SPATIO-TEMPORAL VARIATIONS OF SEISMIC ANISOTROPY IN SEISMOGENIC ZONES

M. Saade(1), J P. Montagner(1), P. Roux(2), P. Cupillard(3), S. Durand(4), F. Brenguier(2).

(1) Institut de Physique du Globe de Paris, France. (2) ISTerre, Université Joseph Fourier, Grenoble, France.
(3) Ecole Nationale de Geologie, Universite de Loraine, Nancy, France.
(4) Laboratoire de Geologie de Lyon, Ecole Normale Superieure de Lyon, France.

ABSTRACT : Seismic anisotropy plays a key role in the study of stress and strain fields in the earth. Therefore, temporal variation of seismic anisotropy can be interpreted as variation of the orientation of cracks in seismogenic zones and thus variation of the stress field. In this study we investigate the variations of the polarization of surface waves in anisotropic media. These variations are related to the elastic properties of the medium, in particular to anisotropy. Hence they can be interpreted as variation of seismic anisotropy. The technique used is based on the cross-correlation of ambient seismic noise that allows to reconstruct the Green's function between two stations continuously (if the sources are randomly distributed in an homogeneous medium) in order to estimate its fluctuations. The monitoring of the Green's function or any cross-correlation (for any other distribution of sources) tensor permits the monitoring of stress and strain fields. This technique was applied on synthetic seismograms computed in a HTI (Horizontal Transverse Isotropy) medium using a code based on the spectral element method. The cross-correlation tensor is computed between each two stations and then rotated in order to approximate the Green's tensor by minimizing the non-diagonal components that are supposed to be null in a Green's tensor. This procedure permits the calculation of the polarization angle of quasi-Rayleigh and quasi-Love waves. Thus we observe the azimuthal variation of the polarization of surface waves.

1- EFFECT OF ANISOTROPY ON SEISMIC WAVES

S- Waves

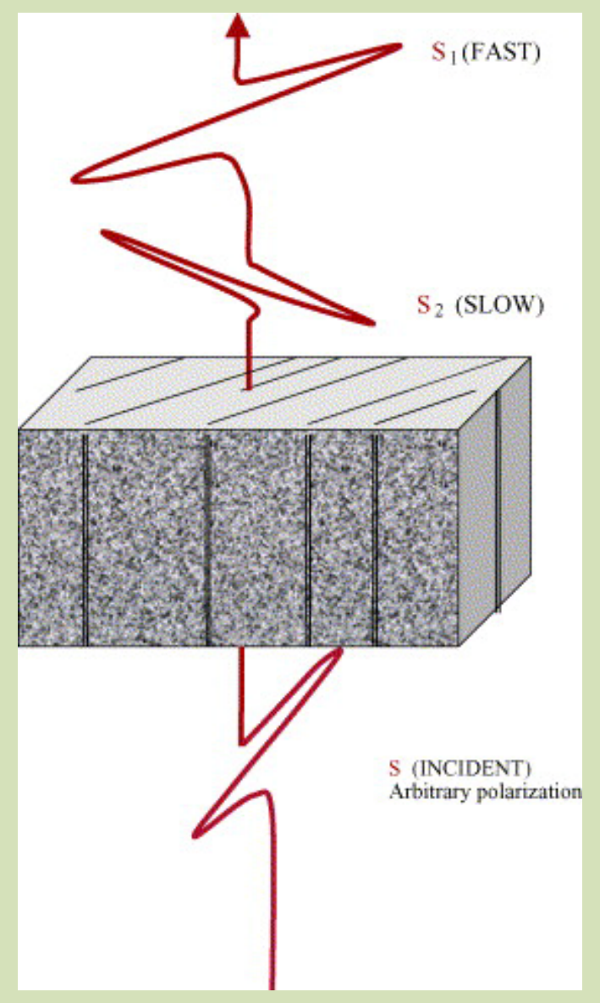

Fig. 1.1 : Shear-wave splitting

Surface Waves

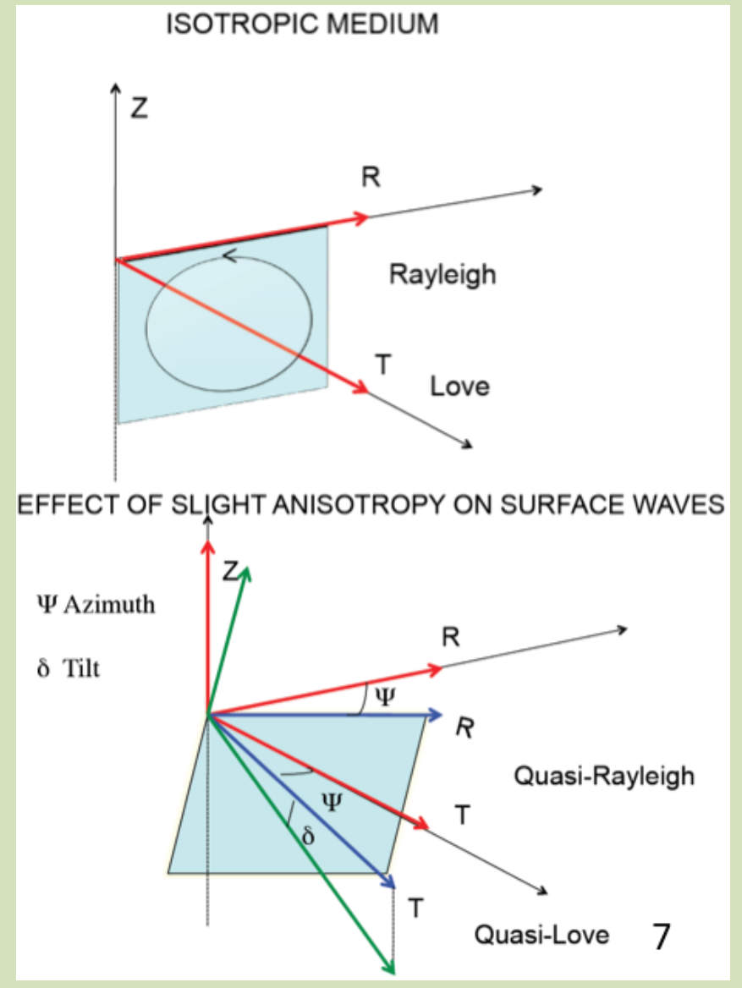

Fig. 1.2 : Surface wave polarization anomaly

2- THE TECHNIQUE

a- Seismic Noise Cross-Correlation

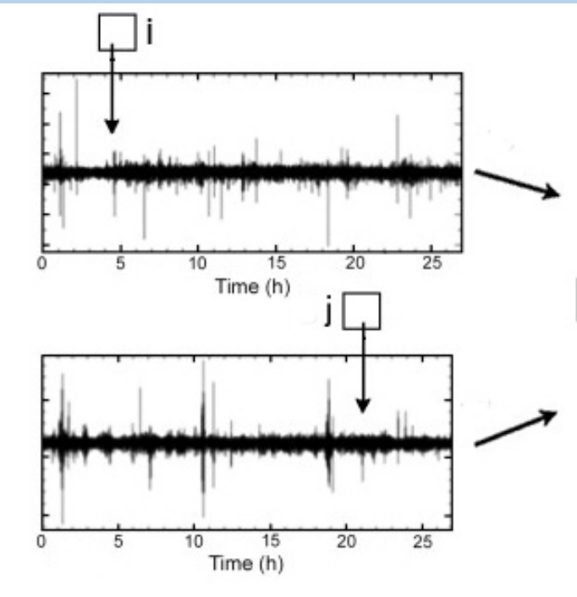

Fig. 2.1 : Noise records at two different stations (i and j)

$$[C_{ij}(t)]_{kl} = \frac{\int_0^T S_{ik}(\tau)\, S_{jl}(t+\tau)\, d\tau}{\sqrt{\int_0^T S_{ik}^2(\tau) d\tau \int_0^T S_{jl}^2(\tau) d\tau}}$$

Eq. 2.2 : Cross-correlation formula – i, j : stations - k, l : components

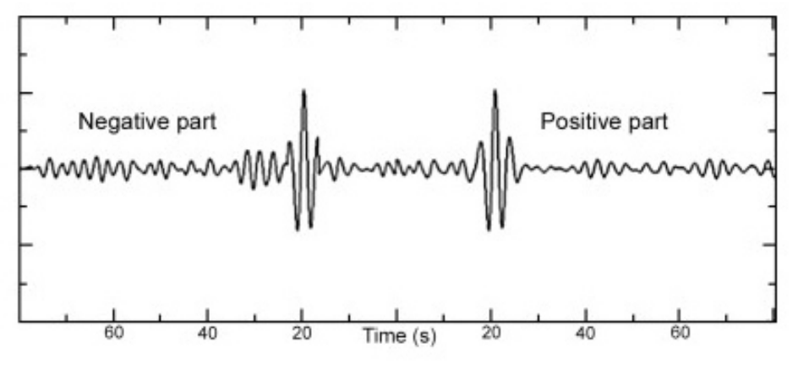

Fig. 2.3 : Nine-components cross-correlation tensor - records mainly surface waves

(If homogeneous media and sources randomly distributed)

$Z_i Z_j$	$Z_i R_j$	≈0
$R_i Z_j$	$R_i R_j$	≈0
≈0	≈0	$T_i T_j$

Fig. 2.4 : CCT in isotropic media (Rayleigh & Love waves)

$Z_i Z_j$	$Z_i R_j$	$Z_i T_j$
$R_i Z_j$	$R_i R_j$	$R_i T_j$
$R_i T_j$	$T_i R_j$	$T_i T_j$

Fig. 2.5 : CCT in anisotropic media (quasi-Rayleigh & quasi-Love waves)

b- Optimal Rotation Algorithm : ORA (Roux et al., 2011)

Function : Minimization of the off-diogonal terms of the CCT : ZT, TZ, RT & TR.
Finding the Rayleigh and Love tensor

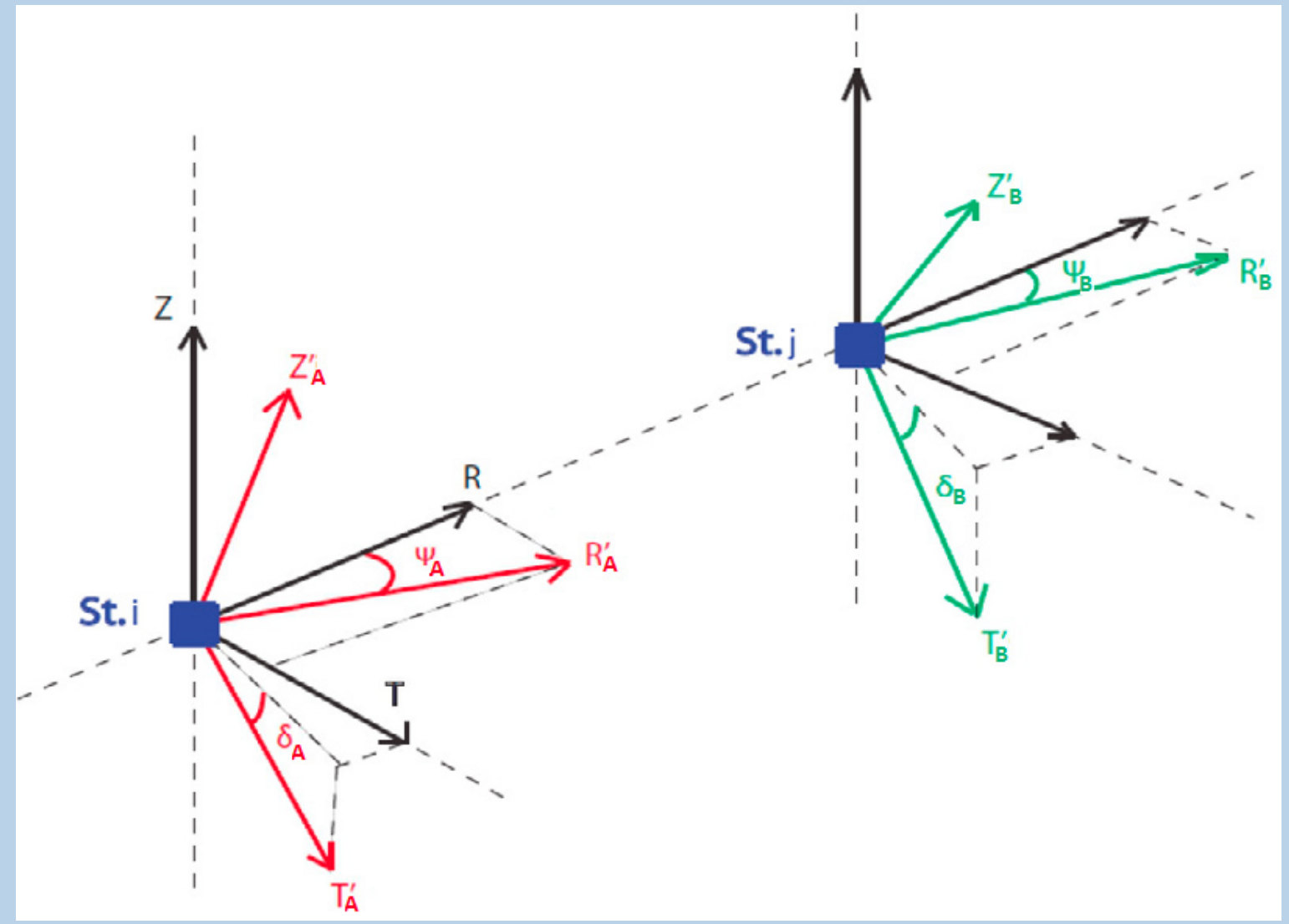

Fig. 2.6 : ORA computes ψA, δA, ψB, δB – the vertical and horizontal polarization anomalies at both stations

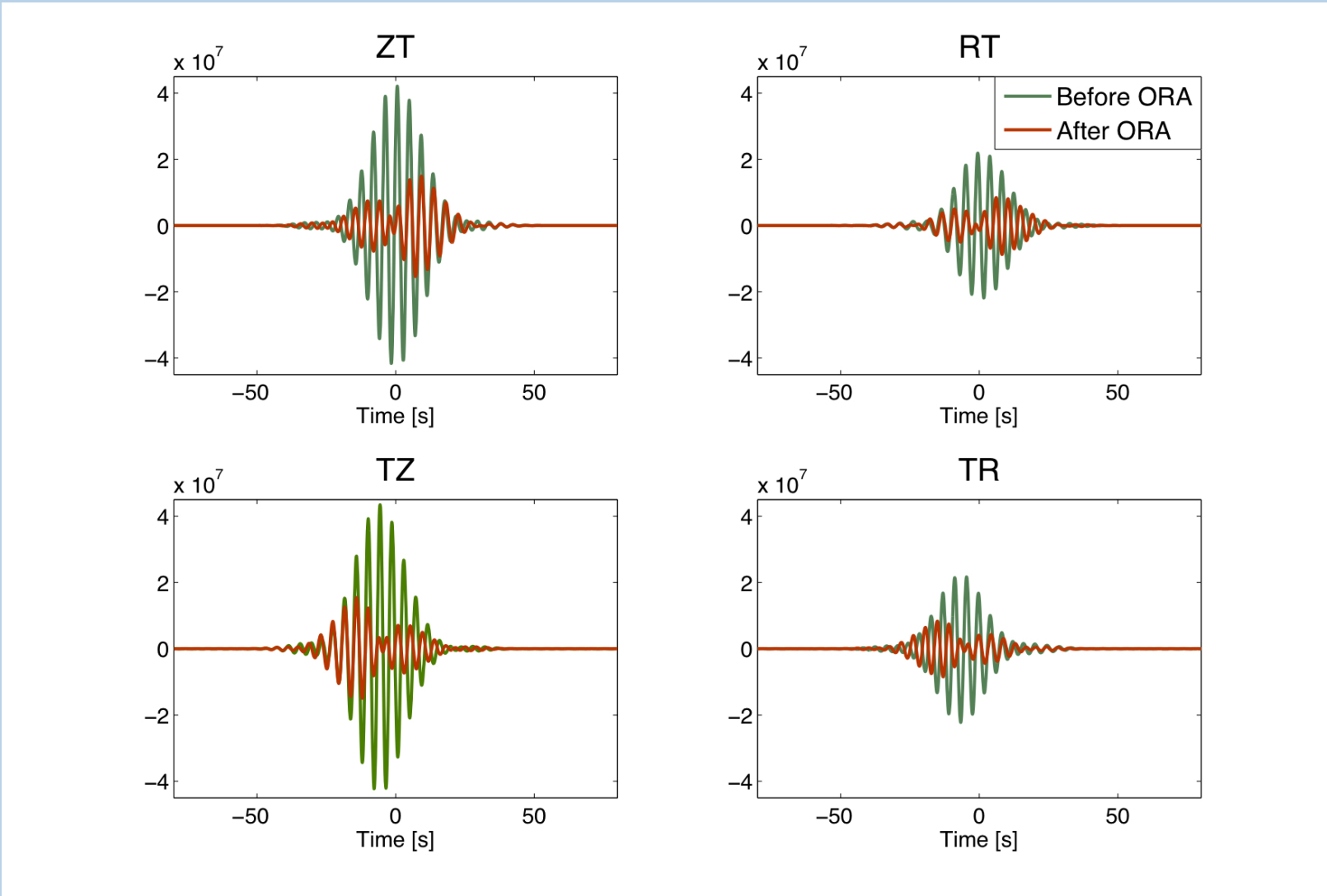

Fig. 2.7 : The four off-diagonal terms before & after ORA

3- SIMULATIONS BY RegSEM

RegSEM : Regional Spectral Element Method (Cupillard et al., 2012)

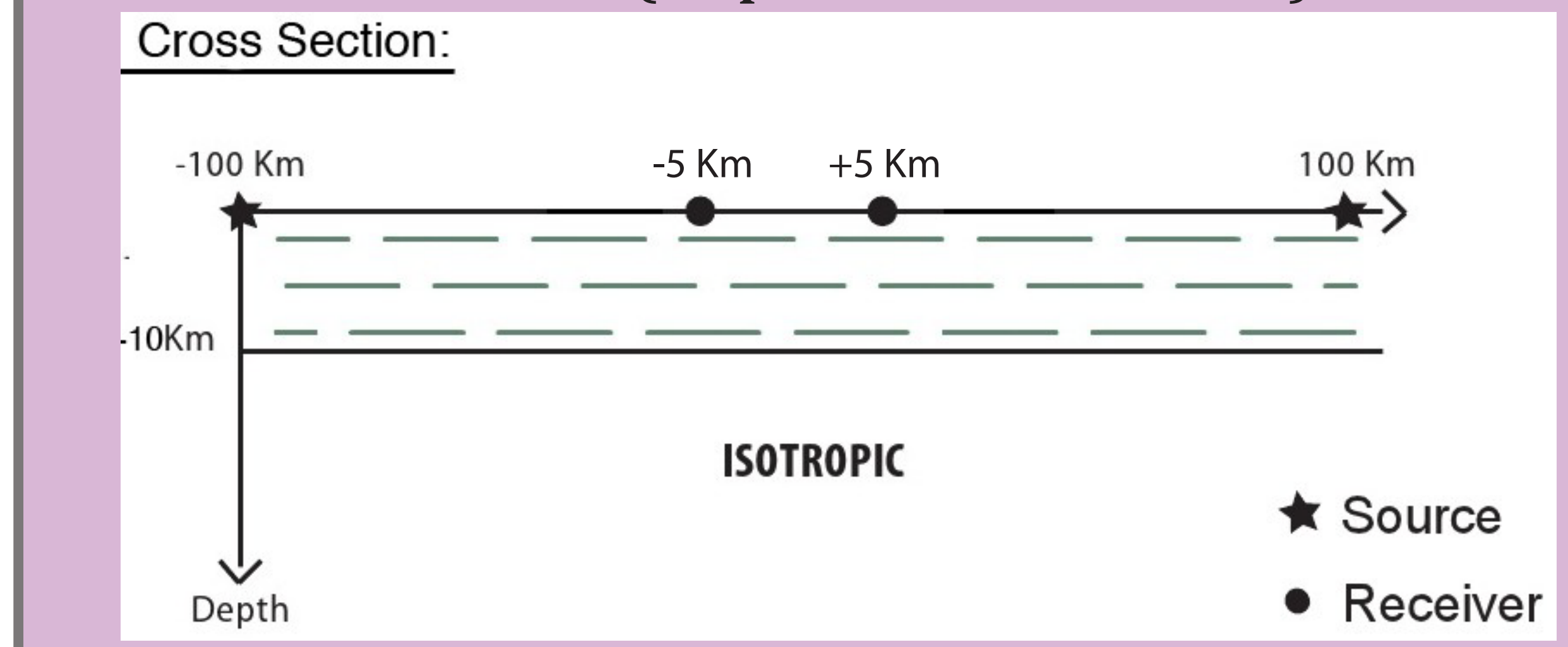

Fig. 3.1 : Vertical profile of the medium simulated by RegSEM.

Medium :
Chunck of the earth
Bottom layer : Isotropic homogeneous half space
Top Layer : Anisotropic homogeneous layer of 10km thickness

Caracteristics of anisotropy :
Horizontal Transverse Isotropy (HTI) : horizontal symmetry axis
Fast direction (symmetry axis) along East-West

Sources (stars) :
72 superficial explosions at 100Km from the center

Stations (dots) :
72 superficial stations at 5 km from the center

ψS= azimuth of source
ψR = azimuth of pair of stations (n and n+36)
ψP = azimuth of horizontal polarization anomaly
(all angles are clockwise relatively to EW)

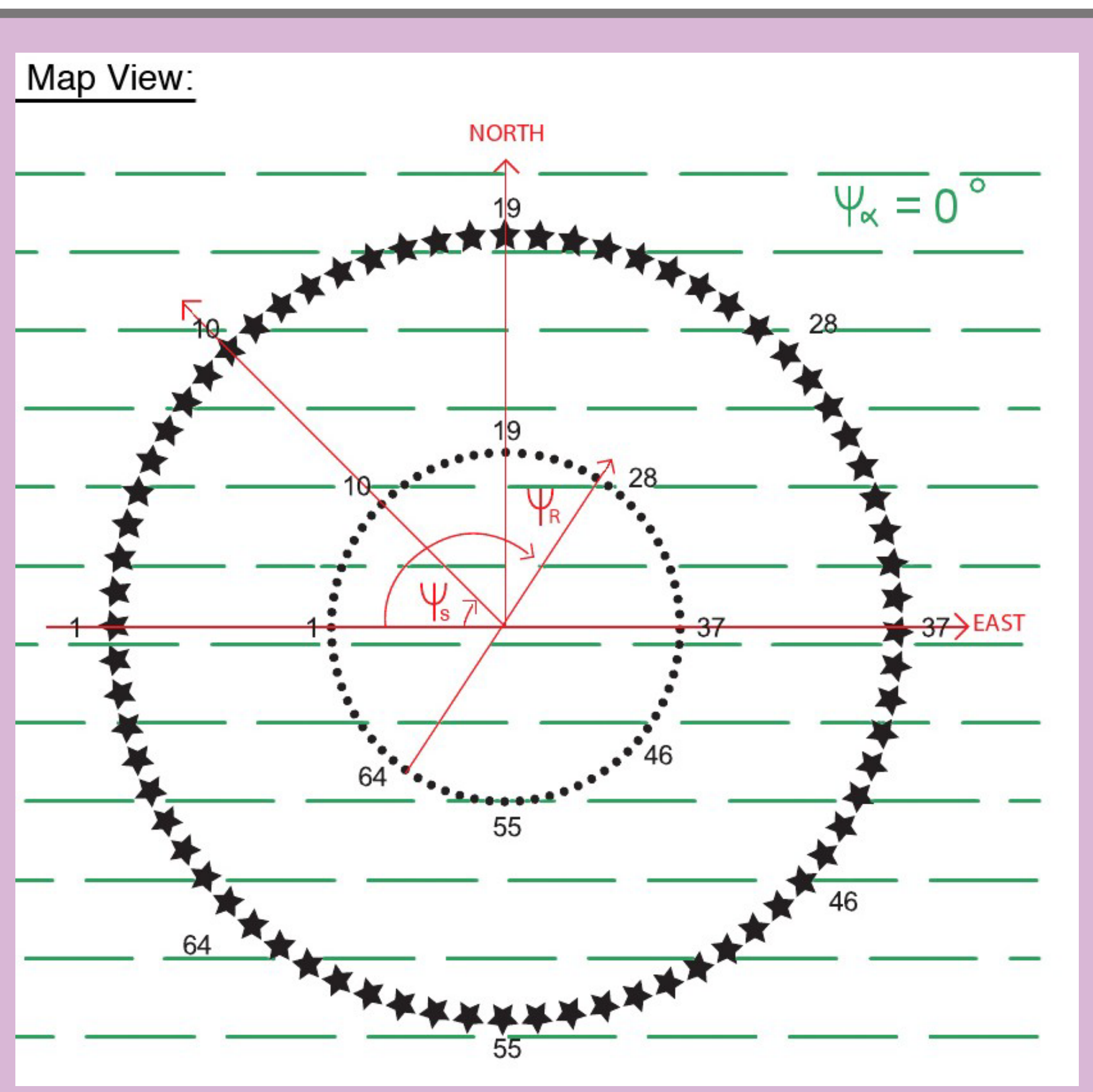

Fig. 3.2 : Horizontal projection of the medium.

4- RESULTS

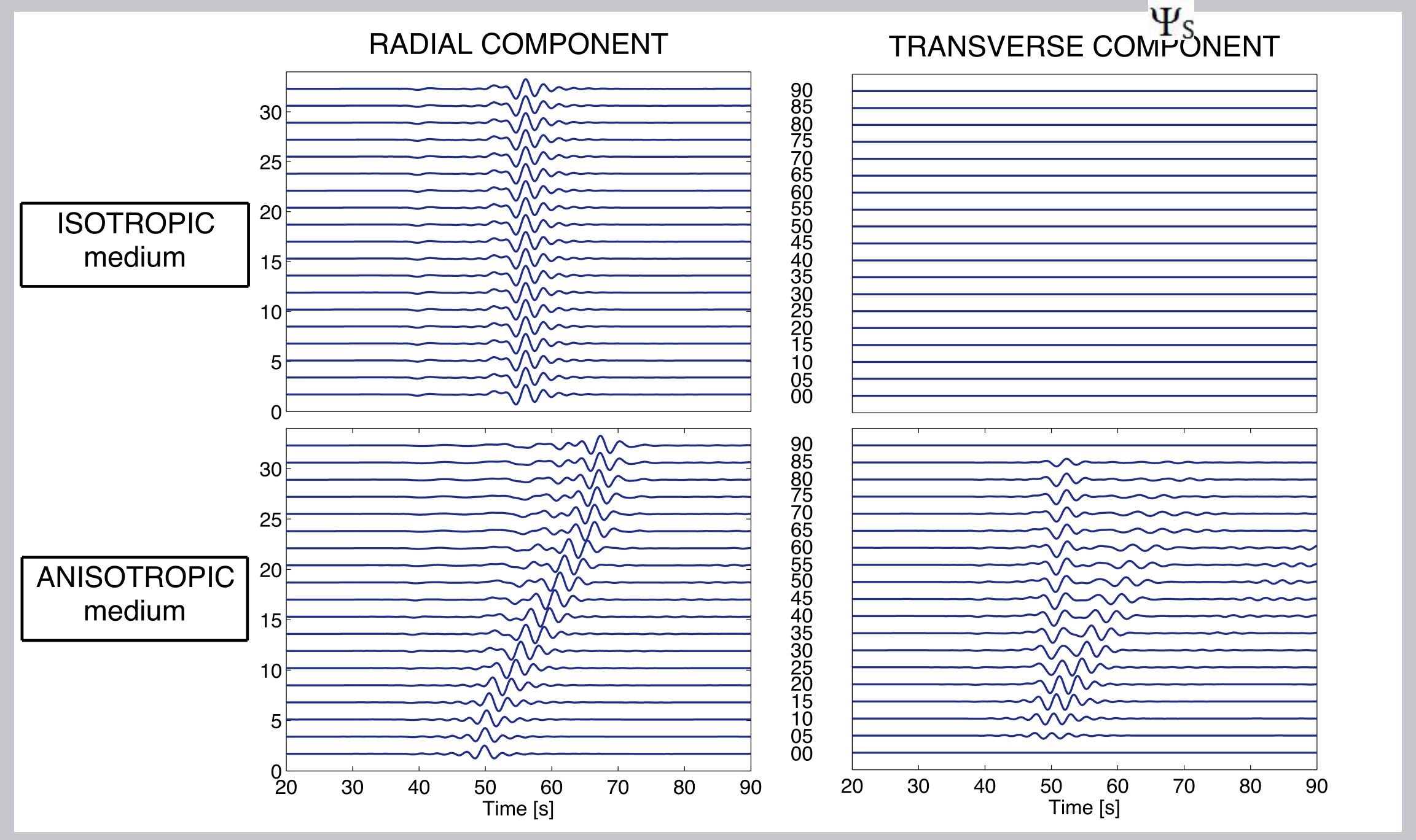

Fig. 4.1: Radial and transverse components of seismograms for source incidences going from 0° to 90°, in an isotropic and 10% anisotropic media. Frequency band = [0.05 – 0.40] Hz.

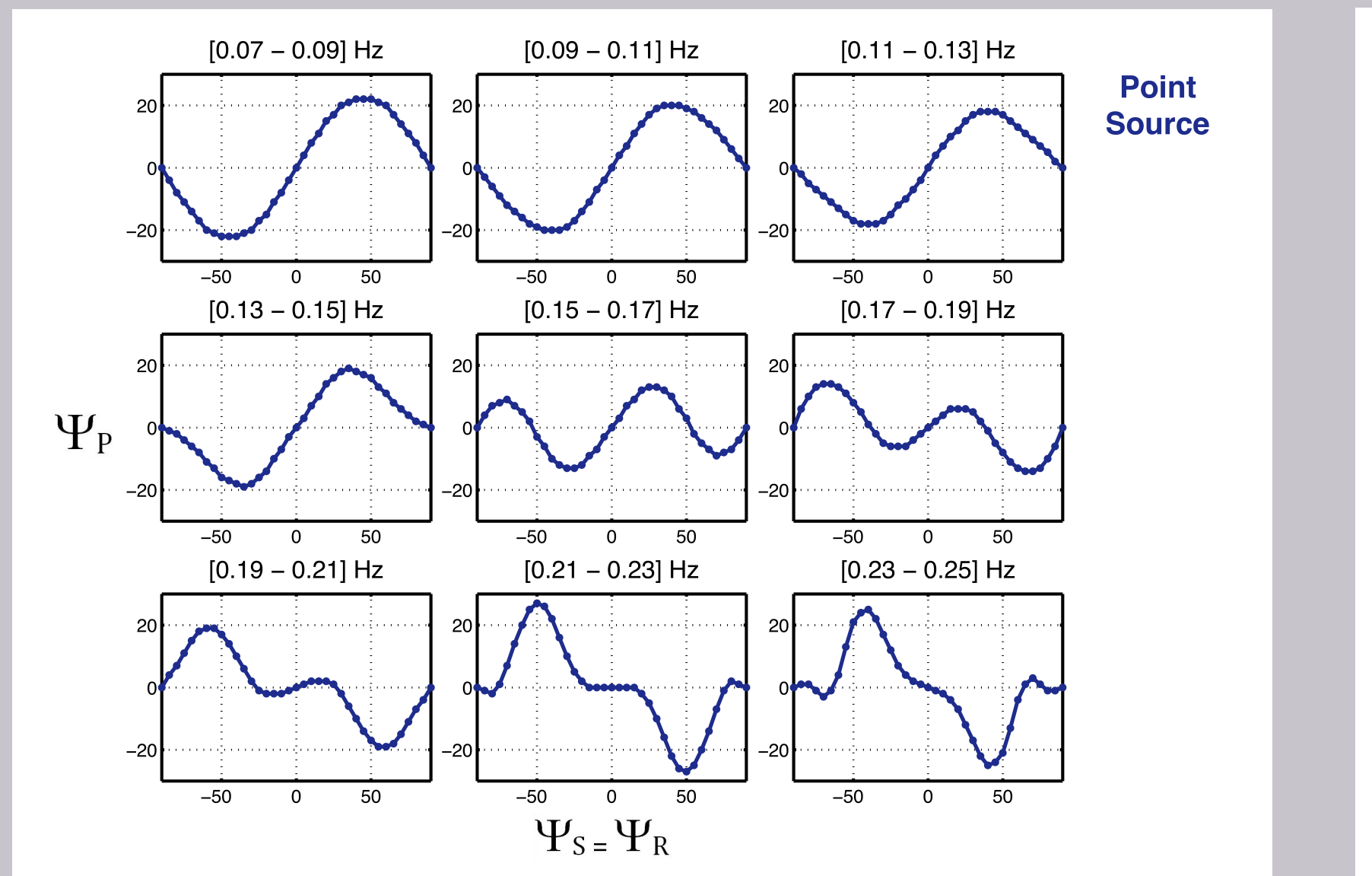

Fig. 4.2 : Variations of the horizontal polarization anomly angle as a function of the incidence of the point source, for different frequency bands admitting the same band width.

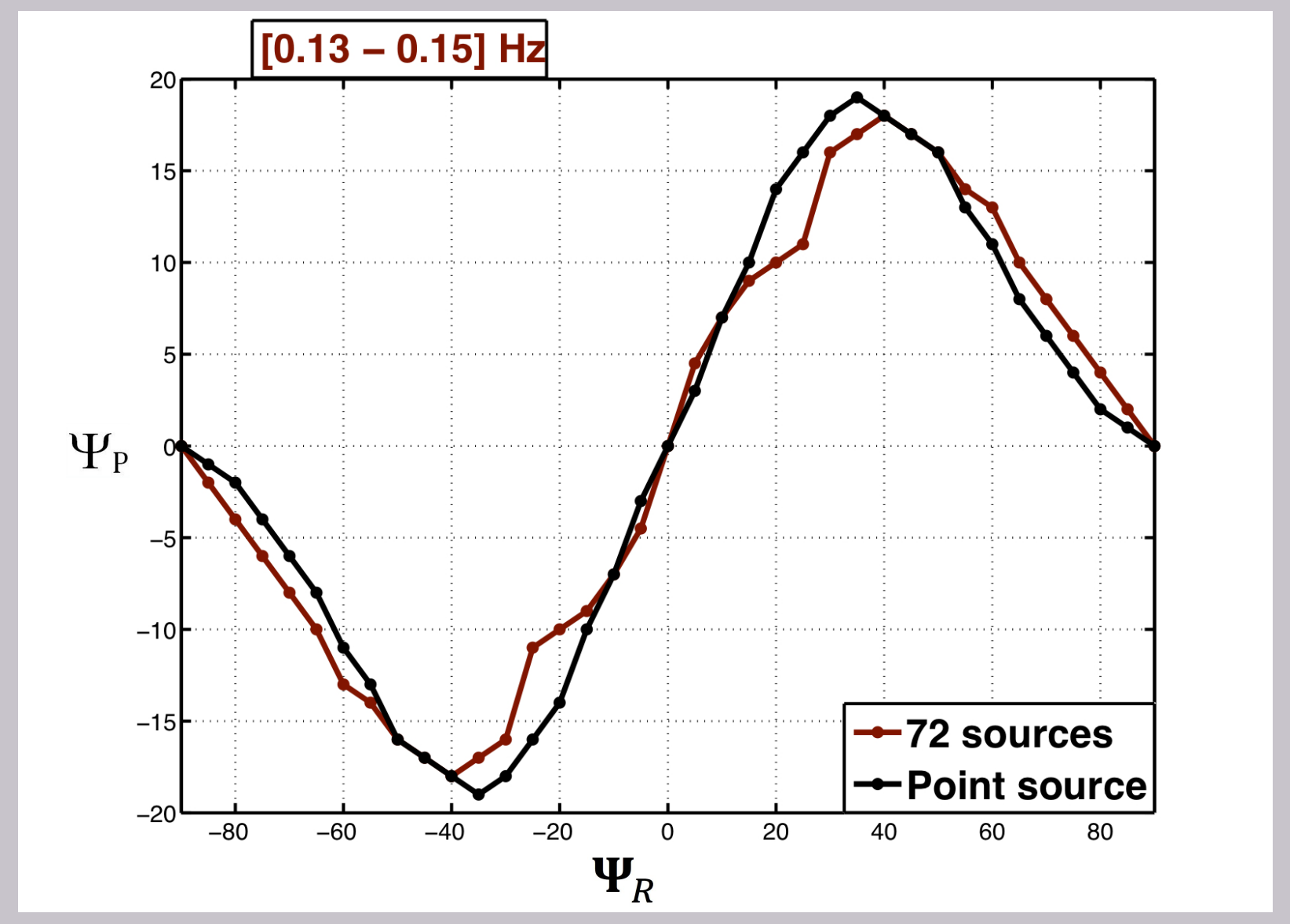

Fig. 4.4: Variations of the horizontal polarization anomaly angle as a function of the azimuth of the pair of stations. Here we sum the contribution of the 72 sources. CCTs stacked à Green's tensor.

Change of the sign of polarisation anomaly near 0.20 Hz

Displacement of the maximum of polarisation anomaly

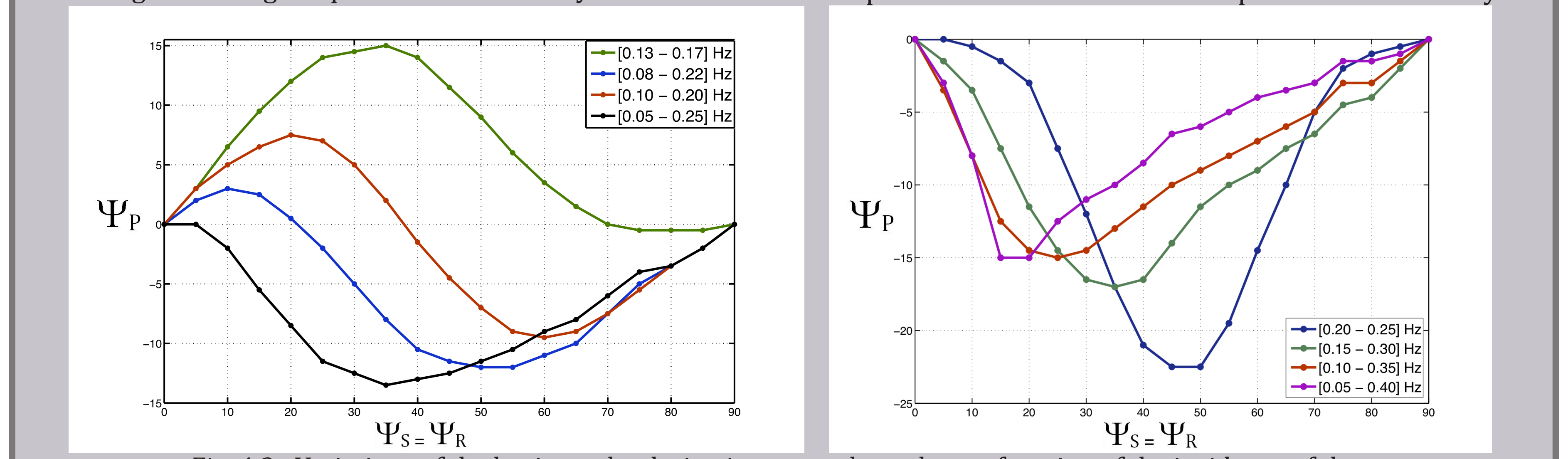

Fig. 4.3 : Variations of the horizontal polarization anomaly angle as a function of the incidence of the point source, for different frequency bands admitting the same central frequency.

5- CONCLUSION

The noise cross-correlation method is a consistent method for monitoring the crustal properties changes, throughout seismic cycles, as seimic anisotropy that is related to cracks distribution.

The results of synthetic experiments showed that the variation of polarization anomaly is complex and depends on many parameters as the configuration of the pair of stations, the amplitude of anisotropy and the frequency band of the signal.

Therefore, it is now possible to explain the large, rapid and very localized variations of surface waves horizontal polarization observed by Durand et al. (2011) during the Parkfield earthquake of 2004.

A current work consists of applying this method on the data of the Iwate-Miyagi earthquake (14 June 2008 - Mw=7.2) then on the 2011 Tohoku earthquake.

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