Comment on "Thirty Years of Confusion around 'Scattering Q'?" by Igor B. Morozov

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In his Opinion article, "Thirty Years of Confusion around 'Scattering Q'?" in *SRL* **80** (1) (hereafter referred to as M09), Igor Morozov briefly reviews seismic attenuation studies and criticizes virtually all of them as being based on improper model parameterization and interpretation of results. Morozov is correct in stating that many attenuation studies quantify the effect of wave front expansion on amplitude measurements by the "geometrical spreading term (GST)," which he calls $G_0(t)$ (Equation 1 of M09). However, it is not true that the subsequent attenuation measurements are always conducted using the parameterization of seismic quality factor (Q). To the contrary, two quantities have been used for the parameterization: 1) the attenuation coefficient, defined as the amplitude reduction per unit distance (*e.g.*, Dwyer *et al.* 1983), and 2) Q, defined as the inverse of energy loss per wavelength multiplied by the angular frequency. The two quantities are interchangeable and neither implies a favored physical mechanism of attenuation. Some authors further assume a power-law frequency dependence of $Q(f) = Q_0 f^{\eta}$. The interpretation of the measured Q in terms of the intrinsic or scattering Q, caused by the inelasticity or heterogeneity of the Earth, is less common and is typically discussed together with the uncertainties.

Morozov argues that the frequently observed frequency dependence of Q is dubious because of the non-uniqueness of fit of amplitude data. Regrettably, he ignores numerous published laboratory measurements of frequency-dependent intrinsic Q of crustal/upper mantle materials (*e.g.*, Faul *et al.* 2004). Similarly he ignored synthetic studies that show that Q measured using the crustal guided *Lg* waves can be frequency dependent even if the crustal layers all have frequency-independent intrinsic Q (Mitchell 1991).

Morozov criticizes the use of a scattering Q, through the form of $e^{-\pi f t/Q_s(f)}$, to quantify the scattering loss of a heterogeneous Earth medium. He then proposes to replace the commonly used GST ($G_0(t)$) by a new form, $G(t) = G_0(t)e^{-\gamma t}$ (note a typo of missing "t" in M09 when $G(t)$ is defined). Will the use of the new GST improve our physical understanding of seismic attenuation? The original $G_0(t)$ is typically calculated for seismic waves in a 1D velocity structure that best approximates the true structure. The 1D calculation is precise for any body, surface, refracted, or guided wave. Let us consider three scenarios: 1) The 1D structure well approximates the true structure on all scales. By compensating $G_0(t)$ in the data, one can obtain good measurements of Q, which is an intrinsic property of the inelastic Earth. 2) The true Earth medium contains heterogeneity that can be characterized as a collection of random scatterers. Forward-propagating seismic waves may be broadened by forward scattering, strengthened by mode-conversion scattering, and dissipated due to back scattering. Energy loss from forward-propagating waves due to scattering is a form of seismic attenuation, which can be quantified by Qs and cannot be neglected since this leads to the formation of seismic coda. The use of $G_0(t)$ in this case still allows a good measurement of the total attenuation, which includes intrinsic and scattering losses. A reliable separation of intrinsic and scattering losses using amplitude data alone is not viable. However, methods that fit the entire shape of seismogram envelopes at various distances have been proposed and shown to give robust measurements of intrinsic and scattering attenuation without resorting to assumptions about the form of geometric spreading (Fehler *et al.* 1992). Such methods are not based on assumptions about the frequency dependence of intrinsic or scattering Q; the frequency dependence is inferred from the measurements made on each frequency independently. While initially developed and applied to models with homogeneous background velocity, more recent work has included the effects of layered structure on the analysis. 3) The Earth medium contains localized deterministic 3D structures (such as a subducting slab), causing complicated processes such as diffraction, strong deterministic scattering, focusing/defocusing, and multipathing of waves in the vicinity of the structure. In this case it is usually impractical to acquire a detailed knowledge of a localized 3D structure to estimate its effects on seismic amplitudes. Therefore attempts at measuring attenuation (which includes intrinsic and scattering loss due to random heterogeneity) might fail because of unknown effects caused by the deterministic 3D structure on seismic amplitudes. The $G(t)$ proposed in M09 will not make the measurement any more feasible because the added term $e^{-\gamma t}$ quantifies a frequency-independent loss occurring along the entire propagation path; hence it is not appropriate for quanti-

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fying the unknown, localized, and strong 3D effects. The true Earth medium can be considered as a superposition of those in the three scenarios considered. Therefore using the new $G(t)$ does not improve attenuation studies from a physical point of view.

Numerically, the new $G(t)$ introduces a new unknown parameter γ in addition to the traditional unknowns (Q or attenuation coefficient). It requires fitting usually noisy amplitude data with an additional free parameter. Not surprisingly, the larger number of free parameters can fit the same data equally well (see Figure 1 of M09) at the costs of an increased parameter trade-off and more importantly, of a confusion about the physical meaning of the parameters being fitted.

This letter does not represent views or policies of U.S. government agencies.

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