# Supplementary Information for:
# Global 3D model of mantle attenuation using seismic normal modes

Sujania Talavera-Soza[1*], Laura Cobden[1], Ulrich H. Faul[2,3], Arwen Deuss[1],

[1]Department of Earth Sciences, Utrecht University,
[2]Earth Atmospheric and Planetary Sciences, Massachusetts Institute of Technology
[3]Research School of Earth Sciences, Australian National University

*To whom correspondence should be addressed; E-mail: s.a.talaverasoza@uu.nl

## 1 Robustness tests for splitting function observations

In order to assess the potential of measuring mantle anelastic structure and the robustness of $d_{st}$ measurements, we designed a set of tests[1]. These tests evaluate our ability to recover 3D anelasticity splitting functions from synthetic data, as well as the dependence of the $d_{st}$ values on potential uncertainties or systematic bias in the earthquake magnitudes.

In our first test[1], we evaluate the ability of our method to recover anelastic splitting functions from synthetic spectra, when the $d_{st}$ amplitude is much smaller than the $c_{st}$ amplitude. We use the elastic splitting function predictions of the $v_s$ mantle model S20RTS[2], together with three different 3D anelastic splitting functions obtained by scaling S20RTS using the relationship $\delta Q_{\mu}^{-1} = R_q \, \delta v_s / v_s$ and $R_q = -0.2, 0, 0.2$. We follow the inversion steps previously outlined. In all cases we are able to recover both the input elastic and input anelastic splitting functions. In the particular case of the zero 3D anelastic input model (i.e. $R_q = 0$), our recovered measured synthetic $d_{st}$ coefficients are non-zero, but negligible. Furthermore, the amplitudes of the recovered anelastic splitting functions are only slightly smaller (less than 10%) than the amplitudes of the input anelastic splitting functions.

Thus, the effect of the damping in the inversion on reducing (and potentially underestimating) the anomalies of the recovered splitting functions is minimal. In addition, we also tested a 3D input anelastic splitting function that holds no correlation to the elastic splitting function predictions of S20RTS, and again we are able to recover both the input $c_{st}$ and $d_{st}$ coefficients.

In our second test[1], we investigate the effect of the earthquake magnitude on the anelastic splitting function measurements. From previous studies[3,4], we know that unaccounted 3D mantle elastic heterogeneity may alter the scalar moment $M_0$ of the moment tensor solution by up to 10%, when compared to the solutions published in the Global Centroid Moment Tensor database (www.globalcmt.org). We first introduce $M_0$ variations that are random and do not take into account the specific location of the earthquakes. To generate the synthetic data, we vary the $M_0$ of all earthquakes used in this study randomly between $\pm 2\%$ and $\pm 10\%$, which is much larger than the reported uncertainties. We again include the previously mentioned zero 3D anelasticity model, as well as a globally correlated and an anti-correlated model to calculate the synthetic spectra. We then use the unaltered $M_0$ values when measuring the elastic and anelastic splitting function coefficients. We find that when 3D anelastic structure ($R_q \geq |0.1|$) is present, we are able to recover the input $d_{st}$. At the same time, it is important to note that in our tests with zero 3D anelasticity input ($R_q = 0$), we retrieve $d_{st}$ structure that is non-zero and branch consistent, but again negligible.

Next, we explore earthquake location dependence. To evaluate location dependent $M_0$ variations, we include a random increase in $M_0$ magnitude for earthquakes located near oceanic ridges or trenches and a random $M_0$ decrease for continental earthquakes, while oceanic floor earthquakes are given either a random increase or decrease in $M_0$ magnitude[4]. When taking into account location dependent $M_0$ perturbations in combination with a zero 3D $Q_\mu^{-1}$ input model, we again measure 'ghost' structures in a branch consistent manner. The size of the $d_{st}$ ghost patterns is small, in most cases less than $5\%$ of the $c_{st}$ values.

In our last test[1], we investigate if our 3D anelastic measurements are not the result of a local minimum, and if there is enough information in the data to move away from the starting model and not stay too close to it in the inversion. In order to do this, we test the effect of different starting models on our anelastic splitting function measurements. We find that using an anelastic starting model either correlated ($R_q = 0.2$) or anti-correlated ($R_q = -0.2$) to the 3D elastic model S20RTS or even PREM, does not influence our final $d_{st}$ observations. We always arrive at the same $d_{st}$ coefficients within the measurement's uncertainties. This means that we do not need to include any a priori assumptions about the relationship between elastic and anelastic structure in order to measure 3D anelasticity, and therefore we always start our $d_{st}$ measurement from PREM.

# References


1. Talavera-Soza, S. *Observing seismic attenuation in the Earth's mantle and inner core using normal modes*. Ph.D. thesis, Utrecht University (2021).

2. Ritsema, J., van Heijst, H. J. & Woodhouse, J. H. Complex shear wave velocity structure imaged beneath Africa and Iceland. *Science* **286**, 1925–1928 (1999).

3. Hjörleifsdóttir, V. & Ekström, G. Effects of three-dimensional Earth structure on CMT earthquake parameters. *Phys. Earth Planet. Inter.* **179**, 178–190 (2010).

4. Karaoğlu, H. & Romanowicz, B. Inferring global upper-mantle shear attenuation structure by waveform tomography using the spectral element method. *Geophys. J. Int.* **213**, 1536–1558 (2018).