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Comparison of numerical simulations of seismic wave propagation in heterogeneous porous media and corresponding visco-elastic equivalent solid composites

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Heterogeneity in the Earth's subsurface is a ubiquitous phenomenon and spatial changes in the physical properties of fluid-saturated porous rocks can be observed at all scales. There is increasing evidence indicating that the presence of heterogeneities larger than the mean pore size but smaller that the predominant wavelengths may account for observed attenuation of seismic waves. These so-called mesoscopic heterogeneities may be associated with the fluid composition or dry frame properties of the rock, and the corresponding loss mechanism is due to fluid pressure equilibration processes taking place at the heterogeneities of the fluid-saturated porous medium. It can thus be understood as seismic energy conversion between the incident wavefront and diffusive slow waves generated at the discontinuities. As a consequence, centimeter-scale perturbations of the subsurface physical properties should be taken into account for seismic modeling if very detailed and accurate seismic responses of the target structures are desired. However, this is computationally prohibitively expensive since the diffusion lengths associated with the pressure equilibration processes at the heterogeneities are very small compared with the predominant seismic wavelengths, which in turn would mandate excessively small discretization levels. A convenient way to circumvent this problem is through the use of upscaling procedures on the fluid-saturated porous media containing the mesoscopic heterogeneities. The upscaled media are represented by equivalent homogeneous viscoelastic solids exhibiting the same frequency-dependent characteristics with regard to attenuation and phase velocity as the original heterogeneous porous rock. These equivalent viscoelastic solids can, in turn, be used to replace each one of the heterogeneous porous regions composing the geological model, and the viscoelastic equations of motion can be solved to obtain the corresponding seismic response considering mesoscopic attenuation and velocity dispersion effects in a convenient way. While overall validity of this procedure is reasonable well established, there are as of yet no detailed comparisons of corresponding seismograms. To address this issue, we first use Biot's equations of motion to perform numerical simulations of wave propagation through a wide range of models containing realistic mesoscopic heterogeneities. We then use numerical upscaling procedures to estimate equivalent viscoelastic solids to replace the different parts of the geological models under study and repeat the numerical simulations based on the viscoelastic equations of motion in order to compare the seismic data obtained with the two approaches.