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RTM-based waveform inversion

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Waveform inversion that determines the subsurface velocity structures can be implemented in either data domain, which compares the differences between the real data and the simulated data (Tarantola, 2005), or in image domain, which checks the coherency of the events in the CIGs (Common Image Gathers) (Symes and Kern, 1994; Chavent and Jacewitz, 1995).
In the past, classic waveform inversion, as a data-domain approach, has little success in the field data experiments. We believe that one of the problems is the unknown simulation equations. The real waves will likely propagate with different kinds of wave equations at different subsurface areas. This implies that no single simulation equation can adequately describe the wave propagations underneath the earth. Because of the uncertainty of amplitudes of the waves, the objective function for classic waveform inversion that tries to compare the differences between the observed data and the simulated data will definitely hurt than help inversions. Fortunately, although waves propagate in various forms, only the amplitudes of the waves vary. The traveltime for these various forms of wave equations that are determined by the eikonal equations are more or less the same. In other words, traveltime can provide more reliable information than amplitudes. This suggests that an effective waveform inversion should emphasize on the events' traveltime or phase information and downplay the role of amplitude information.
Following Chavent and Jacewitz (1995), we propose an image-domain approach that is based on the criteria that seismic data must be geometrically coherent after prestack depth migration. When the velocity is correct, the events at CIGs should be flat and therefore have maximum stack power for redundant shots. This image-domain approach relies on event coherency (traveltime) and has the effect of emphasizing more on the reliable traveltime information instead of unreliable amplitudes. Here we choose RTM (Reverse-time migration) as the migration engine. Our optimization problem is therefore defined as an image-domain semblance-like objective function, which is constrained by RTM's forward and backward two-way scalar wave equations. The gradient of the objective function that is needed for conjugate-gradient algorithm is derived by the adjoint state technique. Besides the original RTM forward/backward equations, two extra propagation equations, called adjoint equations in control theory, are introduced for this image-domain waveform inversion. These equations combined represent a demigration process that reconstructs the transmitted and reflected wavepaths for both source and receiver data respectively. The simulated reflected data that can be collected during the demigration processes also provide us with another opportunity for data-domain inversion. Finally, because of less emphasis on amplitudes, this image-domain approach may converge slower than classic waveform inversion for synthetic data, but it should be more adequate for field data experiments.