An introduction to this special section: Full-waveform inversion and the way forward

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Lost in the endless valleys and hills of the full-waveform inversion (FWI) misfit functional, we tend to stop and wonder: Are we heading in the right direction? Are we in the right valley? Or within a bigger context, is FWI the way to go? The practice of updating an Earth model and generating synthetic data from it that we can compare to the field data is an appealing concept. If the two data sets (the modeled and field) match, using some measure of misfit, we might have found a good Earth model. This process depends on our ability to fully replicate (simulate) the physics of wave propagation inside the Earth. In principle, our field data carry information from every point in the Earth, but these data are also constrained by the geometry of seismic acquisition.

Therefore we attempt, in a straightforward fashion, to duplicate the experiment in the field with a computer simulation (Tarantola, 1984). We are usually ignorant of the source signature, so we try to invert for it. Given the computing resources available and the data to be matched, we approximate the physics of wave propagation as well as we can and hope data preconditioning allows us to get away with it. However, the critical information that we need to simulate wave propagation, and the reason why the process is called inversion, are the medium parameters (the elastic coefficients or their practical simplification in acoustic media) and the P-wave velocity. Thus, we assume that the majority of the difference between the simulated data and the field data is attributable to having the wrong model parameters and, thus, we use the information contained in the difference (i.e., data misfit) to improve them.

Therefore, FWI describes the process of fitting our synthetic data to field data by updating the appropriate medium parameters in order to optimize this fit. The updating process is open to many possibilities, from Taylor-series-induced up-dating, to model distribution probability and stochastic methods (Sen and Stoffa, 1992; Mallick, 1999).

The most affordable, and therefore popular, process is the gradient-based methods (Sen and Stoffa, 1992; Mallick, 1999). The strong nonlinearity (i.e., cycle skipping) of the problem, which requires accurate starting models when gradient-based methods are used to update the model space.

The limited/poor illumination of the subsurface because of the surface seismic acquisition geometries, which requires regularization of the inversion.

The anelastic and anisotropic nature of the Earth, which requires more accurate simulations, better data conditioning, and (most importantly) better multiparameter inversion strategies.

This special section comprises 12 articles from leading researchers in the field, from both academia and industry, discussing subjects ranging from multiparameter inversion, combining FWI with migration velocity analysis, improved efficiency and case studies. As seen in Figure 1, the number of SEG publications related to FWI has exploded since 2005, covering all aspects of the method. To help organize this rapidly growing topic, we selected four themes related to current practices and research directions in FWI. Admittedly, this classification is arbitrary as many articles could belong to more than one theme. The first three themes cover theoretical aspects of FWI, with some synthetic examples and case studies included, while the last one focuses on case studies only. This classification represents the status of FWI, transitioning slowly but surely out of the academic world into the unforgiving realm of field data.

The first theme describes methodologies and examples of multiparameter FWI. Here, the authors present results and techniques to derive not only P-wave velocity models, but also anisotropic parameters, attenuation, density, etc. Plessix et al. show how intermediate-to-long wavelengths of the velocity
Full waveform inversion was promised to be the final and ultimate solution to the Earth resolution and imaging objective: we are now waiting for this promise to materialize or, more pragmatically, learning what can be expected from this re-emerging method in realistic exploration settings.

References


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Figure 1. Approximate number of SEG publications with the words “full-waveform inversion” or “waveform inversion” or “waveform tomography” in the title. A significant increase of publications is visible after 2005 (corresponding to the rebirth of RTM as a viable imaging technique).