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Effects of seismic anisotropy and attenuation on first-arrival waveforms recorded at the Asse II nuclear repository

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For decades, deep geological storage in former salt mines has been a widely recognized strategy for long-term radioactive waste disposal. However, in the case of the Asse II repository in Lower Saxony, groundwater inflow and instabilities in the geological structures rendered the mine unusable as a long-term solution. The nuclear waste needs to be recovered for safety reasons, hence the need for detailed structural information to build a new shaft. In this context, it is essential to use optimized, modern seismic imaging methods, such as, for instance, full-waveform inversion (FWI), to obtain high-resolution, physical parameter models of the Asse salt structure and its surroundings.

The goal of this study is to draw conclusions on the future application of elastic FWI using first-arrival waveforms at frequencies up to 20 Hz, potentially including anisotropy and attenuation. For this purpose, simple parameter models were created based on previously known geological information and used as reference for synthetic forward modeling tests. The objectives were (a) to see if the models are suitable as initial models for FWI, (b) to assess what type of anisotropy needs to be considered, if at all, and (c) to investigate the significance of attenuation. To facilitate the numerical tests, the mathematics of viscoelastic anisotropic wave propagation was studied and a new 2D finite-difference (FD) anisotropic forward solver was implemented.

A detailed comparison of wavefield snapshots and seismograms was conducted between isotropic, vertical-transverse isotropic (VTI), and tilted-transverse isotropic (TTI), as well as elastic and viscoelastic modeling. The results demonstrate that, in general, the models are likely to meet the prerequisites for successfully applying first-arrival FWI up to frequencies of about 20 Hz. While attenuation turned out to be only a minor factor, it is, however, essential to incorporate anisotropy. As the Asse salt structure is complex and steeply dipping, TTI modeling is the preferred way to correctly map the subsurface in high resolution and match first-arrival traveltimes. Furthermore, a comparison with field data acquired over the Asse hill shows that many features present in that data can already be explained using the current approach.

Category

Geophysics

Authors: Ms SORTAN, Sonia (KIT Geophysical Institute); Prof. BOHLEN, Thomas (KIT Geophysical Institute); Dr HERTWECK, Thomas (KIT Geophysical Institute); Dr HOUPT, Lars (KIT Gephysical Institute)

Presenter: Ms SORTAN, Sonia (KIT Geophysical Institute)

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