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Inversion of band-limited, downward continued multichannel seismic data by combination of travel-time and full waveform tomography

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Seismic tomography methods and in particular full waveform inversion (FWI) of controlled source data are powerful tools to obtain accurate information of the physical properties of the subsurface. One of their main drawbacks is however the strong non-linearity of the problem, which makes the solution strongly dependent on the initial model and on the low frequency content of the data set. A common strategy to mitigate these issues is to combine the robustness of Travel Time Tomography (TTT) to obtain an appropriate reference model that is subsequently refined by FWI.

This combined technique is often used for long-offset acquisition geometries, where refracted waves are present as first arrivals. Conversely, its application to streamer-type multichannel seismic (MCS) data is rare, because these data are intrinsically short offset so the presence of refractions is very limited. In this work we use synthetic data to show how the downward continuation (DC) or redatuming of the MCS data prior to TTT allows obtaining velocity models that can be then used as initial models for FWI even if data lack frequencies below 4 Hz. In summary, the proposed strategy consists of the following steps: 1) We compute the downward continued wavefield using a finite difference solution of the acoustic wave equation in time domain. The solver used for the propagation was developed by the Barcelona Centre for Subsurface Imaging (BCSI) and incorporates a mutli-shooting strategy necessary to back-propagate the wavefield and reduce the computational time. Our new datum level chosen corresponds to the bathymetry of the model. 2) We use the resultant DC MCS wavefield to identify the refracted phases (first arrivals) highlighted by the redatuming process and we invert them applying TTT. The resulting model, which has the low wavenumber information needed to reduce the non-linearity problems of the FWI, is then used as initial model to perform multi-scale FWI of the original MCS data starting at realistic frequencies. High-resolution P-wave velocity results are obtained and also an improvement of the inversion stability is observed using DC MCS TTT - FWI strategy. Another advantage of this methodology is that the ray coverage increases in the deeper parts of the model (DC MCS data). It is also shown that, due to the lack of low frequencies, FWI does not converge unless the CD MCS TTT model is used.