The Separation of Multipath Angle Domain Common Image Gathers for Complex Structures

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SUMMARY

Imaging complex subsurface targets, for example subalt sediments and salt flanks becomes more and more challenging in seismic exploration. When the cross-correlation image condition is used in reverse time migration for each source, the contributions are summed across all the time steps to give one migrated image. The stacked image includes contributions from all primary and prismatic waves, or even artifacts. Thus the final image summation contains a variety of wavefield distortions. Nevertheless, if the image time for each multipath arrival is saved during wavefield extrapolation, and apply image condition at their image times for multipath contributions, we can obtain the multipath partial images. The separate partial images can by displayed for the primary contributions, or any combination of different types of waves (with or without artifacts). The synthetic data from the Sigsbee2 model shows that the relative contributions of multipath arrivals to subsalt images are different.
Introduction

Reverse-time migration (RTM) is currently used as an effective tool to generate prestack depth migration images. When cross-correlation image condition is applied, all kinds of waves are used to construct the image. Cavalca and Lailly (2005) showed that prismatic reflections could help provide complete target information for complex geological structures, such as high dip structures, subsalt sediments and basin bottoms. Nevertheless, the conventional cross-correlation image condition across all image times does not keep track of the image time for each arrival contribution; the image time by default is typically the first or maximum amplitude arrival time, which means only one source reflector path contributes to the common image point; multipath reflections are all stacked and the contributions from other types of arrivals other than primary waves (like prismatic waves) are superimposed with primary reflections and smeared. This happens usually since they have amplitudes with the magnitude with one order smaller. It may produce Angle Domain Common Image Gathers (ADCIG) with artifacts due to the improper mapping of multipaths.

Multipath contributions should be separated from each other in the migration images and also ADCIGs when each has a different incident angle and dynamic attributes such as amplitude and phase. The solution to this problem is to retain the image time dimension. A search of a few highest amplitude wavelet peaks during forward propagation save the image time for each arrival and apply image condition just around their image times to obtain the multipath partial images. The incident angles are also calculated around the image times using pointing vector (Yoon et al., 2011).

Methodology

The conventional cross correlation image \( I(x,z) \) produced by 2D RTM (Claerbout, 1971) is a function of spatial location \((x,z)\) and image time \(t\), which is given as

\[
I(x,z) = \sum_t S(x,z,t) R(x,z,t) \tag{1}
\]

and it’s source normalized version (Kaelin and Guitton, 2006)

\[
I(x,z) = \frac{\sum_t S(x,z,t) R(x,z,t)}{\sum_t S^2(x,z,t)} \tag{2}
\]

The multipath RTM separation can be achieved with several criterions available. The largest source excitation amplitude (Nguyen et al., 2013) is one way to define the primary part of the image; other waves such as multiples and prismatic waves that belong to non-linear part of the wave fields can be separated. If we solve for the two largest amplitude waves that are imaged at one point and then separate them, the two image conditions (and the two images \( I_1(x,z) \) and \( I_2(x,z) \)) can be defined as:

\[
I_1(x,z) = \sum_{t=t_1-\Delta t}^{t_1+\Delta t} S(x,z,t) R(x,z,t) \tag{3-a}
\]

\[
I_2(x,z) = \sum_{t=t_2-\Delta t}^{t_2+\Delta t} S(x,z,t) R(x,z,t) \tag{3-b}
\]

where \( t_1 \) and \( t_2 \) are the image times corresponding to the first and second largest amplitudes wavelet arriving from the source and \( \Delta t \) is the time window.
Numerical Examples

We use a 2D Sigsbee2B (Paffenholz et al., 2002) model (Figure 1) to illustrate the idea. The synthetic test data were computed using a Ricker wavelet with dominant frequency of 20 Hz in a 2D eighth order in space and second order in time utilizing a finite-difference solution of the scalar wave equation. The finite difference grid is constructed of 3196 points horizontal and 1201 in depth, with a grid increment of 7.62 m and the time sample increment of 0.72 ms. Figure 2 shows (source normalized) ADCIGs at representative horizontal positions between 4.6 and 16.7 km for the primary and multipath contributions respectively. At 4.6 km, both the primary and multipath ADCIGs show clean reflectors; however; the multipath CIGs have a larger range of incident angles, especially at shallow depths. The large angle data benefits amplitude versus angle inversion. In the CIGs that penetrate the salt body (from positions 10.6 to 16.7 km in Figure 2), the contributions from primary reflections (Figure 2a) are more confined in angle, while multipath arrivals (Figure 2b) are less coherent and have more artifacts. The shallow sediments (labelled in C) are not illuminated by multipath arrivals.

![Figure 1](image1.png)

**Figure 1** Sigsbee2B model used to generate synthetic common source data.

![Figure 2](image2.png)

**Figure 2** ADCIGs for the Sigsbee2 model at 9 horizontal locations. (a) are the primary contributions for each image point (b) are all other multipath contributions.

Conclusions

The separation of multipath ADCIGs allows consideration of the separate contributions for one common image point from different types of arrivals. Examples show multipath arrivals usually have different amplitude and phases, as well as incident angles and image times, when imaging. If they are not separated, the amplitudes and phases in the final prestack image will not stack coherently across sources. The additional information provided with the multipath ADCGIs will benefit migration velocity analysis (MVA) and full waveform inversion (FWI).
References


