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Kernel-based coda-attenuation imaging: a non-linear multi-scale approach

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Coda waves are continuous wave trains of progressively decreasing amplitude generally visible after body wave arrivals. Their envelopes smoothly decrease with lapse time. Coda waves contain information about the heterogeneity of the subsurface, quantified by the coda quality factor, called Q_c. Q_c imaging has been widely used for estimating characteristics of the lithosphere and the attenuation of the crust in several regions and scales, including volcanoes. Attenuation imaging is sensitive in identifying fractures, melt and sedimentary deposits and thus, velocity and attenuation imaging can unravel different characteristics of the Earth. There are several methodologies developed and used for coda attenuation imaging and mapping using passive sources. Generally, the energy decay of coda waves is expressed as $E(t, f) = S(f)t^{-\alpha} \exp\left(-\frac{2\pi f t}{Q_c(f)}\right)$ where $S(f)$ is the frequency-dependent source term and α is a constant related to geometrical spreading. This expression is linearised and used to calculate the coda quality factor Q_c between each source-receiver pair, a parameter depending on both the scattering and the absorption properties of the medium. Q_c can be mapped in space using a regionalisation approach or inverting for the spatial distribution of Q_c using appropriate sensitivity kernels defined on a space grid. These novel space-weighting functions were developed for coda wave back-projection mapping by solving the Energy Transport theory equations using Monte Carlo methods. In this study, we propose a new non-linear approach to invert the spatial distribution of coda energy at different lapse times and thus calculate Q_c in space using a non-linear grid-search approach. We test the new approach and compare it with the standard linearised one using three datasets from areas which cover different geological settings and scales: Pollino (Italy), Mount St Helen volcano (USA) and Vrancea (Romania). The preliminary results of the proposed methodology share strong similarities with the current results, which shows potential for the new, more robust methodology to become one of the future standard methods for coda attenuation imaging.