Some Thoughts on the Inclusion of Multiple Scattering in a Phase-Space-Based Marching Velocity Field Reconstruction Algorithm

Lou Fishman
MDF International
Slidell, LA 70461 USA
Shidi53@aol.com

Historically, seismic imaging and inversion have been, for the most part, based on a linearization (Born approximation) of the underlying wave equation. Starting with a data set, a “smooth” background velocity component is determined through a velocity analysis, and, subsequently, applied in the linearized (primaries only) construction of a reflectivity or velocity field estimate, often through migration or downward continuation procedures. By far, the most challenging and rate determining step, in proceeding from the data to the final image, is the velocity analysis. Considerable effort has been expended on this pivotal problem in seismic data processing. But why expend all that time and energy on the velocity analysis just to produce a first-order perturbation theory result in the end? Why not focus on developing a full multiple-scattering approach that requires no initial velocity model at all? An important clue for potential success comes from the experiences with the optimization, or model matching, approaches that are prevalent within the greater inverse problems community. While essentially brute force approaches, optimization methods certainly account for the full multiple scattering in their repeated numerical solutions of the direct problem. But even this approach requires a reasonable, smooth initial velocity model, enabling the search algorithm to start in the neighborhood of the global minimum and, subsequently, produce acceptable results. This initial velocity model can be viewed as prior information needed to construct a successful algorithm. The lesson here is that it will almost certainly be necessary to incorporate appropriate prior information into the desired full multiple-scattering algorithm; it just won’t be the costly and time consuming initial velocity model.

The motivation for the full multiple-scattering algorithm derives from the standard, depth migration, seismic imaging algorithms based on an “approximate imaging condition” that provides a reflectivity estimate; essentially a ratio of the up- and down-going wave fields at a fixed level. However, this is just an approximation to an “exact imaging condition,” expressing the exact relationship between the up- and down-going wave field components, at a fixed level, through the nonlocal reflection operator, accounting for all of the multiple scattering in the environment. This exact relationship provides the starting point for a classical “layer-stripping” algorithm. While the reflection operator kernel is a natural physical choice for the “data” equation, the reflection operator symbol (related by a straightforward initial transform) results in the most promising and efficient algorithm. The operator symbol effectively “images” the underlying environment, revealing the velocity profile, at a fixed level, through the operator symbol (weak) singularity structure. Combining the uniform asymptotic operator symbol analysis, from the explicit, exact, well-posed, one-way reformulation of two-way wave equations, with the reflection operator symbol (“data”) equation results in an explicit expression, for the reflection operator symbol, formulated in terms of two, simplified, nonsingular wave fields, governed by, in the leading-order result, a rather simple linear ode system. The prior incorporation of the uniform operator symbol asymptotics (1) reduces the numerical back propagation and regularization of a first-order, quadratically nonlinear, nonlocal “data” equation to that of a simple linear ode system, (2) eliminates the numerical integration through the singularities, and (3) serves to “constrain” the available “filtered” data in the reconstruction process. Not all prior information need be in the form of an initial velocity model.

The machinery developed for the full multiple-scattering reconstruction algorithm can also be applied to the seismic multiple-removal problem. Furthermore, time permitting, the application of “exact semi-classical methods,” for the construction of fast algorithms, will be briefly discussed.

Minisymposium: Inverse Problems for Wave Propagation, Liliana Borcea