

# **Rotational Signals In The** P Coda

#### Introduction

The collocated observations of rotations around a vertical axis and translations obtained by a 4xtm ring laser and traditional broad band seismometer accently opened opportunities to find out additional information that may not be contained in classical three-component recordings. By investigating the cross correlation between transverse acceleration and rotation rate around a vertical axis we recognized that there is significant rotational motion component in the P coda of seismic signals. Theoretically, in spherically symmetric isotropic media we should not observe a vertical component of rotation before the onset of SH waves. Two possible not observe a vertical component of rotation before the onset of SH waves. Two possible explanations for this phenomenon are: (1) Till of the Earth's surface caused by Naves polluted the ring laser measurements; (2) P-SH converted energy (because of 3D effects) close to the receiver. In this study, till in the P coda of the seimic signal as well as its effects on the Ring Laser records have been calculated from translation data of a 3-component-seismometer. These estimates indicate that the P coda of the due to both P-SH scattering and ring laser. The estimates indicate that the A code rotations are due to both P-SH scattering and ring laser and the thereby separating out the SH contribution in the scattering field.

Keywords: cross correlation, transversal acceleration, rotation, tilt, tilt coupling, scattering

#### Observations

Figure 1 & 2: Observations of translational and rotational ground motions induced by earthquakes. Two Inguer 1921. Constructions of trainatourus and orbanolar global includes a functional plotting the set of the period implies that the P coda rotations are predominantly in the high frequency range. Left: Hokkaido event 25/09/2003, M8.3; Right: Sumatra event 26/12/2004, M9.3.

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Figure 4. 5 & 6. Top three traces: Vertica acceleration, transverse acceleration and rotation rate, respectively. The fourth trace: zero lag normalized cross correlation coefficients calculated for time windows of 2 s between rotation rate and transverse acceleration after applying high pass filter with cut-off period 1 s. Bottom: the correlation coefficients as a function of time and cut-off period (engrh of siling) time window histor as long as the high pass out off period applied before correlating). Following the direct P – wave. This correlation smears out and becomes less pronounced with increasing period, while the corresponding correlation of SH – type signals and Love waves increases with period. transverse acceleration after applying high pass

The observations indicate that there are significant rot al motion components in the P coda. The user values instruct that there are significant rotational mount components in the P coda. Theoretically, in spherically symmetric isotropic media we should not observe vertical component of rotation before the onset of SH waves. So the main questions to additess here are: What is the cause of rotational motions in the P coda? Can we extract additional information of the wave field from this pheno

#### Possible Causes - Tilt Coupling

The Sagnac equation (e.g., Schreiber et al., 2005) reads :

 $\Delta f = \frac{4\mathbf{A}}{\lambda P} \left[ \dot{\Omega}_{E0} \cos(\alpha_1) + \dot{\Omega}_Z \cos(\alpha_2) + \dot{\Omega}_{NS} \cos(\alpha_3) + \dot{\Omega}_{EW} \cos(\alpha_4) \right]$  $\Rightarrow$ (1)

Here  $\Delta f$  is the Sagnac frequency the ring laser sensor records; A and P are area and perimeter of the ring laser,  $\lambda$  is laser wavelength;  $\Omega_{a,b}$  is rotation rate of the Earth around its rotation axis;  $\Omega_{a}$  is earthquake-induced rotation rate around the ventical axis;  $\Omega_{a}$  and  $\Omega_{a,p}$  are till traces around Ns and  $\Omega_{a,p}$  are till traces around Ns and  $\Omega_{a,p}$  are till axis around Ns and  $\Omega_{a,p}$  are till axis around Ns are angles between the normal unit vector of the frame laser and unit beso vectors of the Earth's rotation axis, vertical axis and horizontal axis in NS, Store NS are around the vector of the Earth's rotation axis, vertical axis and horizontal axis in NS. directions at ring laser location, respectively. These angles can be calculated if tilt components and latitude of ring laser position are known.

The rotation rate presented in the observation ignored a possible tilt contribution in equation (1). In fact, when seismic waves arrive they do generate tilt at the Earth's surface (i.e. rotational motions around the horizontal axes). This will pollute the ring laser measurements through changes of  $\alpha$ ,  $\alpha$ ,  $\alpha$ , and  $\alpha$ . This phenomenon is called "tilt coupling". Since the mechanical instrument was made as rigid and stable as possible, two possible explanations for the P coda re: 1) Tilt coupling; 2) 3D effects (P-SH scattering close to the receiver location to about the right part of the relation of the relation of the relative robuston in the relative robuston is a second se





Figure 8. Top: theoretical tilt; Middle and bottom: calculated rotation rate due to the top theoretical tilt in different directions. Middle: effects of NS tilt; Bottom: effects of EW tilt.



### Li's tilt and tilt coupling in the P coda rotation

To estimate whether the tilt coupling contributes to the observed rotational signal in the P-coda, tilt data is indispensable. However, tiltmeters - sensors that measure the horizontal components of rotational motions at the Earth's surface - are sensitive to translational motions, and thus do not provide the correct signals of tilt. A solution for getting tilt in P coda here is L's method (Li et al., 2001), an approach that allows to obtain tilt (under cortain conditions) from translation data.

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Figure 12. Hokkaido event 25/9/2003, M8.3. (From top to bottom):  $V_2$ : vertical component of velocity, A<sub>7</sub>: transverse acceleration;  $C_{m_1}$ : calculated tilt coupling;  $C(\Omega_{T_m})$ A<sub>7</sub>): Normalized cross correlation roefficients between O. and A : O. 2 efficients between Q<sub>1</sub> and A<sub>1</sub>; Q<sub>1</sub> ertical rotation rate after subtracting tilt coupling;  $C(\Omega_z - A_\tau)$ Normalized cross correlation coefficients between  $\Omega_2$  and  $A_T$ .

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Figure 13. Hokkaido event 25/9/2003, M8.3. (From top to bottom):  $A_{T}$  transverse acceleration; N: Random noise which has no similarity with  $A_{\tau}$  and its maximum amplitude is the same with that of the rotation rate;  $C(N-A_{\tau})$ : Normalized cross correlation coefficients between cross correlation coefficients between N and A<sub>7</sub>,  $\Omega_{TH}$ : the calculated tilt coupling;  $C(\Omega_{TH}, A_7)$ : Normalized cross correlation coefficients between  $\Omega_{TH}$  and  $A_7$ ,  $N+\Omega_{TH}$ ; Random noise N added  $\Omega_{TH}$ ;  $C(N+\Omega_{TH}, Random noise N added <math>\Omega_{TH}$ ;  $C(N+\Omega_{TH}, Random noise N)$ elation coefficients between nes cor N + Ω<sub>Tilt</sub> and A<sub>T</sub>

We cannot reproduce the increase in correlation between transverse acceleration and rotation rate with tilt-coupling. This result indicates the negligible contribution of tilt coupling in the observed P coda rotatio

#### Conclusions

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- The main cause for observed P coda rotation is due to 3D effects (P-SH scattering)
- The observations may provide a means to estimate near receiver P-SH scattering in a quantitative way, thereby separating out SH motions from the scattering field.
- We will now proceed to quantify the observed P-SH scattering with 3D modeling

Schreiber, GEOserso

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