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The research of early arrival waveform inversion and its application in imaging the shallow fault zone structure

Xiaona Ma, Weitao Wang, Shanhui Xu, Wei Yang, and Yunpeng Zhang
Institute of Geophysics, China Earthquake Administration, Department of Advanced Earth Physics Technology, Beijing, China (kymxn0224@163.com)

Waveform inversion is a robust geophysical tool for reconstructing subsurface structures, involving an iterative process that begins with an initial model and utilizes complete information from observed data to update the target model. However, its wide field applications have been impeded by challenges such as strong nonlinearity, nonconvexity of the misfit function, and complexity of the propagation medium. To mitigate these issues and enhance the linearity and simplicity of the inversion process, we employ early arrival wavefields to construct misfit function that promotes global convergence.

High-resolution structure imaging of active faults within urban areas is vital for earthquake hazard mitigation, so we perform a seismic survey line crossing the Pearl River Estuary Fault (PREF) in Guangzhou, China. First, ten shots of a new and environmentally friendly gas explosion source are excited with about 1 km spacing and recorded by 241 nodal short-period seismometers with an average spacing of 60 m. Then, based on these acquisition data, we adopt waveform inversion to explore the kinematic and dynamic information of early arrival wave-fields to recover the subsurface structures. Here, the early arrival wavefields were defined as those events that arrived within a few periods of the first arrivals. The inversion results indicate that while the low-velocity zone (LVZ) in depth surrounding the PREF is 2.5 km in width and extended to 0.7 km, another LVZ of 1.5 km in width and extended to 0.7 km in depth is surrounded by the Beiting-Nancun fault. We observe that the analysis of evolution and activities of the fault systems reveal no historical earthquakes in our study area; we interpret that the two LVZs controlled by the faults are probably attributed to the fluid dynamics, sediment source, and fault motion at different geological times, rather than fault-related damage zones.

Summarily, the results can provide significant basis for earthquake prevention and hazard assessment in Guangzhou. The finding also shows that the waveform inversion can effectively explore the fine structure of active faults in urban area with dense linear array and spare active source excitations. This acquisition and inversion methods should have broad applications in other cities.