Excitation of the gravest modes of the Earth after the 2011 Japanese earthquake (Mw=9.0) and comparison with two other events: Sumatra-Andam (2004, Mw=9.2) and Chile (2010, Mw=8.8)

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After a major earthquake, the Earth rings like a bell, as shown by Figure 1. (see e.g. http://homepage.oma.be/mvc/osclibres/Free_Oscillations.ppt). Analyzing the spectrum of these oscillations allows one to learn about the Earth structure as well as on the focal mechanism of the earthquake. In particular, the overall amplitude depends on the magnitude and the relative amplitude of the different modes depends on the focal mechanism, the orientation of the fault plane and its depth.

Figures 2 and 3 show the spectra of time series from the superconducting gravimeter of Membach (eastern Belgium, data available on http://www.iris.edu/servlet/quackquery/budFileSelector.do, network “SG”). The times series used to calculate the spectra are 60 hours long and start 4 hours after the onset of 3 major earthquakes in Japan (11 March 2011, Mw=9.0), Chile (27 Feb 2010, Mw=8.8), Sumatra (26 Dec. 2004, Mw=9.2).

On Figure 3, one clearly sees multiplets on ${}_0S_2$, ${}_0S_3$ and ${}_0S_4$, caused by the Earth’s small departure from spherical symmetry, i.e. the Earth’s diurnal rotation, ellipticity and 3D structure. This phenomenon is similar to the Zeeman effect, splitting the spectral lines of atoms when placed in a magnetic field.

After giant earthquakes (Mw≥9.0) the balloon mode ${}_0S_0$, of which the attenuation is quite low, can be observed several weeks after the event; in other words the Earth will still be ringing at Easter. Figure 4 shows the time series from Membach after applying band pass filters to separate the ${}_0S_2$, ${}_0S_3$ and ${}_0S_0$ modes. ${}_0S_0$ dominates the time series one week after the earthquake; it will lose 90% of its initial amplitude on May 6 only!

Two toroidal modes ${}_0T_3$ and ${}_0T_4$ slightly appear; they should not for a symmetric non rotating Earth (there are only horizontal components) but due to mainly the Coriolis effect, a vertical component is present and detected by the gravimeter.

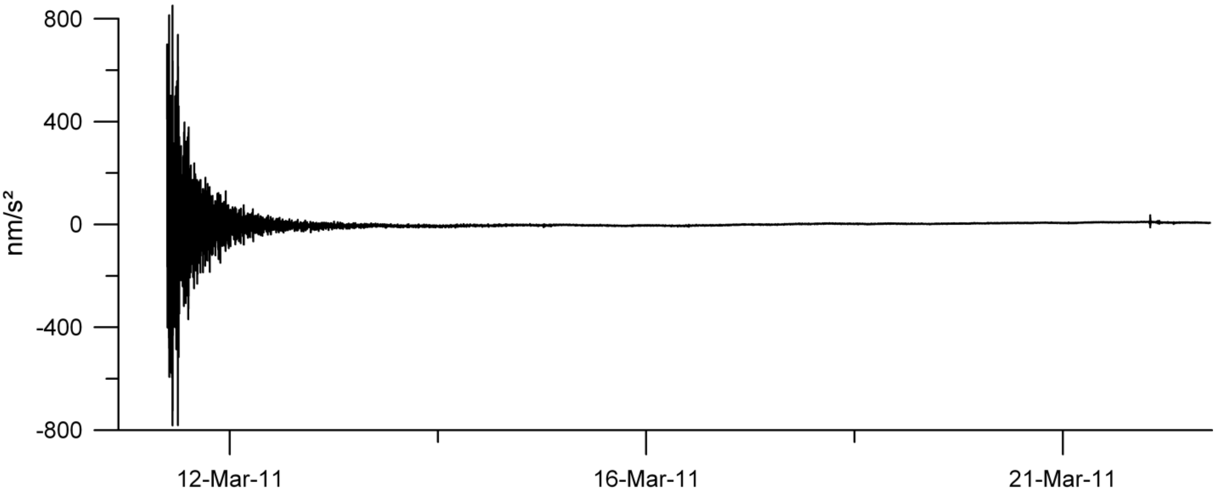

Figure 1. Time series of the superconducting gravimeter GWR-C021 of Membach, after the Mw=9.0 Tohoku earthquake. Data are low pass filtered at 200 s period.

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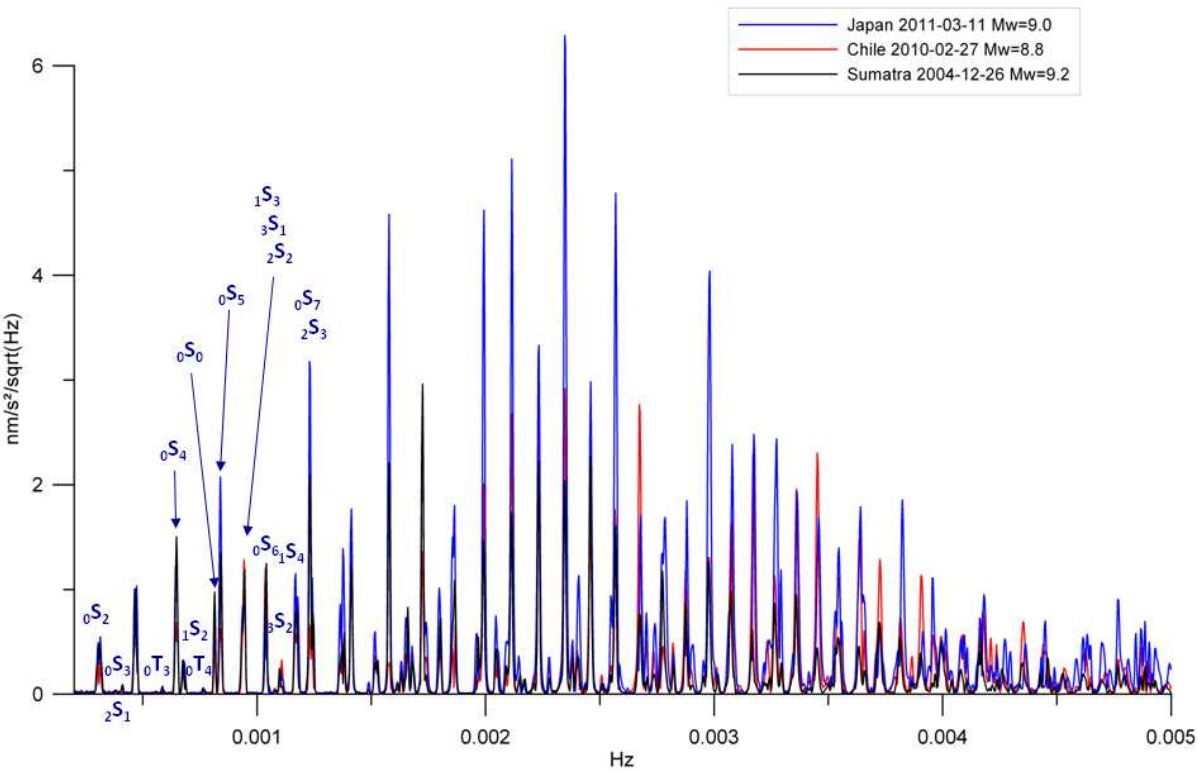

Figure 2: Spectra of the times series from the superconducting gravimeter of Membach GWR C021. This shows the excitations of the different eigenfrequencies of the Earth after 3 different earthquakes, for frequencies shorter than 5 mHz (or periods longer than 200 seconds). The “football” mode $_0S_2$ is the slowest one (period ~54 minutes).

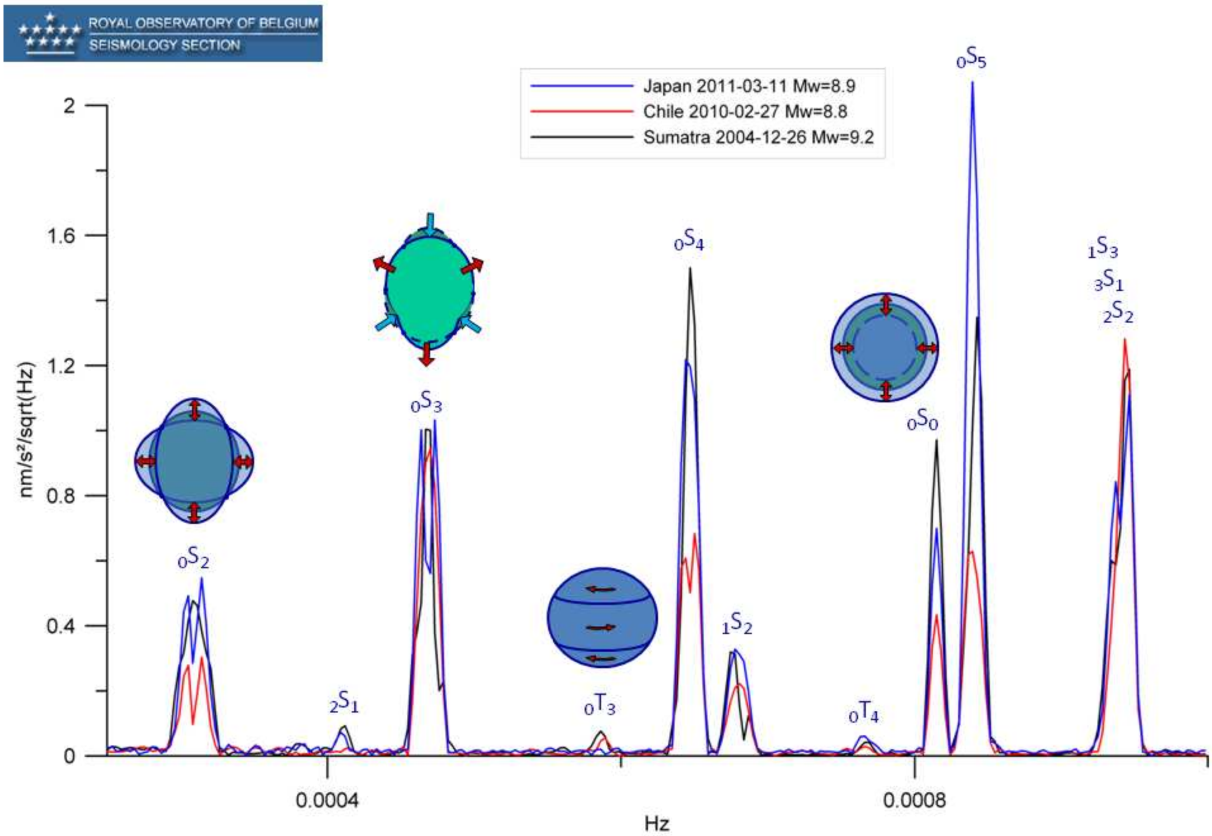

Figure 3: Same as Figure 2 but for the gravest modes (frequencies shorter than 1 mHz or periods longer than 1000 seconds).

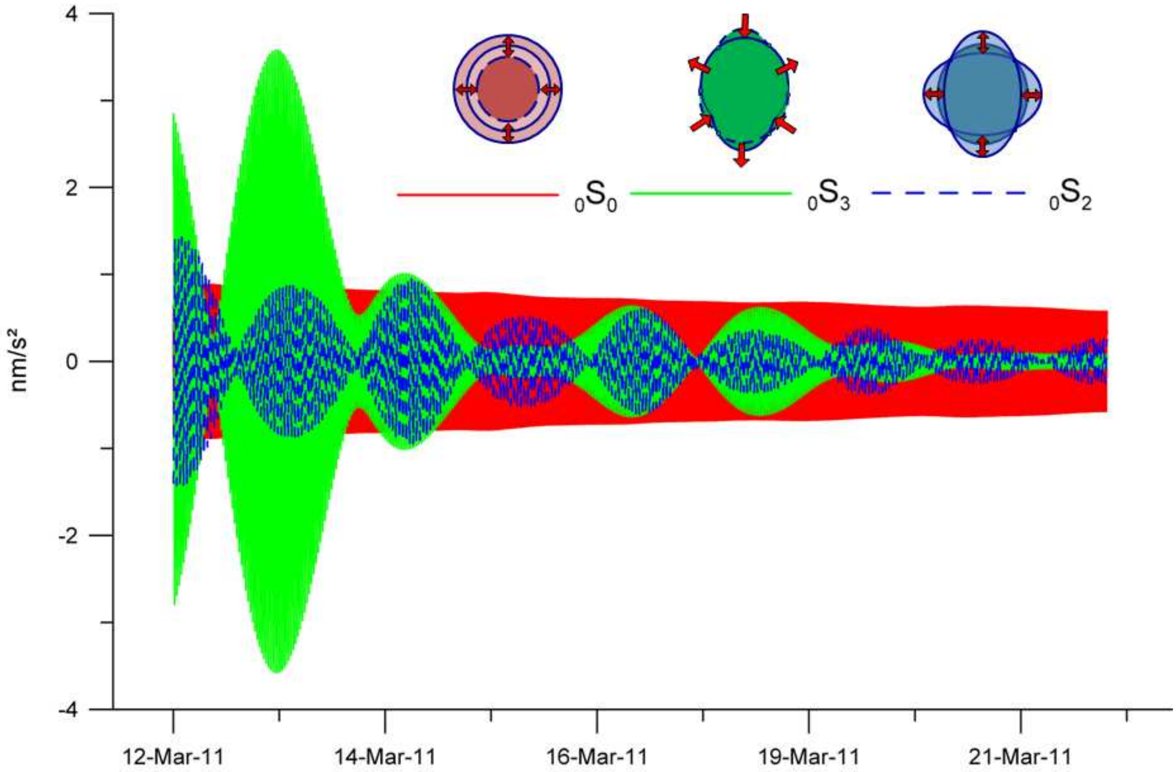

Figure 4: Times series from the superconducting gravimeter at the Membach station, after applying band-pass filters to separate the modes ${}_0S_2$ (period ~54 min), ${}_0S_3$ (period ~35 min), and ${}_0S_0$ (period 20 min). Although ${}_0S_0$ was lesser excited at the time of the earthquake, it is much lesser attenuated than the other modes and eventually dominates the recording, losing 90% of its initial amplitude early in May. The ${}_0S_2$ and ${}_0S_3$ modes are much more attenuated and the beats are due to the interferences between the different multiplets (frequencies very close to each other, as shown by the spectrum on Figure 3).