Summary

Surface acceleration caused by the radial modes depends only on the $M_r$ component of the centroid moment tensor and on its depth assuming the isotropic component to be negligible. The $Q_k$-mode amplitude enables one to obtain a relatively narrow interval of $Q_k$ values, whereas $S_k$-mode amplitude is more sensitive to centroid depth. We have used these facts to analyze the 2010 Maule (Chile) $M_{W}$=8.8 and 2011 Tohoku (Japan) $M_{W}=9.1$ earthquakes using PREM. Superconducting gravimeter data available within the framework of the Global Geodynamic Project reveal that the $M_r$-components of these earthquakes should be in the interval 0.95–1.15 $10^{22}$ Nm (Maule) and 1.50–1.75 $10^{22}$ Nm (Tohoku), respectively.

We re-evaluated the modal quality factors $Q_k$ needed to obtain constraints on $M_r$ self-consistently. The joint analysis of gravity data from the Maule and Tohoku events yields $Q = 5500 \pm 140$ for the $S_0$ mode and $Q = 2000 \pm 80$ for the $S_0$ mode. We were not able to determine the quality factor of the $S_0$ mode with an accuracy sufficient to allow meaningful constraints ($Q = 1120 \pm 270$), details in Zábranová et al. (2012b).

We also used the $S_0$ and $S_0$ modes of the 2012 Sumatra double-event $M_{W}=9.6$ and 8.2 to obtain constraints on the $M_r$ components of these earthquakes. However, records of these events are not well suited for determination of the quality factors.

Superconducting gravimeter data

The data for the Maule and Tohoku earthquakes are freely available on the Global Geodynamic Project web pages. Moreover, we have only three records of the Sumatra earthquakes from Poznań and Weitstetten stations. A high-pass Butterworth filter (above 0.1 mHz) was used to remove local tides from raw gravity data (sampled at 1 s) corrected for atmospheric effects using locally recorded atmospheric pressure data and a nominal admittance factor of -3 nm/s²/hPa.

Method and Synthetic calculations

The acceleration of a spherically symmetric, non-rotating, anelastic Earth excited by a moment-tensor source $M$ is given by a superposition of spherical and toroidal modes,

$$a_{n_1,n_2}(x,y,z)=\sum_{\mu=0}^{\infty}C_{n_1,n_2}^{\mu}(\mu,\omega)M_{\mu}(\omega)P_{n_1,n_2}^{\mu}(\theta,\phi)$$

where the upper 3-km layer of water is replaced by a 1.2-km-thick rock-layer with the same mass, by means of our pseudospectral finite-difference matrix-eigenvalue approach (Zábranová et al., 2009, 2012a).

If non-spherical corrections due to the rotation and elasticity are considered in this degree-zero case, only the frequencies of the modes are slightly shifted. Moreover, Aisat et al. (2007) showed that for a three-dimensional rotating elastic Earth model, the difference between theoretically predicted minimum and maximum amplitudes of the $S_0$ mode reaches only 2%; therefore, we assume that excitation is almost independent of source-station horizontal geometry, and we averaged observed signals from different stations to suppress the noise.

2010 Maule earthquake

The triangles represent the SG sites used in this study. Star cross are employed for both events, yellow only for the 2010 Maule earthquake and yellow only for the 2011 Tohoku earthquake.

Quality factors of radial modes

We analyzed gravity data from the Maule (left panels) and Tohoku (right panels) earthquakes (32- and 19-days long records, respectively, for 0S0, 13-days long records for 1S0 and 5-days long records for 2S0) using several shifted time windows and the fact that

$$Q^{-1} = T/2\pi\Delta t \ln (A_{n_1,n_2}(t_2)/A_{n_1,n_2}(t_1))$$

for each record, where $\Delta t$ is a time period of a mode, $\Delta t_{\text{fr}}$ is time shift from the origin time and $\Delta t_{\text{fr}}$ is time shift between time windows used to calculate spectral amplitudes $A_{n_1,n_2}$ and $A_{n_1,n_2}$. We have used FFT filter for and Fourier transform were applied to 600- and 300-hour records.

References

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2011 Tohoku earthquake

2012 Sumatra double earthquake

Constraints on the $M_r$ components of the 2012 Sumatra double-event (for several depths of the centroid) obtained from the 0S0 (solid line), 1S0 (dashed line) and 2S0 (dotted line). For each depth, the interval corresponding to one standard deviation of amplitude spectra and quality factors is drawn. Stars denote published point-source solutions (PS1, PS2 and PS3).

Vertical acceleration amplitude spectra of the modes $S_0$ and $S_0$ from the SG data (red - average of three records from Poznań and Weitstetten stations) and the three synthetics for the point-source (PS1, PS2, PS3). A Hann filter and Fourier transform were applied to 450- and 170-hour time series.