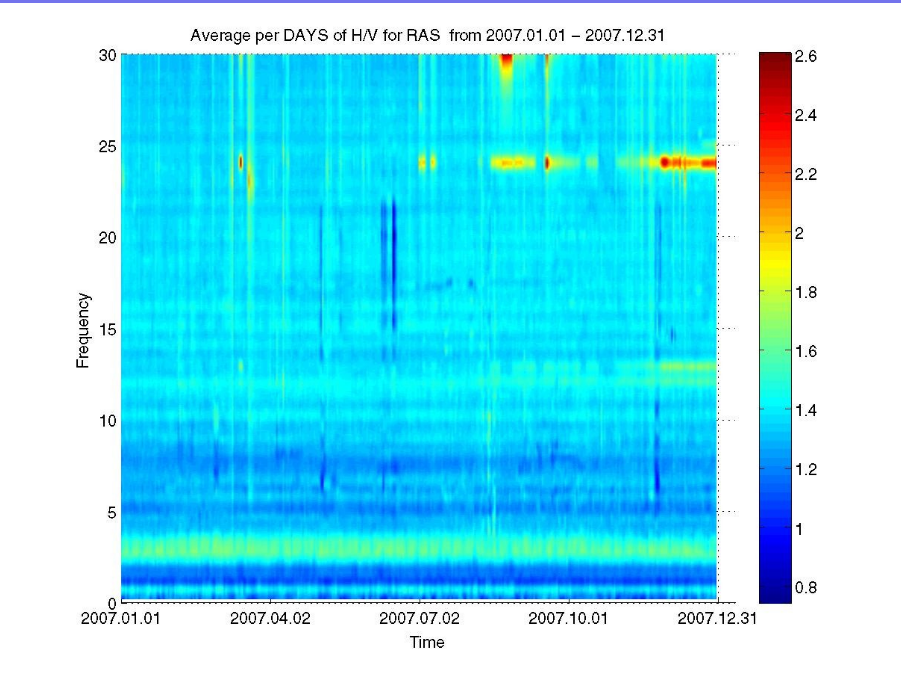
$$r_i \quad \frac{\sqrt{FFT(\mathrm{n\_i(t)})\,|\hat{}2 \quad |\,\mathrm{FFT(e\_i(t))}\,|\hat{}2}}{|\,\mathrm{FFT(z\_i(t))}\,|}$$

- The median of the ratio is chosen for each hour .

H/V ratio

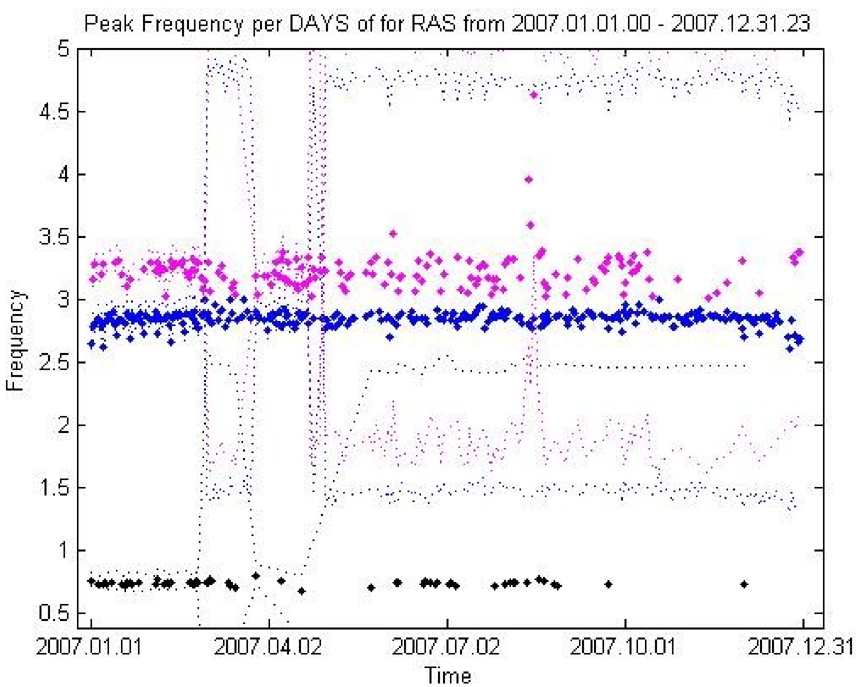


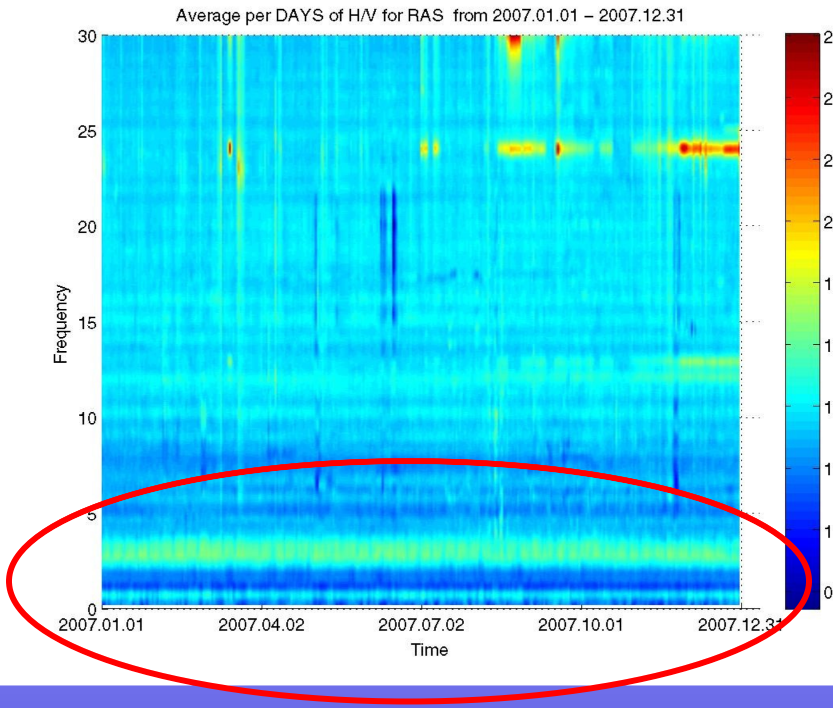
Average per DAYS of H/V for RAS from 2007.01.01 – 2007.12.31
3
2.5
2
1.5
1
0.5
30
20
10
0
Frequency
2007.01.01
2007.04.02
2007.07.02
2007.10.01
Time
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8



Average per DAYS of H/V for RAS from 2007.01.01 – 2007.12.31
30
25
20
15
10
5
0
Frequency
2007.01.01
2007.04.02
2007.07.02
2007.10.01
2007.12.31
Time
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8

H/V ratio





Low resonant frequencies of the soft soil at RAS:

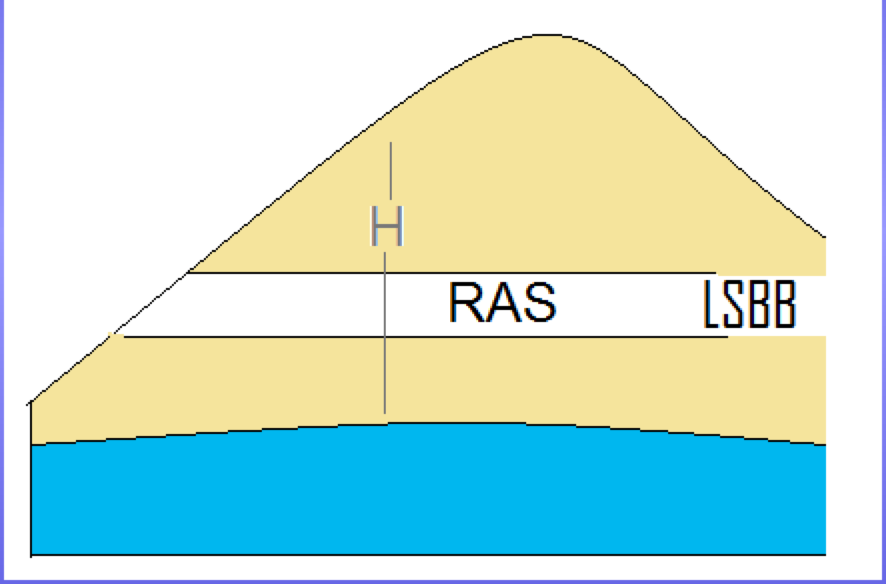
$$f_0 \quad 0.75 \quad 1.75 Hz$$

$$f_1 \quad 2.85 \quad 1.6 Hz$$

$$f_2 \quad 3.2 \quad 1.8 Hz$$

H/V

Below LSBB, there is an aquifer, which supplies water for towns and villages in the surrounding area.



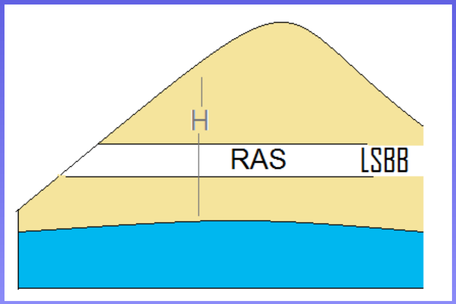
Can we estimate the level of water in the aquifer using seismic data?

H/V ratio

$$H \quad \frac{v_s}{4f}$$

H distance between the bottom of the soil and the surface.

v_s shear velocity



$$v_s \quad \frac{5000}{\sqrt{3}}\frac{m}{s} \quad 2887 m/s$$

z 518m :

Distance from the surface to RAS

Resonant frequencies of the soft soil :

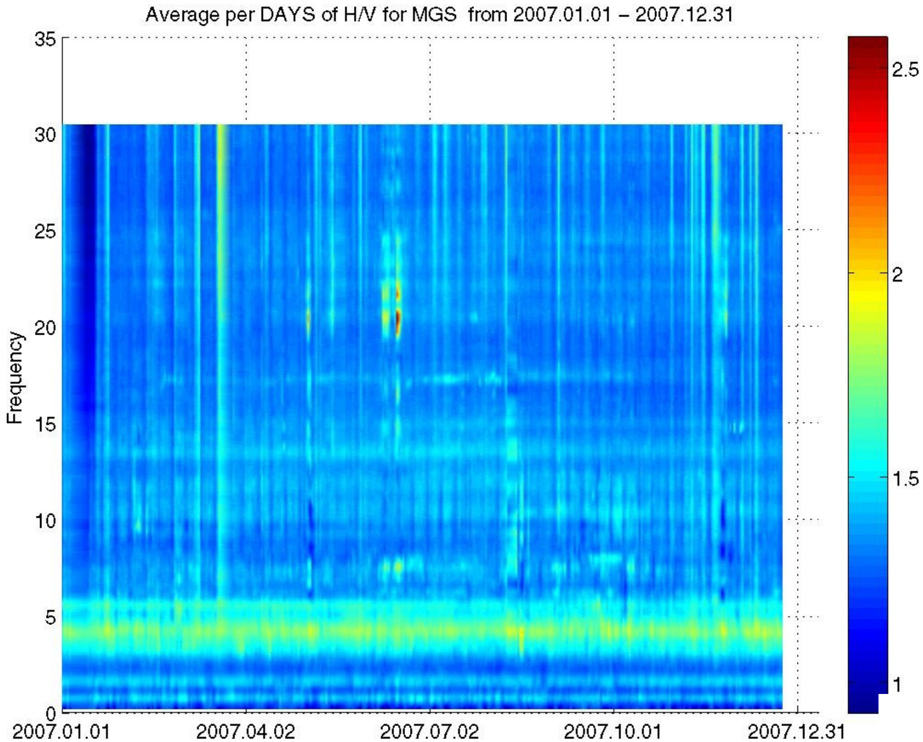
$f_0 \quad 0.75 \quad 1.75 Hz$

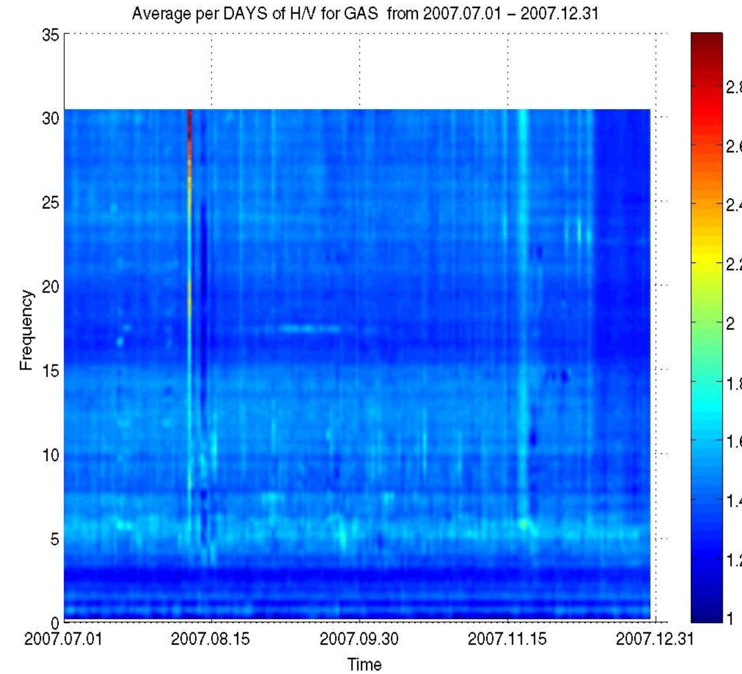
$f_1 \quad 2.85 \quad 1.6 Hz$

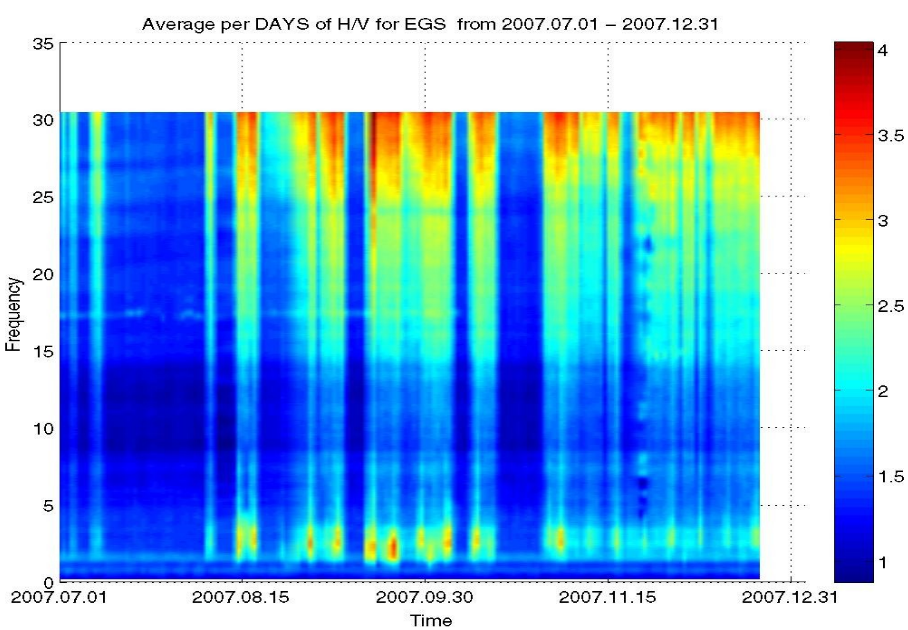
$f_2 \quad 3.2 \quad 1.8 Hz$

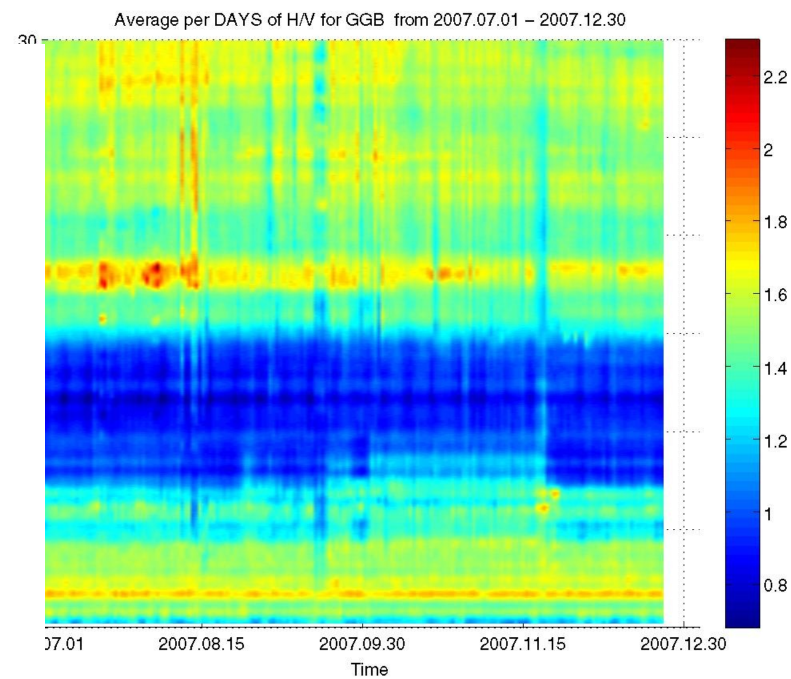
(Hz)	(Hz) Δ	(M)	(M)	(M)	(M) h0 +Δ	(M)	(M)
f0	f0 1.7	h0	Δ h0 412.393049	h0 -Δ h0 549.857399	h0 1,374.6	Depth min	max
0.75	5 Δ	962.25	4	2	4 h1+Δ	3	856.64
f1	f1	h1 253.22	Δ h1 451.054897	h1-Δ h1 -197.831095	h1	Depth min	max
2.85	1.6 Δ	4	8	5	704.28 h1+Δ	5	186.28
f2	f2	h2 225.52	Δ h2 400.937686	h1-Δ h1	h1	Depth min	max
3.2	1.8	7	9	-175.410238	626.47	-693.410238	108.47

Measured from RAS


Average per DAYS of H/V for MGS from 2007.01.01 – 2007.12.31
Frequency
0
5
10
15
20
25
30
35
2007.01.01
2007.04.02
2007.07.02
2007.10.01
2007.12.31
1
1.5
2
2.5


Average per DAYS of H/V for GAS from 2007.07.01 – 2007.12.31
Frequency
Time
0
5
10
15
20
25
30
35
2007.07.01
2007.08.15
2007.09.30
2007.11.15
2007.12.31
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8


Average per DAYS of H/V for EGS from 2007.07.01 – 2007.12.31
Frequency
Time
0
5
10
15
20
25
30
35
2007.07.01
2007.08.15
2007.09.30
2007.11.15
2007.12.31
1
1.5
2
2.5
3
3.5
4


Average per DAYS of H/V for GGB from 2007.07.01 – 2007.12.30
Time
30
07.01
2007.08.15
2007.09.30
2007.11.15
2007.12.30
0.8
1
1.2
1.4
1.6
1.8
2
2.2

Grafica de Camilo!!!!

Cross-Correlation

Can we gain more information about the earth's interior?

coherent seismic waves:
waves emitted by explosions or earthquakes.

These waves are used to measure travel times of the body waves and dispersion curves of the surface waves with the use of ray theory.

This procedure has been used only in highly seismic areas.

Recently, a method to study low seismic regions has been proposed.

The distribution of the ambient **seismic noise** over long periods of times, is **random.**

Multiple scattering tends to **homogenize the phase space**, consequently, the deterministic **Green function can be extracted from the ambient seismic noise**.

Cross - Correlation

Green function can be found computing the **cross correlation** between two stations

$$C_{ij}^{d}(\quad) \qquad {}_{c}^{d\quad T} S_i(t \qquad)S_j(t)dt$$

By doing the cross-correlation of the noise at two sites, the fundamental mode **Rayleigh wave** emerges .

Therefore, there is a possibility to **invert the Rayleigh waves** reconstructed from the cross correlation to find the **group velocity dispersion curves**.

Cross - Correlation

<u>Outline of the procedure:</u>

- Synchronize the signals by taking segments of one hour, and guaranteeing they begin at the same time and have the same number of points.

- Detrend the series and extract the mean.

- Whiten the signal by making the amplitude of each frequency component equal

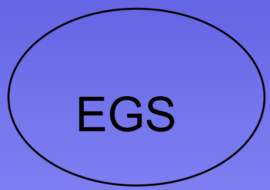
- Binarization

- Cross correlation between two stations is calculated in windows of 130 s with 25 percent overlap

- Filter the cross correlated trace between 0.2Hz and 40Hz.

- Cross correlation of windows is stacked.

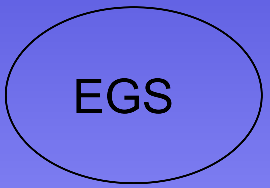
Cross - correlation

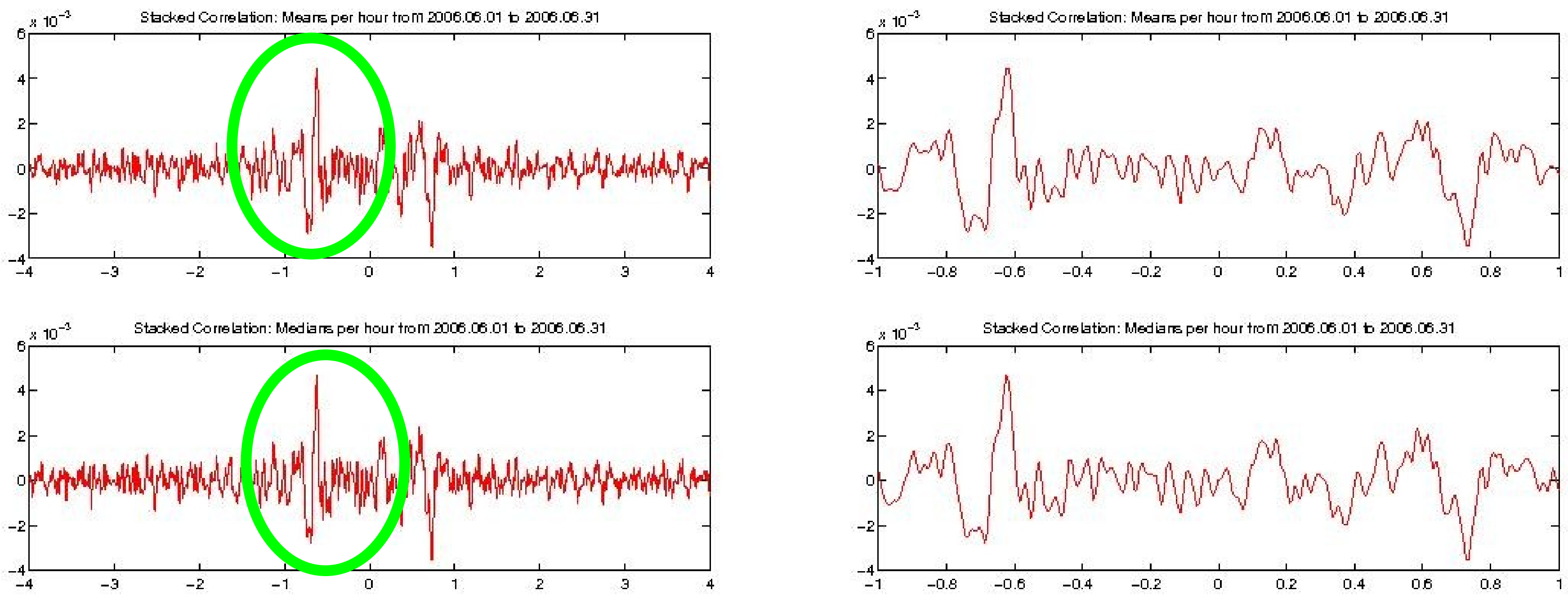


$$d_{AB} \quad 1518m$$

$$v \quad 5000m/s$$

$$t \quad \frac{d_{AB}}{v} \quad 0.304s$$





Conclusions

The H/V ratio technique was tested and used to find the resonant frequency of soft soils. Clear peaks were seen and those in the low frequency regime were used to find a range of depth where the acquifier might be located. Further analysis needs to be done to improve the dispersion in the results and to compare the peak's trend with the rainfall trend for each year.

The resonant frequencies above 5Hz have not been analyzed. They correspond to layers above the RAS station, and the thickness of the these layers can be approximated.

The analysis can be taken one step further. The H/V ratio can be inverted to find the velocity profile. This would be interesting to do, to compare it with the velocity profile obtained through the cgreen's function method.

Conclusions

The cross correlation makes use of the noise signals to reconstruct Rayleigh wave. There is no need of an energetic signal so, this method has the advantage that it can be applied wherever seismograms are located, and that it is possible to have long time series.

Finding Green's between two stations allows us to have information about the geological structure around these two points.To reconstruct the Rayleigh wave successfully , the cross correlations should be *smartly* stacked. A good criteria should be delevoped to determined which correlations should be stacked. Also, an analysis is needed to determine the minimum number of correlations needed in order to obtain a stable Green's function.

The inversion to determine the velocity as a function of depth, has not been done yet.