Relaxing the initial model constraint for crustal-scale full-waveform inversion with graph-space optimal transport misfit function

Andrzej Górszczyk$^{1,2}$, Ludovic Métivier$^{1,3}$, and Romain Brossier$^1$

1ISTerre, Univ. Grenoble Alpes, Grenoble, France
2Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland
3CNRS, Univ. Grenoble Alpes, LJK, Grenoble, France

Investigations of the deep lithosphere aiming at the reconstruction of the geological models remain one of the key sources of the knowledge about the processes shaping the outer shell of our planet. Among different methods, the active seismic Ocean-Bottom Seismometer (OBS) experiments conducted in wide-angle configuration are routinely employed to better understand these processes. Indeed, long-offset seismic data, combined with computationally efficient travetime tomographic methods, have a great potential to constrain the macro-scale subsurface velocity models at large depths.

On the other hand, decades of development of acquisition systems, more and more efficient algorithms and high-performance computing resources make it now feasible to move beyond the regional raytracing-based traveltime tomography. In particular, the waveform inversion methods, such as Full-Waveform Inversion (FWI), are able to exhaustively exploit the rich information collected along the long-offset diving and refraction wavepaths, additionally enriched with the wide-angle reflection arrivals. So far however, only a few attempts have been conducted in the academic community to combine wide-angle seismic data with FWI for high-resolution crustal-scale velocity model reconstruction. 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.

In its classical form FWI is a nonlinear least-squares problem, which is solved through the local optimization techniques. This imposes the strong constraint on the accuracy of the starting FWI model. To avoid cycle-skipping problem 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 wavefront 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 GSOT misfit-function has potential to reduce the risk of cycle-skipping. We demonstrate the robustness of this novel approach using 2D wide-angle OBS dataset generated in a GO_3D_OBS synthetic model of subduction zone (30 km x 175 km). We show that using GSOT cost-function 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.