Realistic Long Period Synthetic Seismograms, using Normal Modes of a 3D Anelastic Elliptic Rotating Earth

Raphaële Millot-Langet, Eric Clévédé, Philippe Lognonné

e-mail : rmillot@ipgp.jussieu.fr

Laboratoire de Sismologie Globale, Département de Géophysique Spatiale et Planétaire

Institut de Physique du Globe de Paris

CONTEXT

As of today, we know a lot about the Earth's spherical structure and we start to accumulate a lot of information on its lateral heterogeneities. Still, it remains a challenge to compute realistic synthetic seismograms in such a model. And if one wants to refine our knowledge on elastic heterogeneities and most of all on anelastic heterogeneities, still poorly resolved, one needs such a tool. Normal modes of the Earth are a good candidate to help in constraining the deep structure, especially low tones which have a sensitivity down to the CMB. But these modes are also very sensitive to various effects, such as rotation, ellipticity, 3D structure, and you need a theory capable of modelling all these effects.

METHOD

We here present the results of a direct computation of the Earth's normal modes that takes into account its rotation, ellipticity, 3D elastic structure and 3D anelastic structure. We use non-asymptotic perturbation theory (from Quantuum Mechanics) up to the 3rd order to compute the eigenfrequencies and eigenfunctions of the perturbed model. We are then able to compute synthetic seismograms which have a real Fresnel zone (off-path sensitivity). Since we are interested in low tones, the modal approach is relevant.

NORMAL MODES

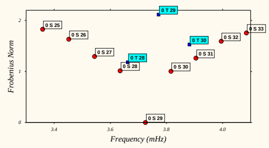

Figure 1 : Coupling strength between neighbouring modes due to rotation, ellipticity, 3D elastic and anelastic structure. **frob** $= -\log \| M_{couplage} \|$.

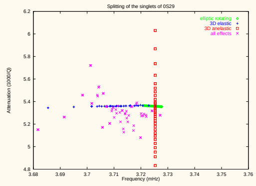

Figure 2 : Frequency and attenuation splitting of mode 0S29 due to the separated effects of rotation, ellipticity, 3D elastic and anelastic structure.

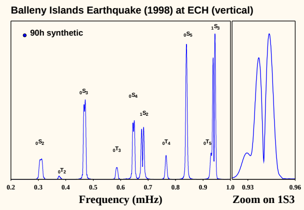

Figure 3 : Spectrum of a synthetic seismogram from normal modes computed with the only perturbation of rotation and ellipticity. This includes spheroidal/toroidal coupling, and this is why toroidal modes such as 0T2, 0T3 ... can be observed on the vertical component. Note the strong splitting effect on modes 0S4, 1S2, 1S3.

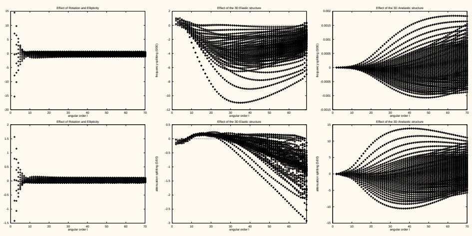

Figure 4 : The three top figures show frequency splitting pattern (in $^{\circ}/_{\circ\circ}$) due respectively to rotation and ellipticity, 3D elastic structure and 3D anelastic structure. The lower ones show the same results but for the attenuation splitting due to these effects.
Note that rotation and ellipticity play a major role for low angular orders, that elastic structure mainly splits frequency, and that the strongest effect of the 3D anelastic structure is on the attenuation of the modes.

SYNTHETIC SEISMOGRAMS

This is the result of a synthetic experiment. We have computed fundamental spheroidal modes up to 7 mHz ($l = 65$), considering along-branch coupling up to $\Delta l = 8$. We have calculated 2 sets of modes : one using 3D elastic model SAW12D and one using 3D anelastic model QR19. We have thus calculated 3 different synthetics for each station on a profile : spherical, 3D elastic and 3D anelastic.

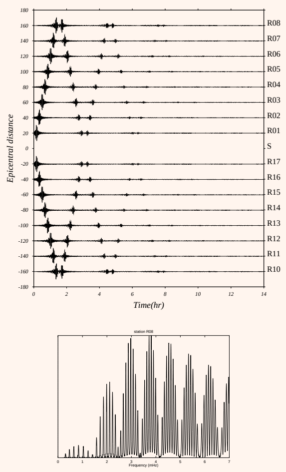

Figure 5 : The upper figure represents the spherical synthetic seismograms for the profile. All amplitudes have been normalized. The lower figure shows a spectrum of the R08 trace.

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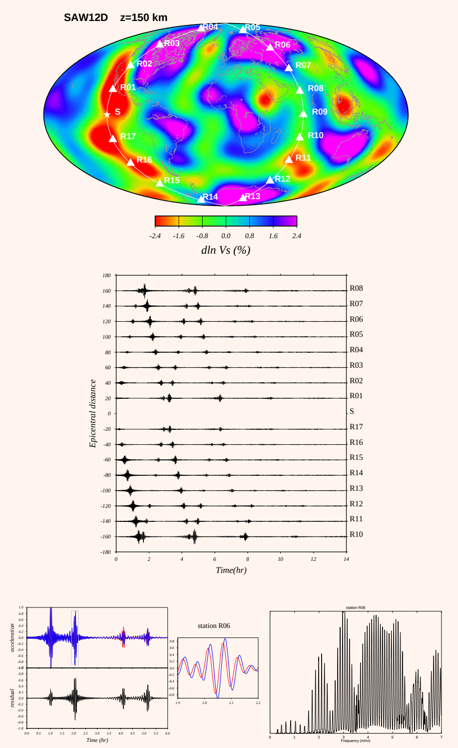

Figure 6 : ELASTIC STRUCTURE
The top figure represents a map of the 3D elastic model SAW12D at a depth of 150 km. The middle figure shows the residuals between the 3D elastic seismogram and the spherical one, along the profile. Amplitudes were normalized by the spherical trace before calculating the residual. No amplification factor has been applied.
On the lower left figure, we focus on station R06. The red synthetic is the spherical one and the blue corresponds to the 3D elastic case. The main effect of the elastic structure is (as expected) a phase shift. On the lower right figure is a spectrum at station R08. Note the major difference in shape with the spherical spectrum.

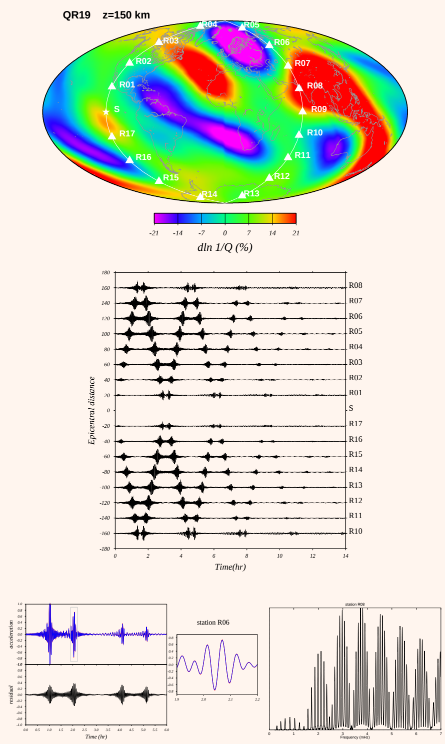

Figure 7 : ANELASTIC STRUCTURE
Same as previous figure but for the 3D anelastic model QR19. An amplitude factor of 30 was applied to the anelastic residuals. On the lower left figure, it is obvious that the 2 seismograms are in phase and that the main effect of the 3D anelastic structure is (as expected) an amplitude effect. It is of the order of 1%. On the lower right figure is the corresponding spectrum, very similar to the spherical one.