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A practical 1.5D approach to internal multiple elimination on mildly structured 3D data

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Summary

In this paper we introduce a practical 1.5D approach to internal multiple elimination (IME) for 3D data application in relatively simple geological settings. The 1.5D approach, or so-called CMP approach, is a low dimension implementation of the so-called common-focus-point (CFP) approach proposed by the DELPHI consortium. An algorithmic improvement to obtain a better intermediate dataset for calculating CFP gathers is discussed, and some practical aspects of the CMP approach such as handling statics and topography for land data are addressed as well. Testing results demonstrate that the CMP approach of IME generates reasonable results of internal multiple removal for mildly structured land data.

Introduction

Multiples can be divided into two classes: surface-related multiples and internal multiples. The method of surface-related multiple elimination (SRME) has been well established and evolved rapidly, both algorithmically and computationally (Verschuur et al., 1992; Moore et al., 2008). However, the removal of internal multiples is still a challenging problem and more difficult to address. There are various methods developed for internal multiple removal. Berkhout and Verschuur proposed a CFP approach that uses the convolution of three virtual gathers to predict the internal multiples (Berkhout and Verschuur, 1997; Berkhout and Verschuur, 2005). The layer-based implementation of this approach requires approximate picking of multiple generating layers. The method proposed by Jakubowicz (1998) uses the convolution and correlation of surface data to predict internal multiples. This approach does not need subsurface velocity information but also requires picking of multiple generating horizons. The method of inverse scattering series (ISS) (Weglein et al., 1997) does not require the picking of multiple generators and theoretically can remove all orders of multiple, but the implementation of this method for 3D data is prohibitively expensive. For all these methods, the predicted internal multiples are usually removed from data by adaptive subtraction.

Generally, full 3D implementation of the methods mentioned above for IME are computationally expensive. In order to make the implementation more practical, lower-dimension approximation schemes can be an appropriate choice to save computation cost if the associated geological settings are relatively simple. Western Canada seems to be a suitable area for applying lower-dimension methods, and there have been some examples of applying IME methods to Western Canada data in recent years, such as the 1D ISS approach by Melo et al (2014) and the 3D Jakubowicz approach by Wang and Wang (2014). We adopt a 1.5D implementation of the CFP approach with some algorithmic improvements, and test our implementation with synthetic data and real data.

Theory

The CFP approach decomposes the internal multiples into three wavefield components, which correspond to three virtual gathers. The concept of this approach is illustrated in figure 1, which shows one possible ray-path of an internal multiple with source at j and receiver at i. The dash line intersects the ray-path and divides it into three parts. Each part can be taken as a trace of a virtual gather. The part in blue can be regarded as a trace of the virtual common-shot gather with source at surface and receivers at depth level z_n; the part in red can be regarded as a trace of the virtual common-receiver gather with receiver at surface and sources at depth level z_n. The part in green can be regarded as the virtual reflection as "seen from below" for an experiment where both sources and receivers have been sunk from surface down to depth level z_n. Berkhout and Verschuur (2005) reformed the virtural common-receiver gather and common-shot gather as CFP gathers and the virtual reflection data as a so-called "grid-point gather". Then, the internal multiples can be predicted by the convolution of CFP gathers and grid-point gather.

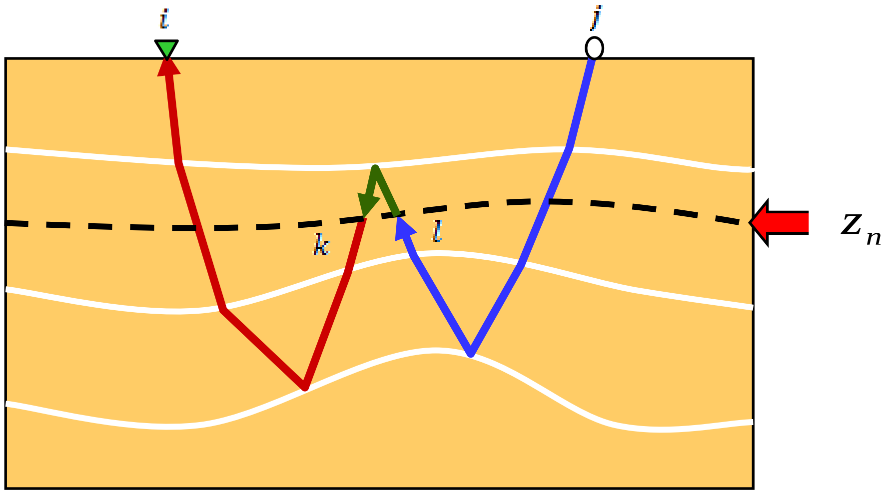


Figure 1. Theory of internal multiple elimination (Berkhout and Verschuur, 1997). The raypath of internal multiples can be divided into three parts. The part from *j* to *l* corresponds to a trace of virtual common-source gather; the part from *l* to *k* corresponds to a virtual reflection trace as seen from below at depth z_n; the part from *k* to *i* corresponds to a trace of virtual common-receiver gather. The partial contribution to interal multiple can be calculated by convolving these three traces. The internal multiple for one source-receiver pair can be predicted by summing all possible partial contributions.

If the subsurface roughly exhibits a 1D gelogical structure, the shot gather and receiver gather are similar(in the context of the above algorthimic description) to a CMP gather, and the CFP and grid-point gathers can be approximately calculated from CMP gathers. So, our implementation of IME is conducted in the CMP domain. To improve the prediction of the multiple model, the CFP and grid-point gathers, which are intermediate datasets required to implement the aforementioned convolutions, should be subject to certrain processing steps to supress artifacts and noise. As an algorithmic improvement, redatumed geologically plausible velocities are employed to achieve better flattening and smoothing of these intermediate results

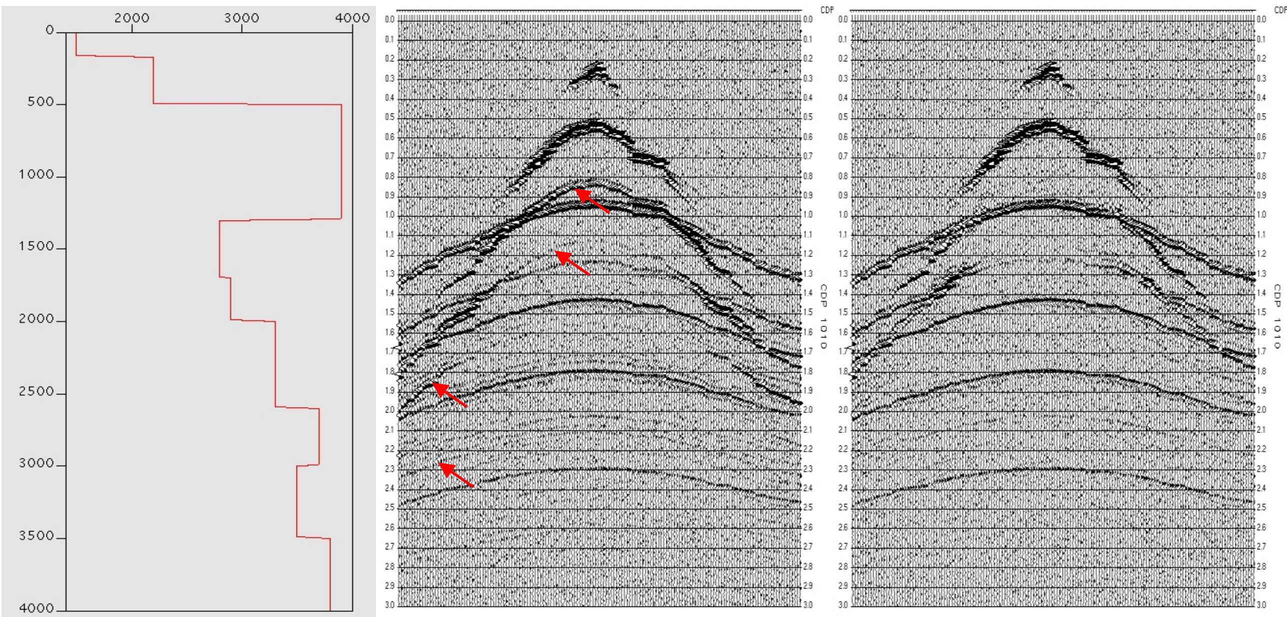
It should be pointed out that the predicted multiple model is layer-based. We need to approximately define layers that contain main internal multiple generators. For example, the dash line in Figure 1 defines a two-layer subsurface. For the internal multiples down-reflected by the reflctor contained in the first layer, their raypaths cross the dashed line at least four times, a geometrical condition which must exist to allow these particular internal multiples to be predicted and removed from input data. If we want to remove the internal multiple down-reflected by the second reflector in Figure 1 as well, we need to pick another depth curve below the second reflector to ensure satisfaction of the above condition, which leads to defining a three-layer subsurface, and so forth.

After the prediction of multiple models for all defined layers, the multiples are removed from input data by adaptive subtraction, which typically consists of two stages of match filtering: global match filtering and local match filtering. The global match filtering helps match the source wavelet of input data, and the local match filtering further honors the local variations of input data in terms of phase and amplitudes.

For land data application, topography and near surface statics should be accounted for properly. For the present CMP-based implementation, this can be readily accomplished by ensuring the input data are corrected to a CMP-consistent floating datum. Any travel time errors caused by the assumption that all near surface statics are similar within a CMP gather can be addressed by the match filtering.

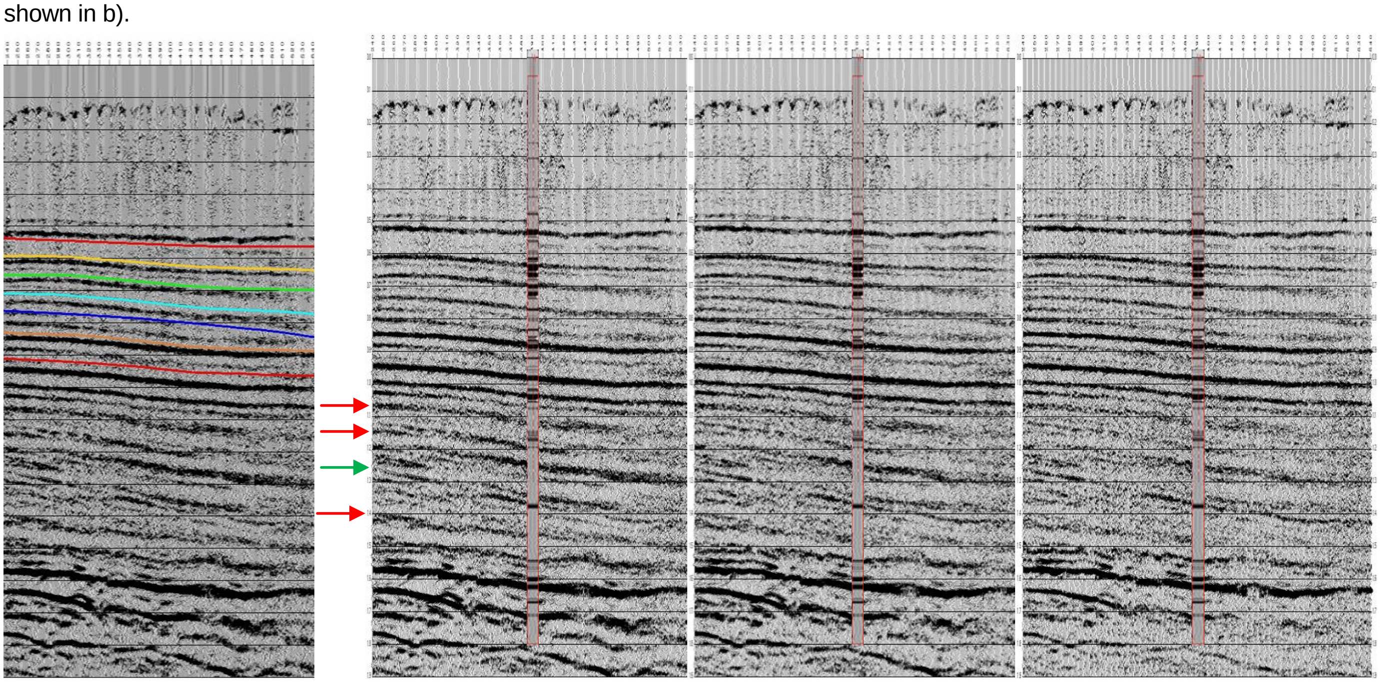
Examples

Synthetic data are used to test the CMP approach of IME first. Figure 2 shows a 1D earth model, a synthetic CMP gather with internal multiples and random noise, and the de-multiple result. We can see that the internal multiples, as indicated by the red arrows, are effectively attenuated.



a) b) c)

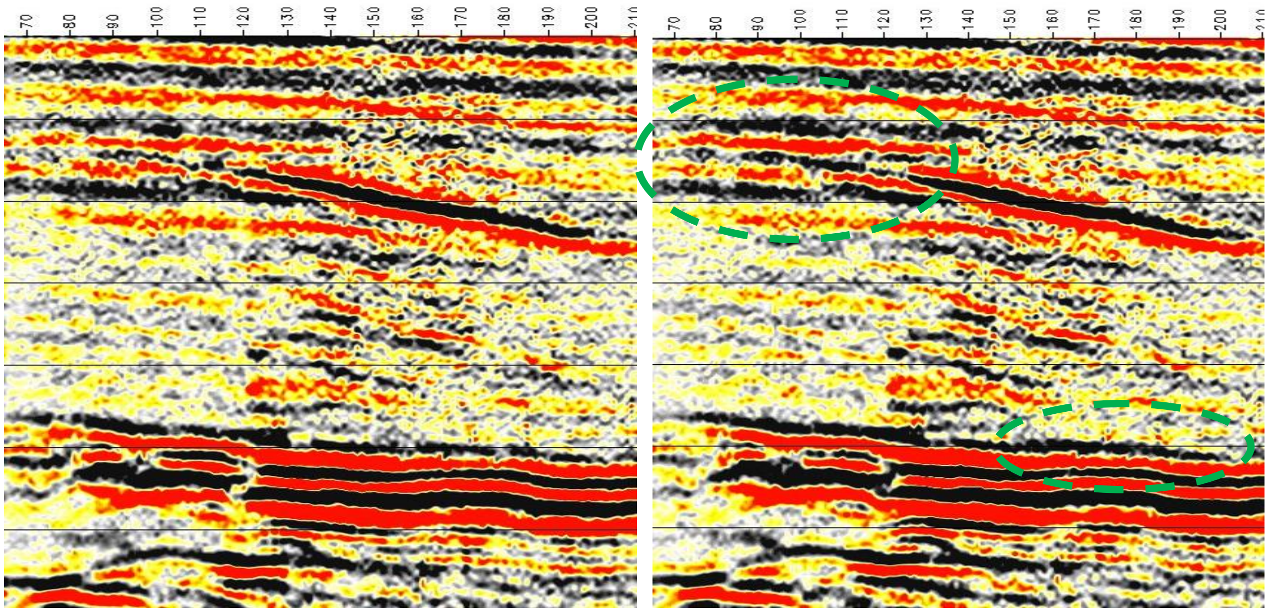
Figure 2. synthetic example of internal multiple elimination. a) 1D earth model. b) a CMP gather with internal multiples (indicated by red arrows) and random noise created from the model in a) by the reflectivity method. c) de-multiple result of the CMP gather shown in b).



a) b) c) d)

Figure 3. a) layer picking for internal multiple prediction. b) stacked input data. Some possible multiples are indicated by red arrows, and a primary event is indicated by a green arrow c) stacked output data with SRME applied. d) stacked output data with SRME and IME applied.

Then, we apply the CMP approach of IME to a real 3D data set from the Horn River region of Western Canada, and the results are shown in Figure 3. Seven layers are picked to predict the multiple models (Figure 3 a)), and each layer has a corresponding multiple model. These multiple models are matched to and simultaneously subtracted from input data by two stages of adaptive match filtering. Figure 3 b) shows the stacked input data for a single inline, and a synthetic trace created from neighbouring VSP data is mapped onto the stacked section. Some possible multiple events are indicated by red arrows, and an primary events is indicated by green arrow. With SRME applied, the marked primary event becomes consistent with VSP data, while the multiples are still obviously present (Figure 3 c)). With IME applied, the multiples are more effectively attenuated and the primary is more consistent with VSP data (Figure 3 d)). Figure 4 shows the effect of our algorithmic improvement for calculating CFP and grid-point gathers. From the stacked IME result, we can see that the continuity of events is improved, as indicated by the green circles.



a) b)

Figure 4. a) zoomed stacked output with IME applied using the original algorithm in which CFP gathers are flattened and smoothed using manually hard-coded constant velocity. b) zoomed stacked output with IME applied using our new modification in which CFP gathers are flattened and smoothed using redatumed geologically plausible velocities.

Conclusions

A CMP approach of internal multiple elimination is discussed in this paper. With an assumption of 1D geological structure, our implementation of IME is conducted in CMP domain, which can be quite practical and efficient. Algorithm improvement for calculating intermediate results of CFP gathers is discussed, and practical issues such as topography and statics are addressed for the application to land data. Testing results show that the CMP appraoch of IME produces reasonalbe result for mildly structured data.

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