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Lapse time dependence of coda Q: Anisotropic multiple-scattering models and application to the Pyrenees

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The attenuation properties of the crust have been widely explored from measurements of the quality factor of coda waves (Q_c) throughout the world. A number of studies have reported an increase of Q_c with the lapse time in the coda of shear waves excited by local earthquakes. Based on a single-scattering interpretation, this observation is generally ascribed to depth-dependent attenuation properties in the crust. In recent years a number of observations -in particular seismic wave equipartition- have put forward the importance of multiple scattering in the coda. The main purpose of this study is therefore to clarify the role of multiple scattering in the lapse time dependence of Q_c using numerical simulations and observations from the Pyrenees. Thanks to the European project Interreg SISPYR, we collected all available waveform data from various institutions that operate seismological networks along the range. We selected around 5000 waveforms from 159 local earthquakes (with a magnitude larger than 3) which occured between 2001 and 2010. The coda quality factor of short-period S-waves has been measured as a function of the length of the coda window (L_w) for different choices of the onset time of the coda. In the 2-16 Hz frequency band, we observe a transient regime characterized by an increase of Q_c with L_w, followed by a stabilization around a plateau whose value depends on the central frequency of the signal and on the location along the range. Using Monte Carlo simulations of wave transport in a variety of random media (exponential, Von-Karman or gaussian heterogeneity power spectra), we demonstrate that the lapse-time dependence of Q_c in the Pyrenees may be modeled by anisotropic multiple scattering of seismic waves, without invoking any depth dependence of the attenuation properties in the crust. In our model, anisotropic scattering is quantified by the ratio between the transport and scattering mean path (l^*/l). At 6 Hz, we show that pyrenean data require an anisotropy factor l^*/l greater than 5, a transport mean free path l^* greater than 100 km, an intrinsic quality factor Q_i around 900 ± 300. From the frequency-dependent plateau of Q_c at large lapse time, we infer an intrinsic quality factor of the form $Q_i \sim 400 f^{0.4}$ in the Pyrenees. We also show how the rapid increase of the lapse-time dependence of Q_c with frequency may be exploited to put constraints on the power spectrum of heterogeneities in the crust. A preliminary model of heterogeneity consistent with the observed lapse time dependence of Q_c suggests that the Pyreneean crust is relatively poor in short-wavelength structure.