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3D Prestack Full Waveform Inversion

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Abstract

During the last decade, seismic prestack depth imaging became commonplace due to advances in compute capability and proven return on investments. The early approaches using simplified versions of the wave equation proved the value, despite the relatively high computational demand. In many geologic situations these approaches remain adequate for the needs. Complex geology however, exposed the limits of the approximations and methods. As such, the industry responded with alternative algorithms, for example Gaussian beam, wavefield extrapolation, and reverse-time approaches. As well, acquisition methods improved, providing enhanced azimuthal sampling for marine steamer surveys and further challenges for the imaging algorithms,

All depth imaging depends on the velocity model. Everyone struggles to derive a model that represents the geology and fits the assumptions of the chosen imaging method. Many hope to build velocity models by using full waveform inversion due to the greater dependency on recorded data rather than interpretation. On the other hand, given the non-linear and non-unique solution space, its implementation remains problematic. Full waveform inversion also requires significant compute resources, given that multiple iterations of forward modeling and residual wavefield back propagation must be performed.

This paper describes an implementation of a time-domain 3D waveform inversion. Unlike frequency-domain algorithms that use waveform redundancy to lower compute requirements, this method functions efficiently on current computer architecture. Most importantly, high- quality images result from migrations using the model produced by numerous iterations of waveform inversion.

Introduction

The challenge for waveform inversion is to produce an improved velocity model that can be used to predict seismic data that more closely resemble the acquired, observed data and to demonstrate that the updated velocity model is a better representation of the true model than that derived by various model-building methods.

The full-waveform inversion based on the finite difference approach was originally introduced in the time–space domain (e.g.Tarantola, 1984, Gauthier *et al.*, 1986, Crase *et al.*, 1990, 1992, Pica *et al.*, 1990, Sun & McMechan, 1992). The full-waveform inversion described in this paper is solved by an iterative local, linearized approach using a gradient method (e.g. Tarantola, 1987). At each iteration, the residual wavefield (the difference between the observed data and the wavefield predicted by the starting model) is minimized in a least-squares sense. The process is iterated non-linearly by using the updated model from the previous iteration for the subsequent iteration.

The inverse problem can also be implemented in the frequency domain (Pratt *et al.*, 1998,Pratt and Shipp, 1999,Ben-Hadj-Ali et al., 2008). The seismic data are decomposed through a Fourier transform into monochromatic wavefields that permits the inversion to be performed using a limited set of discrete frequency data components at a time. The inversion proceeds from low to high frequency components to insert progressively higher wavenumbers into the velocity model. A single frequency is equivalent to a sinusoidal component in the time domain (Sirgue and Pratt, 2004). When a range of frequencies are used, the frequency-domain method is equivalent to the time-domain method when using the same range of frequencies.