TIME FREQUENCY ANALYSIS OF THE LSSB'S GREEN'S FUNCTION

Clara Castellanos
Supervisor: Stéphane Gaffet
GEOAZUR

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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 signals**: 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?

Retrieving Green's Function

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

$$C_{AB}^{d}(\tau) = \int_{c}^{d+T} S_A(t+\tau)S_B(t)dt$$

$$G_{AB}(t) = -\frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{C_{AB}(t) + C_{AB}(-t)}{2}\right] \quad 0 \le t \le \infty$$

Cross - Correlation

Outline of the procedure:

- 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.

- Time Normalization

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

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

-. Cross correlation between two stations is calculated in windows of 130 s with 50 percent overlap

- Cross correlation of windows is stacked according to a signal to noise ratio.

Cross Correlation

Time Normalization:

One Bit normalization:

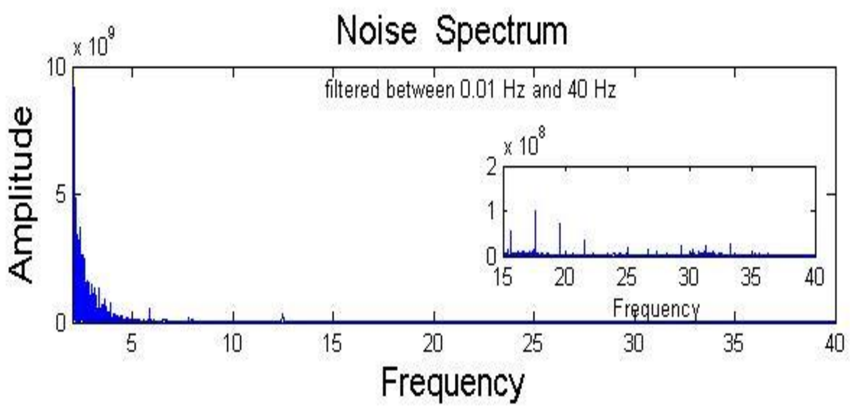
$$\tilde{s}_n(t) = 1, \quad \text{if } s_n(t) > 0$$
$$\tilde{s}_n(t) = -1, \text{ if } s_n(t) <= 0$$

Running Time Window :

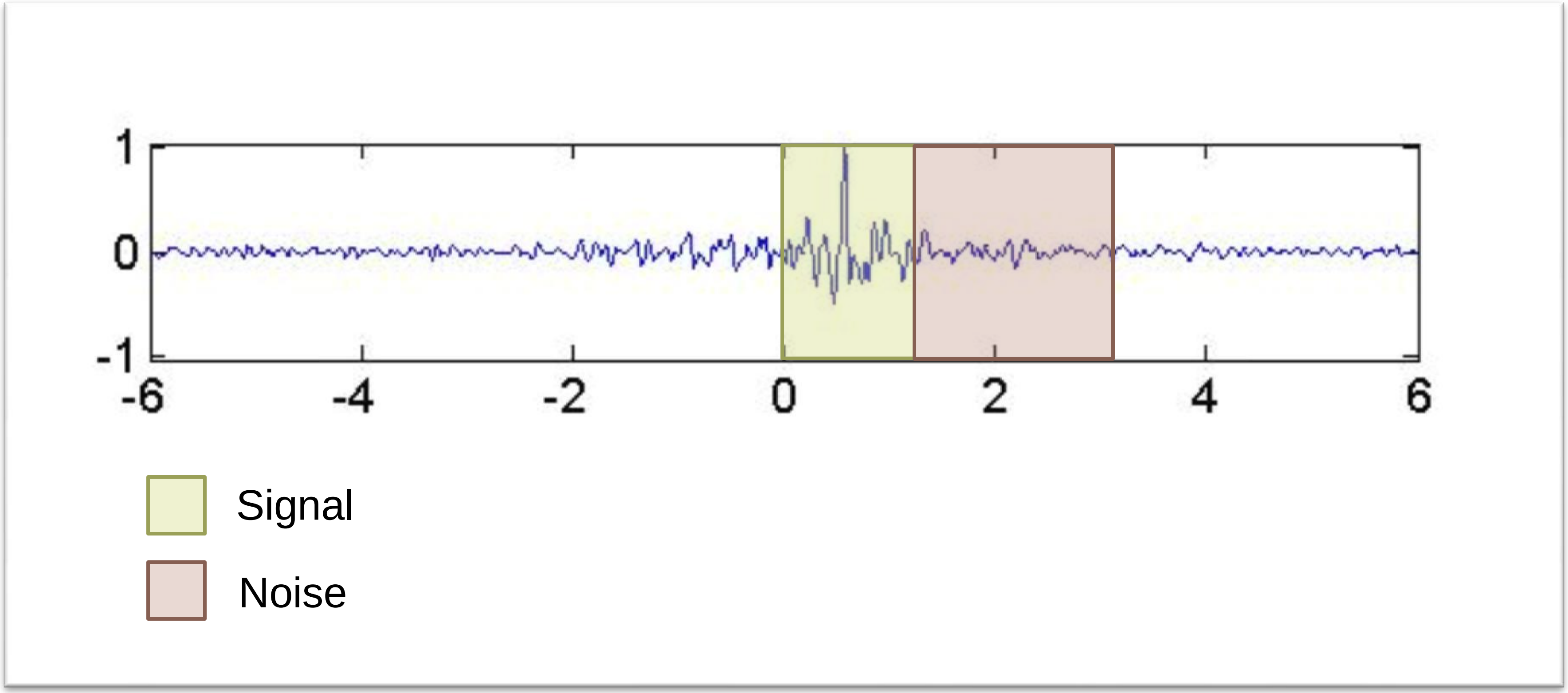
$$\tilde{s}_n = \frac{s_n}{w_n}; w_n = \frac{1}{2N+1} \sum_{j=n-N}^{n+N} |\bar{s}_j|$$

s_n : signal; $\bar{s}_n$: banpassed filtered;

Frequency Normalization:



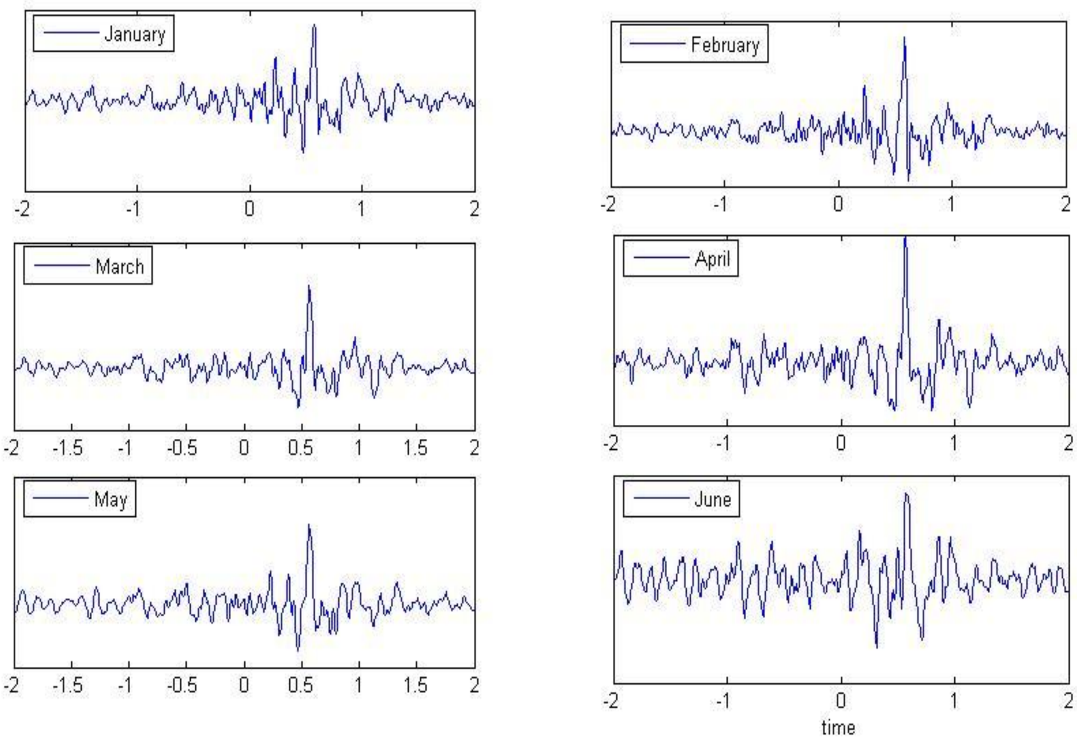
$$f_n = c$$

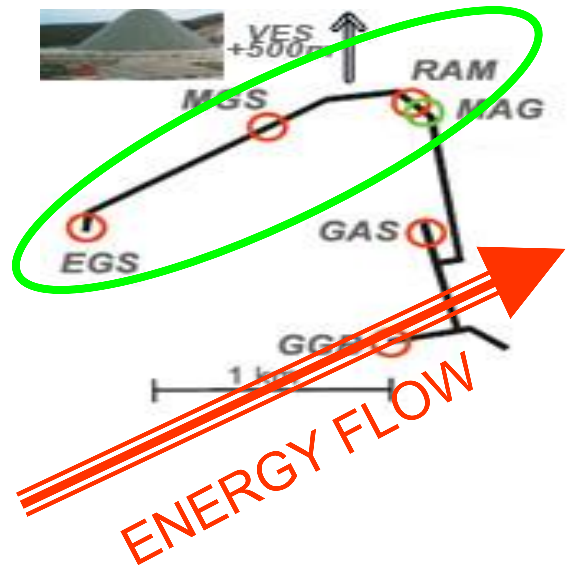

1
0
-1
-6
-4
-2
0
2
4
6
Signal
Noise

Noise Correlation Functions (NCF)

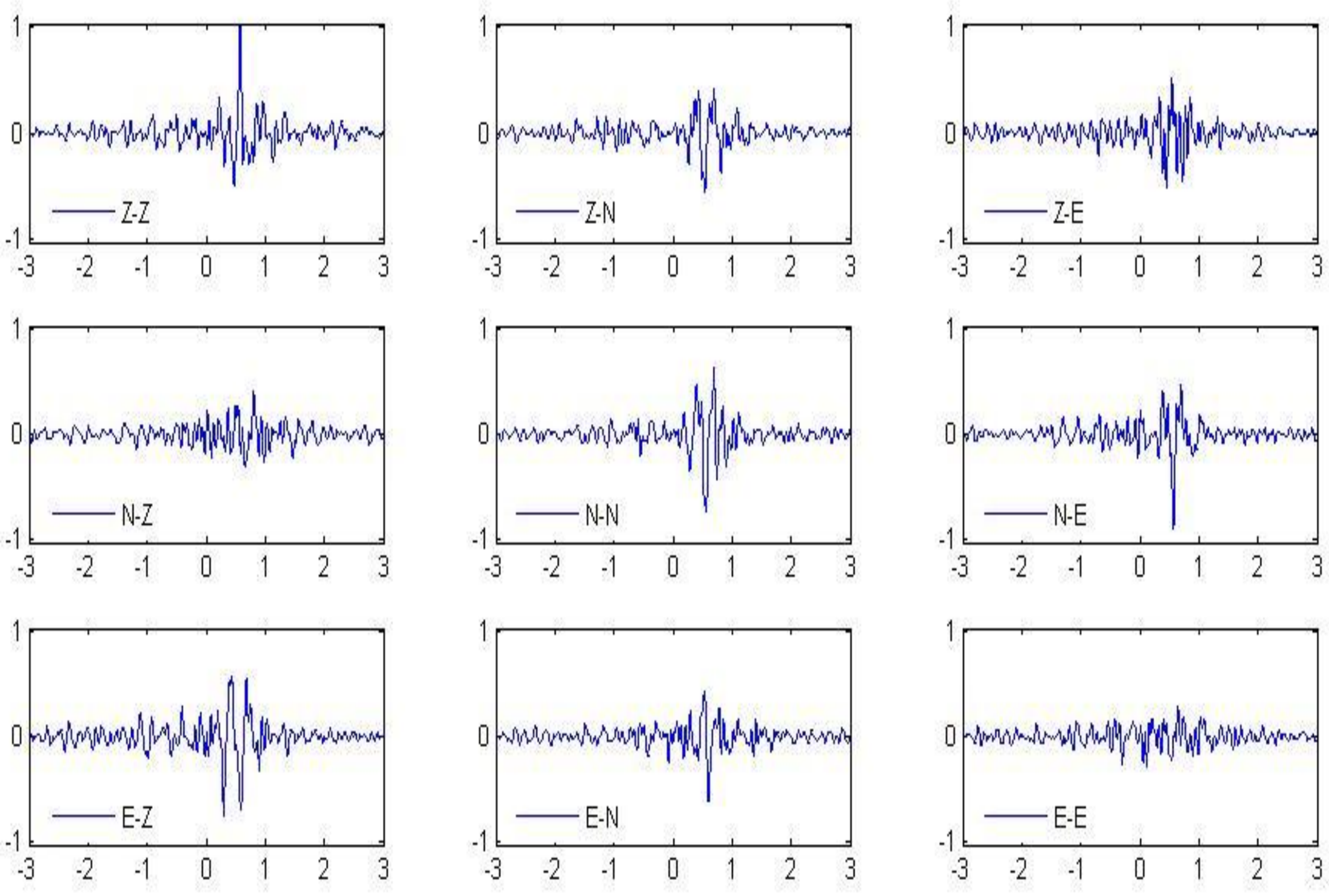
Stations : EGS – RAS.

Time Interval: January 2008 – June 2008

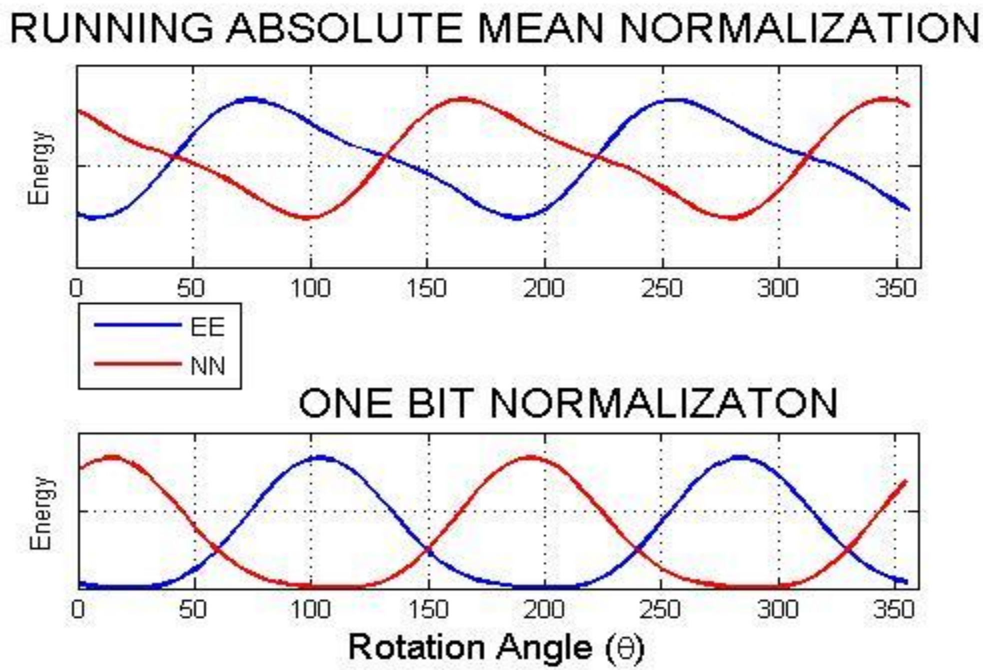


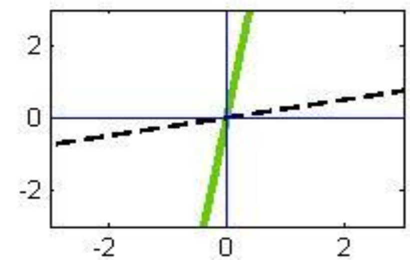


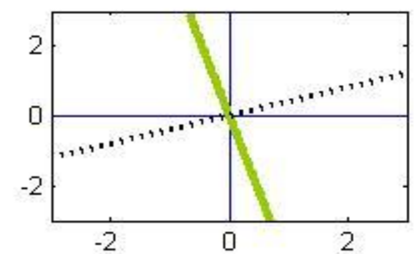
Noise Correlation Functions

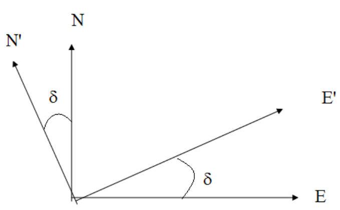


Rotation of E-N components

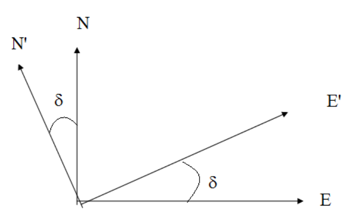








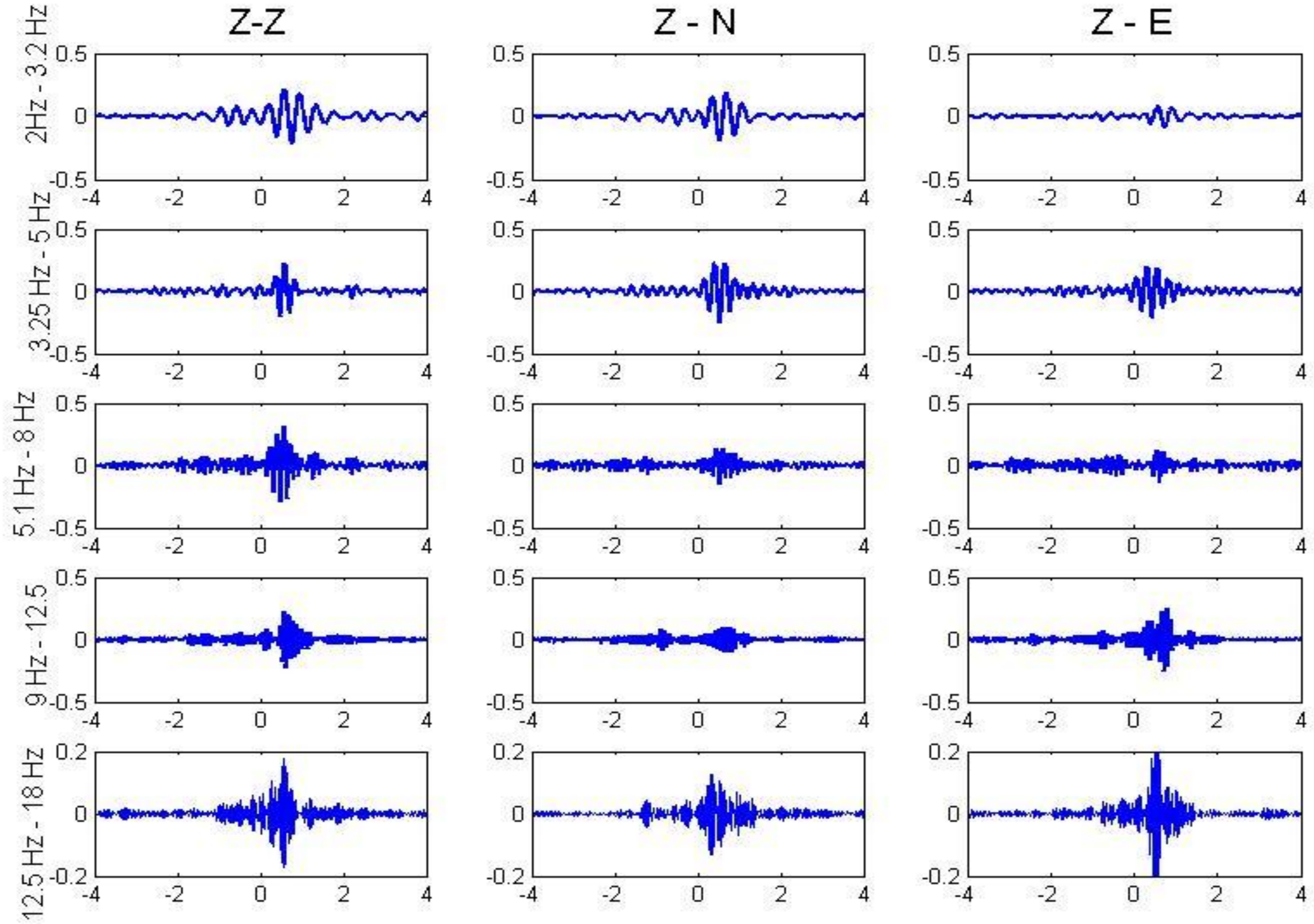
A



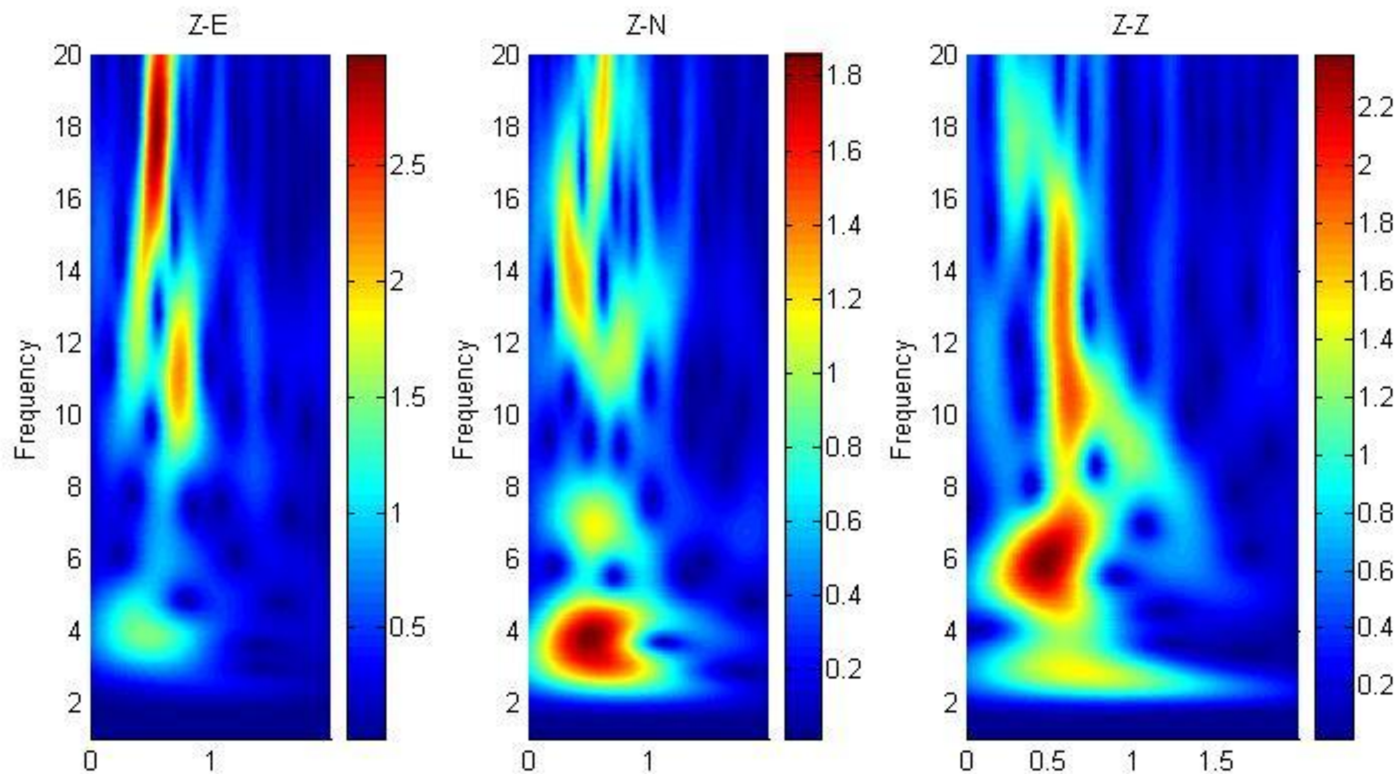
B

Green solid: high energy

Black broken: lowest energy

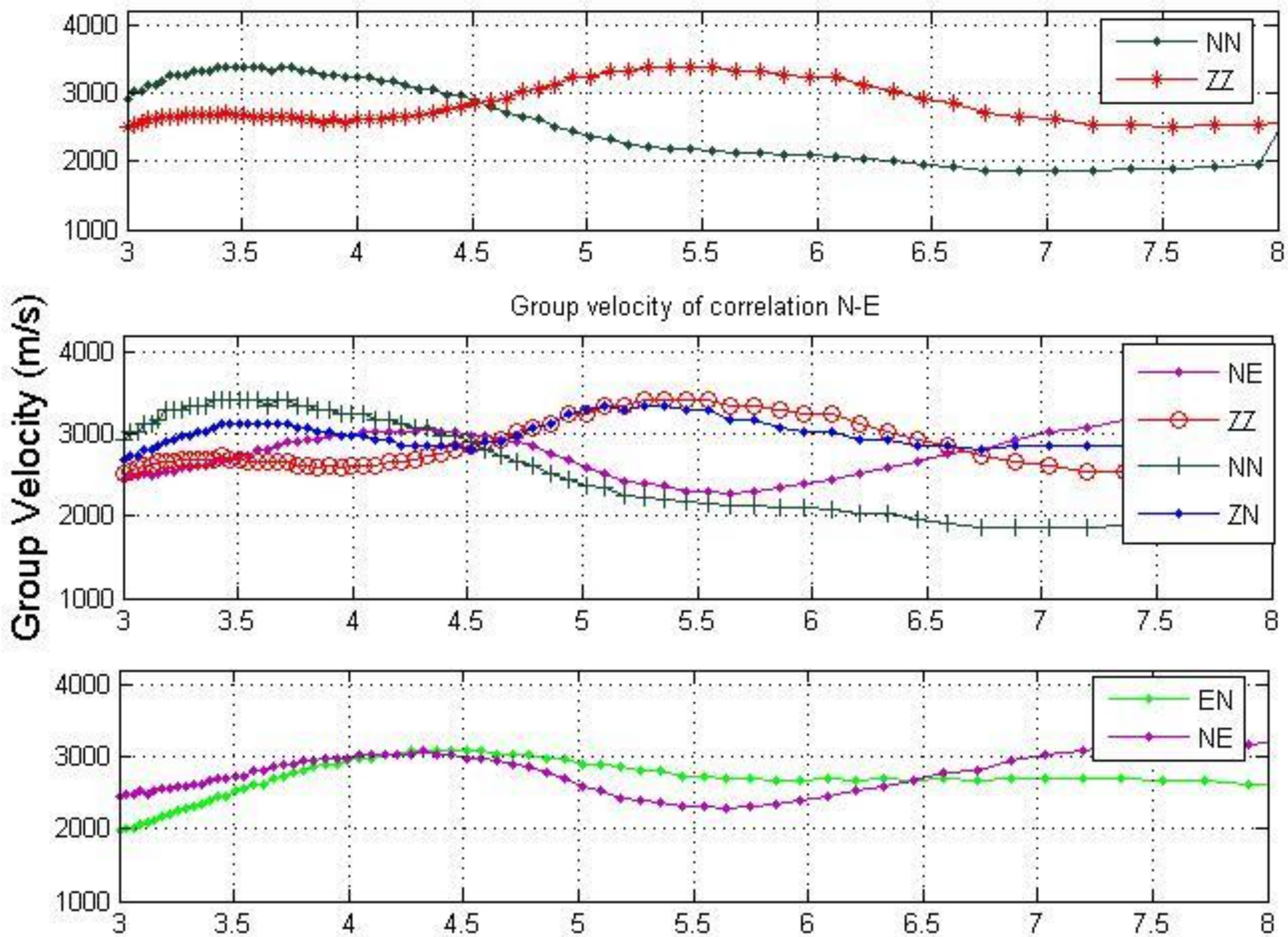

Z-Z
Z - N
Z - E
2Hz - 3.2 Hz
3.25 Hz - 5 Hz
5.1 Hz - 8 Hz
9 Hz - 12.5
12.5 Hz - 18 Hz
0.5
0
-0.5
0.2
-0.2
-4
-2
2
4

FTAN

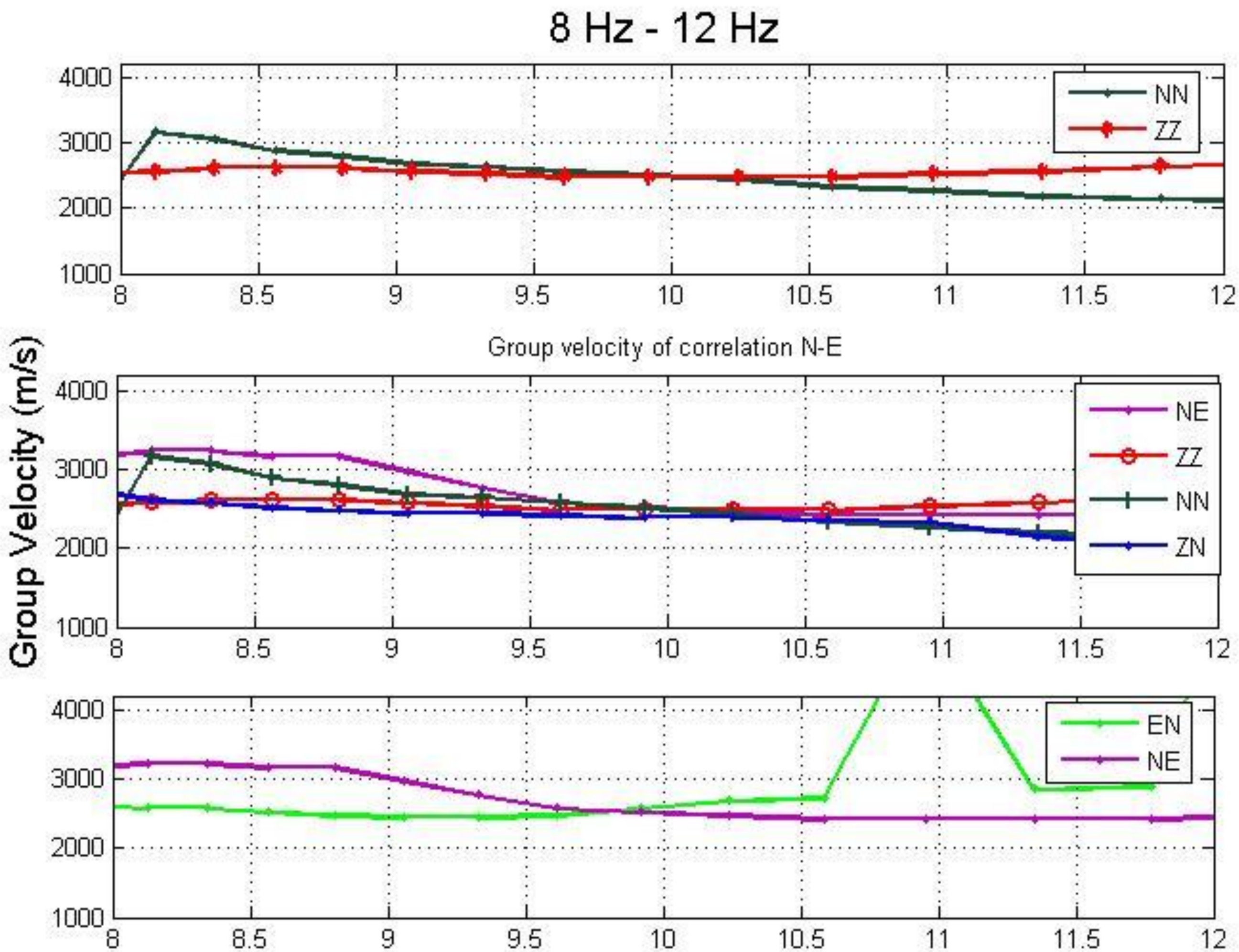

Z-E
Z-N
Z-Z
Frequency
Frequency
Frequency
20
18
16
14
12
10
8
6
4
2
0
1
0.5
1.5
2.5
2
1.5
1
0.5
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

FTAN : GROUP VELOCITY

3 Hz - 8 Hz



FTAN : GROUP VELOCITY



FTAN: ELLIPTICITY

Polarization analysis of a 3-Component signal can be done through the eigenanalysis of the covariance matrix, in the time-frequency domain.

Kullesh et al, 2007

The eigenanalysis is performed on the covariance matrix, with a sliding window of variable length.

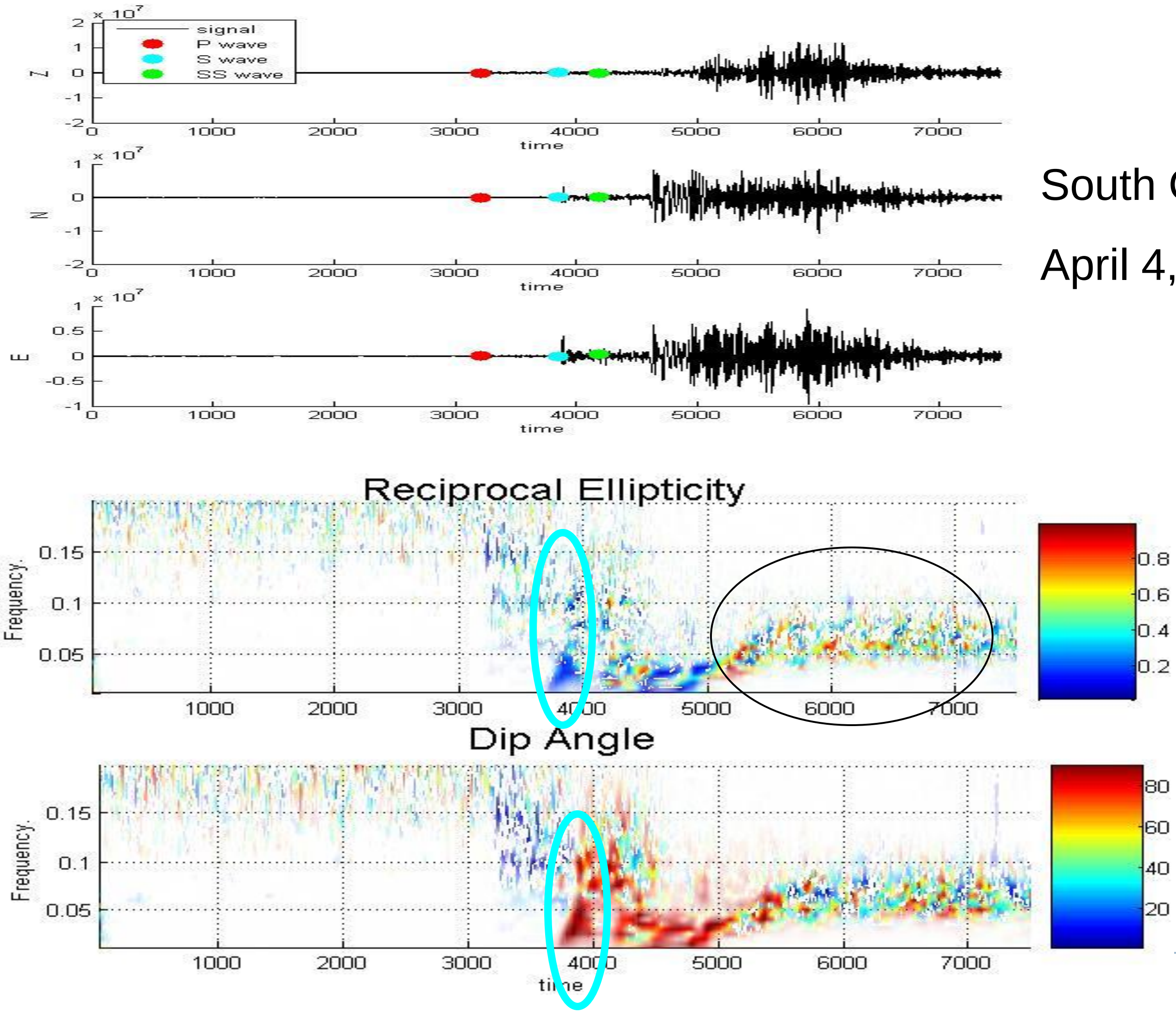
The decomposition produces three eigenvalues, and three eigenvectors.

$$R(\xi)=\sqrt{\lambda_1(\xi)}\,\frac{v_1(\xi)}{\|v_1(\xi)\|};\qquad r(\xi)=\sqrt{\lambda_3(\xi)}\,\frac{v_3(\xi)}{\|v_3(\xi)\|};$$

$$d(\xi)=\arctan\left(\frac{\sqrt{v_{1,x}(\xi)^2+v_{1,y}(\xi)^2}}{v_{1,z}(\xi)}\right);\quad d(\xi)=\arctan\left(\frac{v_{1,y}(\xi)}{v_{1,x}(\xi)}\right);$$

FTAN: ELLIPTICITY

EXAMPLE:

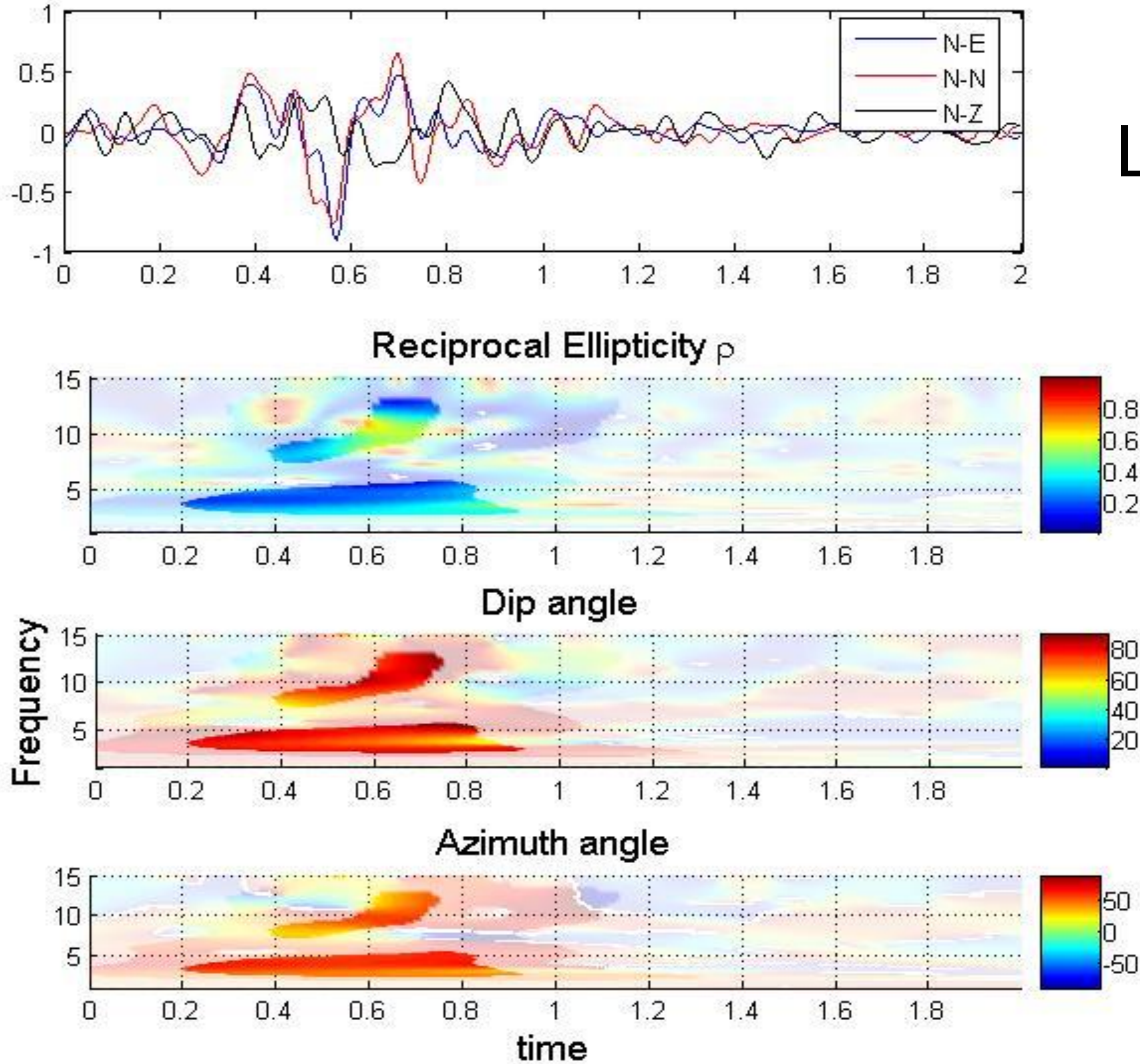


South California,

April 4, 2010

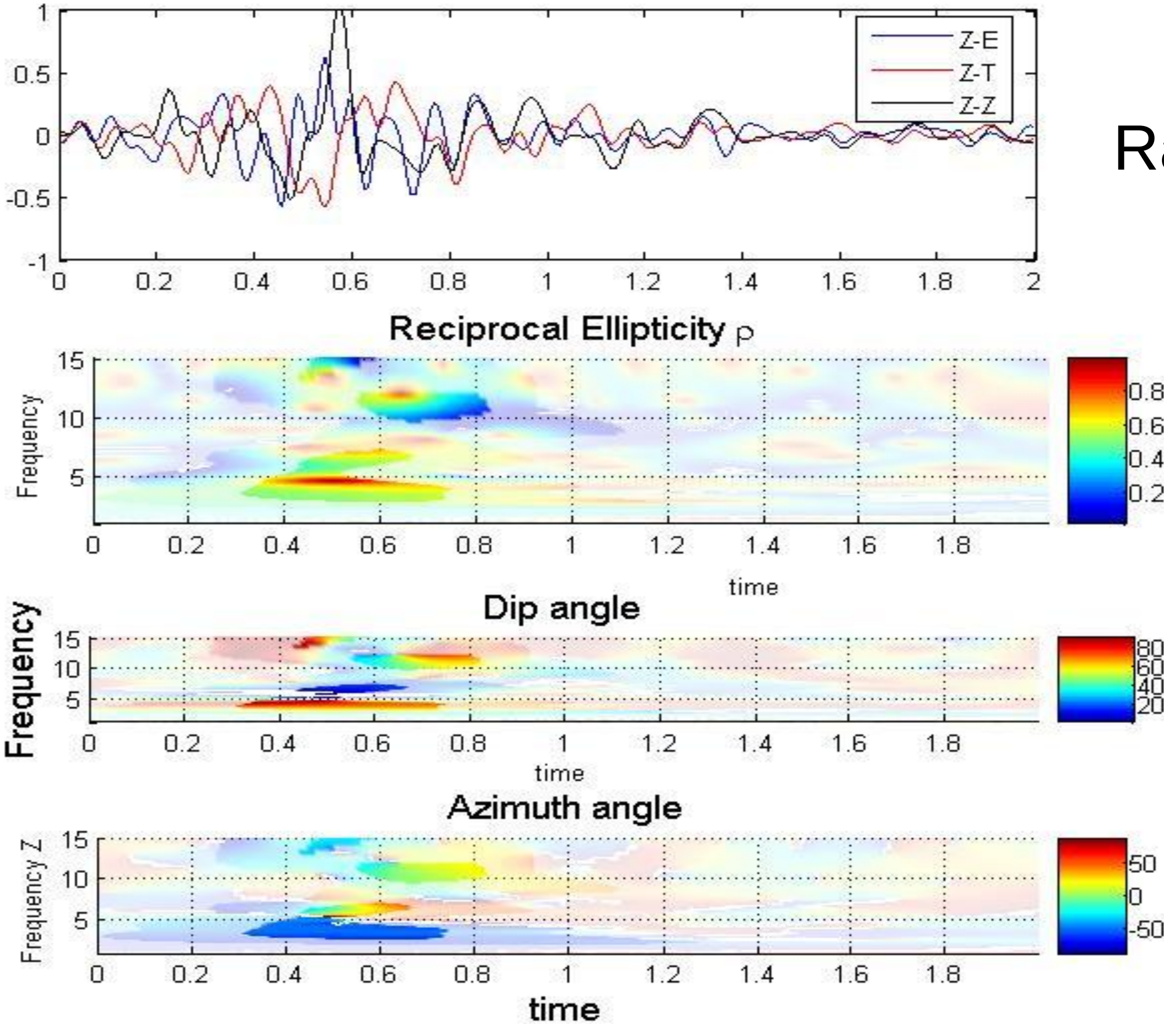
FTAN: ELLIPTICITY

Back to the LSBB Noise Correlation Functions….



LOVE WAVE ?

FTAN: ELLIPTICITY



Rayleigh Wave?

Results and Conclusions

- Using the seismic noise recorded in the LSBB stations, we found the cross correlation functions through which it is possible to passively reconstruct the Green tensor. The stations used were beneath the surface (500m), and at close a close distance (1.5km) which gives rise to conditions not commonly used in previous experiments. The NCF are one sided, which imply a non-homegeneous distribution of the noise sources.

- We found coupling not only on the vertical components but also on the horizontal transverse components. Through a frequency time analysis we conclude that there is a possibility that not only Rayleigh but also Love waves appear on the NCFs.

- Dispersion curves can be found for certain frequency intervals until, approximately, 16 Hz. The group velocities are in the expected range, compared to previous experiments done in the LSBB.

- The polarization analysis suggests that the cross correlations give rise to Love and Rayleigh waves.

Perspectives

- Investigate further on the factors that help in the appearce of Love waves. *Fan-Chi Lin et al.* (2008), also found Love waves through NCF and suggest this occurs if there is radial anisotropy in the crust.

- It is important to find the NCF between other pairs of stations and repeat the whole procedure to test its validity and stability. Once the dispersion curves can be fully trusted, the next step will be to construct group and phase speed maps.

- Search for a method to trace time changes of the medium properties using the NCF. Can the water content be measured throught this technique?

THANK YOU