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Optimizing acquisition setup for full-waveform inversion of cross-hole GPR data using checkerboard test

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Tomographic inversions of cross-hole ground penetrating radar data provide fast and efficient images of electromagnetic properties of the shallow subsurface and are used by hydrologists, geologists, engineers and archaeologists in a wide range of applications. The mapped dielectric permittivity and electrical conductivity images can be related to porosity, water content and salinity, clay content and lithological variations. The resolution of ray-based inversion techniques is limited to the scale of the first Fresnel zone. In contrast, full-waveform inversion incorporates a precise forward modeling based on Maxwell's equations and uses the full recorded signal, including reflected and refracted events, which results in sub-wavelength resolution images. Recently, a 2D time-domain vectorial full-waveform code with a simultaneous update of permittivity and conductivity was developed and an optimized semi-reciprocal acquisition setup with a limited number of transmitters but many receivers was introduced. Instead of an equidistant dense transmitter and receiver setup, a good ray-coverage is maintained by an interchange of source and receiver boreholes.
Here, we evaluate the resolution of the different setups using a checkerboard test, which is commonly used in different applications of seismic tomographic inversion. A resolution analysis of experimental results from cross-hole data recorded in Krauthausen, Germany, showed that the use of the semi-reciprocal setup is optimum for acquisition speed, inversion speed and obtained permittivity inversion results. A new method of time-zero shift correction was introduced by cross-correlating a Zero-Offset-Profile with corresponding horizontal traces of each Multi-Offset-Gather. The obtained experimental results combined with the checkerboard analysis indicate three main permittivity layers that correlate with different porosities characteristic for the generalized stratigraphy of the uppermost aquifer in Krauthausen. In comparison to ray-based results, also fine layered structures within the best resolved middle main layer were reliably imaged.