Removing multiples without subsurface data

Are we seriously considering treating multiples as signal? *(Part 2 of a two-part series)*

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This article is an executive summary of an invited presentation, "Multiples: signal or noise?" at the upcoming 2014 Society of Exploration Geophysicists (SEG) annual conference for the session titled "Recent Advances and the Road Ahead."

In the first of these articles we described the state of seismic multiple removal: (1) the current capability; (2) the challenges; and (3) a strategy to directly respond to the current challenges. That article relates to "the exclusive view" of seismic reflection data, where primaries are signal and multiples are noise to be removed.

There is an alternative view, "the inclusive view" of processing seismic reflection data, where primaries and multiples are treated as signal and used for seismic imaging.

WEM

Migration has two ingredients: (1) a wave-propagation component and (2) an imaging principle or concept. Jon Claerbout was the initial and key wave equation migration (WEM) imaging concept pioneer, and together with Stolt, Lowenthal et al. was among those who introduced imaging conditions for locating reflectors at depth from surface-recorded data.

The three key imaging conditions that were introduced are:

(1) Time and space coincidence of up- and downgoing waves;
(2) The exploding-reflector model; and
(3) Predicting a source and receiver experiment at a coincident source and receiver subsurface point and asking for "time equals zero" (the definition of WEM).

For a normal-incident spike plane wave incident on a horizontal reflector, these three imaging concepts are totally equivalent. For a nonzero-offset surface seismic data experiment, they are no longer equivalent. WEM is defined as using the third imaging condition, predicting a source and receiver experiment at depth at time equals zero. Imaging conditions (1) and (2) are the basis of asymptotic approximate ray travel time curve "Kirchhoff-like" algorithms.

The properties and benefits of WEM are:

(1) Definitiveness as to whether or not to a subsurface point corresponds to structure;
(2) Angle-dependent reflection coefficient at the imaged point; and
(3) Ubiquitous wave propagation and wave illumination compared to limited propagation and illumination of asymptotic ray-theory migration.

RTM

All current reverse time migration (RTM) methods correspond to asymptotic ray-based migration derived from imaging condition (1).

The currently applied RTM methods consist of back-propagating the receiver field and forward-propagating the source field, where each is carried out using the wave equation. However, the cross-correlation at zero lag is imaging condition (1), and that step is when the RTM method entered asymptotics and Kirchhoff ray theory.

WEM RTM

M-OSRP provided the first prediction of a source and receiver experiment at depth for two-way wave propagation, that is, the first WEM RTM. WEM RTM is designed for turning-wave primaries and for reflection data consisting of primaries and multiples. The added value of WEM RTM compared to all current RTM methods comprises the same three benefits as between WEM and asymptotic ray Kirchhoff migration.

Figure 1 illustrates the result from applying the first WEM RTM algorithm to data that consist of primaries and all internal multiples from a one-dimensional layered medium. The output of the WEM RTM is shown at different locations in the subsurface, with the correct location of structure. In addition, the correct reflection coefficient is provided on each side of each reflector by the prediction of a coincident source and a receiver slightly above or slightly below each reflector, respectively. Hence, to migrate with primaries and multiples, processors simply follow what George Green prescribed in 1828 extended for exploration seismology where the measured wavefield data are only available on the upper surface of the volume. There is no need for "secondary distributed sources" caused by data; higher-order "scattering theory" allusions and incantations; or other ad hoc or unclear ill-defined constructs, including unnecessarily separating primaries and multiples. And no "crosstalk" artifacts or other imponderable and irreconcilable problems arise.

Hence, the theory for WEM imaging with data from the inclusive view is not really very new in concept. We simply arranged for Green's theorem to require data only on the upper surface, leading to the first WEM RTM.

Improved illumination

Recent efforts in the use of primaries and multiples are aimed at improved image illumination.

A good place to start that discussion is with a method that inputs primaries and multiples and correctly locates reflectors in depth. Correct location comes before good illumination; a misplaced but well-illuminated image is of little or no value.

Illumination is a fundamental and intrinsic issue for rays and all asymptotic migration methods and asymptotic RTM. Waves go everywhere and are space-filling. Rays don't. Where rays don't go, there is an intrinsic symptotic method-produced illumination issue. All currently applied RTM methods are asymptotic migration. Current industry RTM methods certainly use the wave equation in running the data backward and the source forward and cross-correlating at zero lag. However, using the wave equation is not the same as WEM. WEM predicts a source and receiver experiment at depth, and current RTM methods do not meet that requirement. Hence, all of the currently employed RTM methods are contributing to an algorithmic-induced limited illumination issue.

Unfortunately, the methods currently put forth and pursued to realize the inclusive view for illumination do not hark back and begin their development with the solid wavefield prediction provided by Green. The recent and current inclusive view activity very often has shaky underpinnings, at best, and a lack of any clear and firm technical foundation and framework, with ad hoc constructs offered with full confidence and conviction.

The current inclusive activity is, without exception, using variants of asymptotic RTM for primaries, multiples, or primaries and multiples for improved illumination. However, these methods produce false images at depth (due to crosstalk), a serious downside. There doesn't seem to be a way to address that downside and to remove these false events. The reason those "illumination" enhanced imaging methods cannot be advanced and improved to remove the crosstalk-generated false images is that there is no clear wave theory-based starting point and derivation of the method to begin with. If there was, processors could then back up, avoid the unacceptable assumption and fix it.

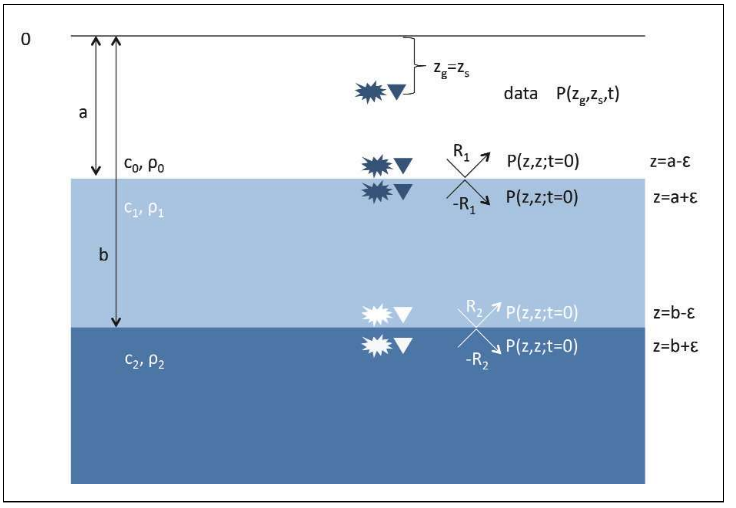

FIGURE 1. WEM RTM imaging with primaries and internal multiples. The result is a correct migration-inversion above and below each reflector, with no 'crosstalk' false images. (Source: M-OSRP)

Working with multiples

Why has the industry treated primaries as signal and multiples as a form of noise? Primaries are much more accepting of an approximate, smooth velocity for structural imaging. Providing an adequate smooth velocity for imaging diving waves going down and under salt remains a tough and daunting problem. Migrating primaries and multiples in data will require an accurate, discontinuous migration velocity model for predicting a source and receiver experiment at depth for WEM. Determining an accurate discontinuous velocity model is not a realistic assumption now nor for any time in the foreseeable future.

WEM imaging with primaries and internal multiples requires an accurate, discontinuous velocity model.

Multiples contain information. Are they signal? Of course multiples contain information, but that's not the point. The point is that they contain too much information. Containing information doesn't classify an event as signal; being able to reliably extract information from an event defines an event as signal.

The reason primaries are separated from multiples in exploration seismology is not due to lack of theory. The basic theory is almost 200 years old. It is due to the inability, in practice, to provide an adequate discontinuous velocity model necessary for the inclusive holistic view.

While M-OSRP recognizes the value that current asymptotic RTM illumination efforts have demonstrated for shallow reflectors using free-surface multiples, it advocates (1) starting with WEM RTM that best serves illumination objectives; (2) seeing what illumination with primaries will provide; and (3) considering adding multiples to the mix following a Green's theorem prescription. That approach will never produce "crosstalk" or other irreconcilable false images.

Industry needs to maintain a balance and perspective and not to be distracted by the inclusive view vogue and fashion—to start to seriously think of multiples as signal. They are not. The point is that the accurate and discontinuous subsurface information they require to be considered signal is unattainable. Multiples were and remain noise. In general, new proposed seismic methods and strategies that will require more detailed subsurface information are headed in exactly the wrong direction, technically and historically.

It is recommended that the industry maintains its focus on the real, tough, adult and pressing challenges of finding significantly more effective methods to remove multiples, directly and without subsurface information. That's where M-OSRP's primary focus and attention resides.

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