Geophysical Research Abstracts
Vol. 14, EGU2012-3323-1, 2012
EGU General Assembly 2012

A critical appraisal of asymptotic 3D-to-2D data transformation filters and the potential of complex frequency 2.5-D modeling in seismic full waveform inversion

L. Auer (1), S. A. Greenhalgh (1), H. R. Maurer (1), S. Marelli (2), and A. Nuber (1)

(1) ETH Zurich, Institute of Geophysics, Switzerland (ludwig.auer@tomo.ig.erdw.ethz.ch), (2) UNIL Lausanne, Institute of Geophysics, Switzerland

Seismic full waveform inversion is often based on forward modeling in the computationally attractive 2-D domain. Any solution of the 2-D cartesian wave equation inherently carries the implicit assumption of a line source extended in the out-of-plane medium invariant direction. This implies that the source energy in homogeneous media spreads over the surface of an approximately expanding cylinder, such that the wavefield amplitudes (at least in the far field) scale inversely with the square-root of distance. However, realistic point sources like explosives or airguns, fired in a 3-D medium, generate amplitudes that decay inversely with the first power of distance, since the wavefield expands quasi-spherically in all three dimensions. Usually, practitioners correct for this amplitude difference and the associated phase shift of $\pi/4$ by transforming the recorded 3-D field data to the approximate 2-D situation by using simplistic, asymptotic filter algorithms. Such filters operate on a square root of time-sample convolutional basis and implicitly assume straight ray paths and a constant velocity medium. The unsubstantiated usage of these asymptotic filters is in contradiction to their well known limitations.

In this study, we present an extensive quantitative appraisal of 3D-to-2D data transformation procedures. Our analysis relies on a simple numerical modeling study, based on propagating 3-D and 2-D wavefields through 2-D media and comparing the true 2-D and the filtered 3-D synthetic data. It is shown that the filtering errors are moderate in purely acoustic situations but become substantial in complex media when arrivals overlap each other or ray paths deviate strongly from straight lines. Normalized root-mean-square deviations up to 5% and maximum relative time domain errors of up to 40% were found in high contrast media, when full elastic treatment was considered. In order to examine if this error translates into a deficient model reconstruction in full waveform inversion schemes, we performed complementary inversion experiments, using an acoustic frequency domain waveform inversion algorithm. Purely acoustic waveform inversions in the frequency-domain seem to be negligibly affected, because the waveform discrepancy is only significant at small distance-to-wavelength ratios which occur in the early (low frequency) iterations. In the later high frequency stages the asymptotic filters are adequate. Work is underway to extend our inversion study to the elastic case, where a more significant S-wave influence is expected to exacerbate the effect.

The alternative to performing 3D-to-2D data transformation is to carry out 2.5-D modeling, which entails spatial Fourier transforming the 3-D wave equation along the invariant axis to the wavenumber domain and solving the resulting equation for many wavenumber components, thus breaking down the 3-D problem to a high number of 2-D problems. When performed in the frequency domain, which is attractive for full waveform inversion purposes, singularities in the wavenumber spectra arise at various critical wavenumbers. We show in this study how such problems can be circumvented through the use of complex frequency. The reconstructed finite-element 2.5-D seismograms compare very well to the reference finite-difference 3-D seismograms, and outperform the asymptotic 3D-to-2D transformation filter approach.