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Rotational Motions From Teleseismic Events Modelling and Observations

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Elitenetzwerk Bayern

Abstract

Currently only ring lasers technology is capable of recording rotational motions resulting from earthquakes with a sensitivity and frequency band that are interesting for broadband seismology. One of those instruments is located at the Geodetic observatory in Wettzell/Germany. Here we present theoretical studies of rotational motions simulated with different Earth models and comparisons with several observations at the Wettzell ring laser. The 3-D global simulations were performed with the Spectral Element Method (Komatitsch and Tromp 2002a,b), that was modified to also allow the output of rotational seismograms. The Earth models used in these simulations range from simple radially symmetric ones, such as PREM, to more complex models including 3D velocity structures, attenuation and geometric effects like topography and bathymetry. Thus, by comparison of the theoretical rotation rates with the ring laser data we show how the results converge to the observed rotation rates when using more realistic Earth models. In a second step we compare rotation rates to the transverse component of translational acceleration both obtained from simulations with 3D velocity structures in crust and mantle. As expected from theory - under the assumption of plane wave propagation - those two signals should be in phase and scale linearly with the phase velocity. Using this relation, it is possible to determine the local phase velocity of transverse signals from collocated measurements of rotations and transverse accelerations.

Why Rotational Motions

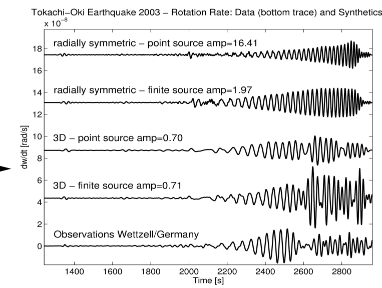
In the last decades it has been noted [e.g., Aki & Richards 2002] that the measurement of rotational motions in seismology is needed in addition to the classical translational motions. The possible applications of rotation rate measurements are still being explored. One such application is the approximation of horizontal Love wave phase velocities and phase velocity dispersion relation at a single station (i.e., by a collocated measurement → no seismometer array is needed) [Igel et al. 2004]. Equation (1) shows how to derive this, assuming Love waves polarized in the y plane and travelling in x direction. $\dot{v} = \frac{\partial v}{\partial t}$ is the acceleration, Ω is the vector of rotation rate, and c is the phase velocity.

$$\begin{aligned} v(x,t) &= v_y sin(k_x x - \omega t) \\ \dot{v}(x,t) &= -v_y \omega cos(k_x x - \omega t) \\ \Omega_z(x,t) &= -v_y \frac{k_x}{2} cos(k_x x - \omega t) \\ \frac{\dot{v}}{\Omega_z} &= \frac{2\omega}{k_x} = 2c \end{aligned} \quad (1)$$

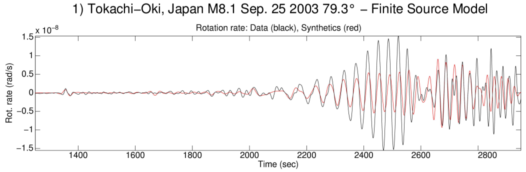
Observation of rotational motions may also be interesting in the near field of earthquakes [Takeo 1998]. There are ongoing plans to use ring laser technology for the study of source dynamics in the Los Angeles Basin, California. This will be the testing ground of the latest generation of ring lasers, the GeoSensor. The GeoSensor is the first purpose built seismological ring laser gyroscope.

Modelling

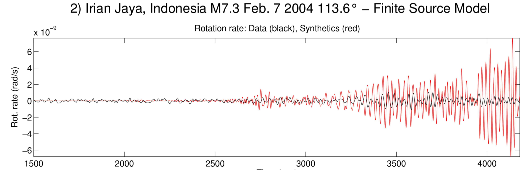
For the first simulations with the spectral element method we used different models - from a simple radially symmetric velocity structure with a point source to complex models incorporating 3D velocity models (S20RTS [Ritsema et. al 2000]), topography/bathymetry, anelasticity and the effects of Earth's gravity and rotation. The resulting rotational motions at station Wettzell/Germany from four of those simulations for the Sep. 25 2003 Tokachi-Oki earthquake are shown to the right together with the real data of the ringlaser. It can be seen that the fit to the data increases rapidly with model improvements. All synthetic traces have been scaled to match the S-wave amplitude (first onset shortly before 1400 s) and the factor *amp* is the ratio of synthetic to real data.



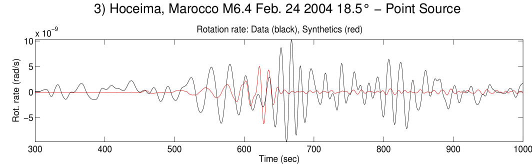
1) Tokachi–Oki, Japan M8.1 Sep. 25 2003 79.3° – Finite Source Model



2) Irian Jaya, Indonesia M7.3 Feb. 7 2004 113.6° – Finite Source Model



3) Hoceima, Marocco M6.4 Feb. 24 2004 18.5° – Point Source



On the left are shown the simulated rotational motions (red) of three earthquakes that were recorded with the ring laser (black) using the best fitting model from above (3D velocity structure, topography/bathymetry, anelasticity, transverse isotropy, Earth's rotation and gravity field). The difference in fit can be explained by the different magnitudes (signal/noise in ring laser data), different epicentral distances (sensitive to different model depths) and different source models.

Acknowledgements

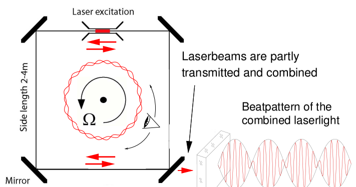
This work is supported by the "Elite-Netzwerk Bayern" as well as by the German Ministry of Research and Education (BMBF) and DFG grant: 03F0325C (publication no. GEOTECH-84). Furthermore B. Schuberth has partly been supported by the KONWIHR project. We are grateful to D. Komatitsch and J. Tromp for providing their SEM code SPECFEM3D and to Ji Chen for providing the finite source parameters for the Tokachi-Oki and Irian Jaya earthquakes. We acknowledge the contributions of the Bundesamt für Kartographie und Geodäsie (BKG) towards the installation and operation of the ring laser at the geodetic observatory Wettzell. Many thanks to the Munich Leibniz Computing Centre for providing access to their supercomputing facilities.

Observations - Measurement Principle

Sagnac (1913): Two counter-propagating light beams within a ring shaped active laser cavity of an interferometer experience a path length difference when the instrument is rotating with respect to the inertial frame.

The difference in effective path length for the two beams results in a beat frequency δf (the *Sagnac-Frequency*) by superposition of the two beams. We have $\delta f = \frac{4\,A}{\lambda P} \mathbf{n} \cdot \mathbf{\Omega}$, where A is the area covered by the instrument, P the perimeter of the instrument, λ the wavelength $\mathbf{n}$ the surface normal, and $\mathbf{\Omega}$ the vector of rotation rate. A He-Ne-gas laser with $\lambda = 633\,\text{nm}$ is used for the gyroscope at Wettzell ($A = 16\,\text{m}^2$) and the resulting Sagnac-Frequency for Earth's rotation is $\delta f = 438.6\,\text{Hz}$. The smallest rotation rate measurable amounts to about $10^{-10}\,\frac{\text{rad}}{\text{s}}$.

This instrument offers a wide dynamic range of operation reaching from geophysical signals of $T \leq 100\,\text{ms}$ to $T > 24\,\text{h}$. This range comprises transient excitations by local and distant earthquakes as well as very small changes of orientation by e.g. ocean loading.

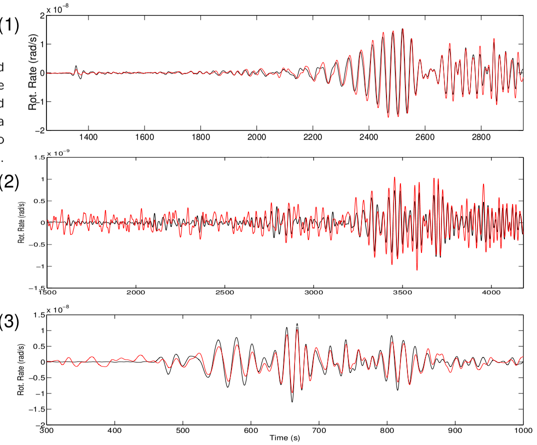


Please also check poster S31B–1058 for studies on array derived rotational motions!

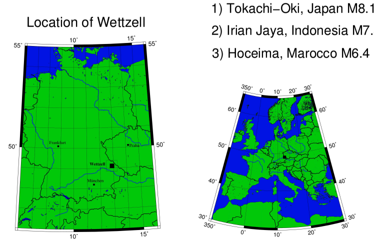
Observations - Data from Wettzell/Germany

On the right the ring laser measurements of rotational motions induced by teleseismic earthquakes (red) are presented together with the transverse component of accelerations derived from a broadband instrument located 300 m away from the ring laser (black). The translational velocity data were rotated to the great circle path and differentiated with respect to time. All data have been lowpass filtered down to a period of 20 seconds. This period was chosen to be consistent with the simulated data.

1) Tokachi–Oki, Japan M8.1 Sep. 25 2003 79.3°
2) Irian Jaya, Indonesia M7.3 Feb. 7 2004 113.6°
3) Hoceima, Marocco M6.4 Feb. 24 2004 18.5°

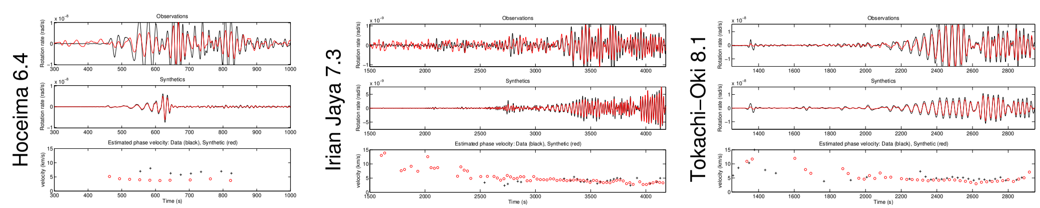


Location of Wettzell



Estimation of Phase Velocities - Observations and Simulations

As shown in Equation (1) it is theoretically possible to derive the horizontal phase velocity at a specific location with to collocated measurements of transverse acceleration and vertical rotation rate. Applying this to the real data observed at Wettzell we can get estimates of the horizontal phase velocity as a function of time using a 30 s sliding window of the two components (upper seismograms). The same is done for the simulated data (middle). The lower graphs show the derived phase velocities for the observed data (black crosses) and the synthetics (red circles).



Conclusions

- Seismic rotations (vertical component) are a new consistent observable for seismology
- Estimates of horizontal phase velocities from collocated measurements of rotations and translations are compatible with theoretical studies
- Observations of rotations allow new processing techniques with the potential for complementary information on structure and source

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