Mitigating the nonlinearity of crustal-scale full waveform inversion through the graph space optimal transport misfit function

Andrzej Gorszczyk[1,2], Romain Brossier[1], Ludovic Metivier[1]

[1]ISTerre, Univ. Grenoble Alpes, Grenoble, France, [2]Institute of Geophysics, Polish Academy of Sciences,

Wide-angle seismic data are routinely employed for the imaging of deep lithosphere. This is because the information collected along the long-offset diving and refraction wavepaths, additionally enriched with the wide-angle reflection arrivals, have a great potential to efficiently constrain the subsurface velocity at depths which are beyond the range of typical reflection seismic data. Although the development of dense acquisition systems, more and more efficient algorithms and high-performance computing resources make it now feasible to invert for the waveforms, only a few attempts to combine wide-angle data with Full-Waveform Inversion (FWI) have been conducted in the academic community. Instead, the routine processing still relies mainly on raytracing and traveltime inversion, utilizing the arrival times of pre-interpreted phases.

This is partially due to the non-convexity of FWI misfit function, which increases with the complexity of the geological setting reflected by the seismograms. Indeed, in its classical form FWI is a nonlinear least-squares problem, which solved through the local optimization techniques. This impose strong constraint on the accuracy of the starting model. The well-known criterion to avoid cycle-skipping (and converging toward local minimum) states that, the initial model must predict synthetic data within the maximum error of half-period time-shift with respect to the observed data. The criterion is difficult to fulfill when facing the crustal-scale FWI, because the long-offset acquisition translates to the long time of propagation and therefore accumulation of the traveltime error along the wavepath simulated in the initial model. This in turns increases the possibility of the cycle-skipping taking into account large number of propagated wavelengths.

Searching to mitigate this difficulty, here we investigate FWI with a graph-space optimal transport (GSOT) misfit function. Comparing to the classical least-squares norm, GSOT is convex with respect to the patterns in the waveform which can be shifted in time for more than half-period. Therefore with proper data selection strategy this misfit-function has potential to reduce the risk of cycle-skipping. We demonstrate the robustness of this novel approach using 2D wide-angle OBS data generated in a GO_3D_OBServer synthetic model of subduction zone (30 km x 175 km). We show that using GSOT-based combined with the multiscale FWI strategy, we reconstruct in details the highly complex geological structure starting from a simple 1D velocity model. We believe that further developments of OT-based misfit functions can significantly reduce the constraints on the starting model accuracy and reduce the overall risk of cycle-skipping during FWI of wide-angle OBS data.