

Multiple Prediction by Wavefield Extrapolation in Common-P Domain

B. Wang, Y. Kim, H. Guan, S. Sen, M. Guo, and K. Yoon

TGS, 2500 CityWest Boulevard, Suite 2000, Houston, TX 77042, USA

Summary

Wavefield extrapolation (WFE) multiple prediction typically operates in common shot domain, and is very effective to predict complex multiples such as diffracted multiples; however, it is a model-based and relatively expensive approach. In this paper, we present a new WFE multiple prediction algorithm which operates in common-P domain. This new algorithm is able to very efficiently predict source-side multiples, and less model-dependent; therefore enables its usage in the early stage of processing. In this paper, we first perform some analysis of two types of diffracted multiples: 1) source-side diffracted multiples and 2) receiver-side diffracted multiple. With the new insight of source-side diffracted multiples, we have developed a new algorithm to predict source-side multiples. This new algorithm for source-side multiple prediction is a variant of WFE approach, but almost model independent. Testing on both synthetic and field data demonstrates the effectiveness of the new multiple prediction method.

Introduction

Removing surface-related diffracted (DF) multiples in 3-D seismic data is a challenge (Baumstein et al., 2006, Page et al., 2007), especially in areas with a rugose water bottom or a rugged top of salt. Wavefield extrapolation (WFE) multiple prediction (Pica et al., 2005) can be an alternative technique to convolution-based SRME techniques and it is particularly well-suited for predicting diffracted multiples. However, WFE multiple prediction is a model-based approach, which requires a velocity model and a reflectivity model which is often derived from a migration image. Since we use the same velocity model for WFE as the model used for migration, WFE is somewhat insensitive to velocity errors at near offsets, but prediction errors can be significant for multiples at far offsets or for diffracted multiples.

WFE in common shot domain (Kabir et al., 2004; Pica et al., 2005; Matsen and Xia, 2007), has many advantages, such as no requirement of shot interpolation; however, it is a model-based and relatively expensive approach. While receiver-side multiple prediction only needs a water bottom surface and a water velocity, source-side multiple prediction is more model-dependent. To be able to predict source-side multiples, WFE should be performed to a depth below the water bottom to contain all the major multiple

generation surfaces. To accurately predict source-side multiples, the reflectivity model has to be high-resolution and sharp enough to contain diffractors, and the velocity field has to be accurate to correctly predict the diffraction tails.

Because WFE requires a reasonably accurate velocity model and a corresponding migrated image, it is often difficult to use WFE in the early stage of processing.

We will describe some characteristic differences between source-side diffracted multiples and receiver-side diffracted multiples. Among other differences, source-side diffracted multiples have the same wave-front curvature as the primary diffraction; while receiver-side diffracted multiples have a larger radius of curvature. Therefore, source-side diffracted multiples are just static vertical time shift of primary diffraction events.

Based upon the fact that the source-side diffracted multiples are a simple static shift of the primary diffractions, we have developed a new algorithm to predict the source-side multiples in common-P domain, which is almost data-driven. This source-side multiple prediction algorithm is very efficient and requires a much less amount of computation than does receiver-side multiple prediction. Testing on both synthetic and field data demonstrates the effectiveness of the new multiple prediction method.

Source-side vs. receiver-side diffracted multiples

Water bottom peg leg multiples can be source-side or receiver-side peg legs (Berryhill and Kim, 1986). Pica et al. (2005) introduced a WFE method that can predict both source and receiver-side multiples by applying WFE to only the common-shot gathers such that it adds a round trip between the water surface and many depth levels that generated source-side multiples (see also, Matsen and Xia, 2007). However, this approach requires a velocity model and a reflectivity model which are often not available at the early stage of processing. Since WFE is a demigration (or modeling) process, it is somewhat less sensitive to the velocity errors as long as we use the same velocity model that was used to generate a reflectivity model. However, prediction errors can be still significant for multiples at far offsets or for diffracted multiples.

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Figure 1a is a schematic diagram showing how a source-side diffracted multiple is generated. The wavefield from a source first has a round trip in the water column before it hits a diffractor. Therefore, a source-side diffracted multiple has the same diffraction moveout as the primary diffraction with the diffraction apex right above the diffractor. That is, the source-side diffracted multiple is simply a delayed primary diffraction by a time shift determined by the time difference between the direct path and the source-side multiple path between the source and the diffractor. On the other hand, a receiver-side multiple is generated in the following sequence (see figure 1b): The wavefield from the source first hits the diffractor, then the diffracted wavefield has one more round-trip inside the water layer before it is recorded. With an assumption of a flat water bottom and a free surface, the one more round-trip inside water layer is equivalent to having the receivers on a surface at a distance twice the water depth up from the water surface. Since the receiver-side diffracted multiple travels in the water layer one more round-trip, the receiver-side multiple has a larger radius of curvature and its apex will be later than that of the source-side multiples.

Figure 2 shows a common-shot gather by acoustic modeling of a flat water bottom (at 1.5 km depth) and with a diffractor located just below the water bottom. The figure illustrates the characteristics of the source-side diffracted multiples as described above in comparison with those of the receiver-side diffracted multiples: 1) a smaller radius of curvature, 2) a time shift from its primary diffraction; 3) the apex arrived earlier than that of the receiver-side diffracted multiple except when the source is directly above the diffractor. In general, the amplitude of source-side diffracted multiples is higher than that of receiver-side diffracted multiples.

A new source-side multiple prediction algorithm

Based upon the fact that source-side diffracted multiples are simply a vertical static shift of the primaries, we have developed a new algorithm which is able to predict not only source-side diffracted multiples, but also source-side reflection multiples as well.

The new algorithm proceeds as follows: 1) Generate a common-p gather, which is basically stacking of all common-shot gathers with each shot record shifted by a linear-delay needed to form a line source (Zhang, 2005); 2) automatically pick the water bottom on the common-p gather; 3) delay each shot record by the picked waterbottom time; 4) stack all the new delayed shot record to form a new common p gather. The new common-p gather will contain all the source-side multiples. The method can be extended to 3-D by generating plane waves instead of common-p waves.

The fact that only the auto-picked waterbottom time is used to shift each shot record has an important implication: The new method does not require a velocity model to predict the source-side multiples. Since multiple elimination must be performed at the early stage of processing, this can be a great advantage over the standard WFE methods that require a velocity model and a reflectivity model below the water bottom. Comparing with the regular WFE method, this new method to predict source-side multiples is very efficient, only has the cost of generating common-p gathers, while the regular WFE's cost to predict source-side multiples approaches wave-equation migration (Matsen et. al., 2007).

Examples

We have tested the new algorithm using both synthetic and field data. For synthetic testing, we used 2D BP synthetic data set. Figure 3b is predicted source-side multiples in common-P domain using the new approach. Comparing with input data shown in figure 3a, this new source-side multiple prediction algorithm can predict any order of source-side multiples at a very low cost. Moreover, it requires a far less amount of computation than predicting receiver-side multiples using WFE, because it only generates a common-P gather. Figure 4 shows a common-p gather containing both source (blue arrow) and receiver-side (red arrow) diffracted multiples. The source-side diffracted multiple arrives earlier, and has a smaller radius of curvature than the receiver-side multiple. Figure 4b shows the results after removing the receiver-side multiples predicted by applying WFE to the common-p gather using only a water bottom model. Clearly, after removing the receiver-side multiple, the source-side multiple still remains in the data. Figure 4c shows the results after removing only the source-side multiples predicted by this new method. Clearly, after removing the source-side multiple, the receiver-side multiples still remain in the data. Figure 4d shows the result after removing both the source-side and receiver-side multiples. Note that both source and receiver-side multiples are removed in figure 4d.

Figure 5 shows another example how source-side and receiver-side multiples are different, and can be removed separately. Figure 5a is the original data containing both source-side and receiver-side multiples for comparison; Figure 5b is the result after removing receiver-side multiples using the regular WFE with only a water bottom model, with source-side multiples still remaining; Figure 5c is the result after removing source-side multiples using the new method, with receiver-side multiple still remaining; Figure 5d is the result after removing both source-side and receiver-side multiples.

We would like to emphasize the fact that using the new method we only have to generate a model containing the

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water bottom, unlike other WFE approaches that require a velocity model and a reflectivity model below the water bottom.

We have successfully tested the new source-side multiple prediction algorithm on a 2D field data set from W. Greenland in conjunction with the regular WFE multiple prediction for the receiver-side. Figure 6a shows a common-p gather containing many orders of multiples and 6b shows the predicted multiples using the new algorithm. Note that since this new algorithm is using the data as input and adding a round trip between the water surface and the water bottom, our method can predict all orders of multiples by converting the primaries to the first order multiples, the first order multiples to the second order multiples, and so on.

Conclusions

For the regular WFE-based multiple prediction techniques, we have to generate a velocity model and a reflectivity model to correctly predict both source and receiver-side multiples, which is a nontrivial task at the early stage of processing. We have developed a new insight on source-side diffracted multiples. Based upon the new insight on source-side multiples, we have developed a new and efficient approach to predict the source-side multiples. Since the receiver-side multiples can be predicted by performing WFE only to the water bottom, and this new source-side multiple prediction is not model-based, and is better-suited at the early stage of processing. Testing on both synthetic and field data demonstrates the effectiveness of the new multiple prediction method.

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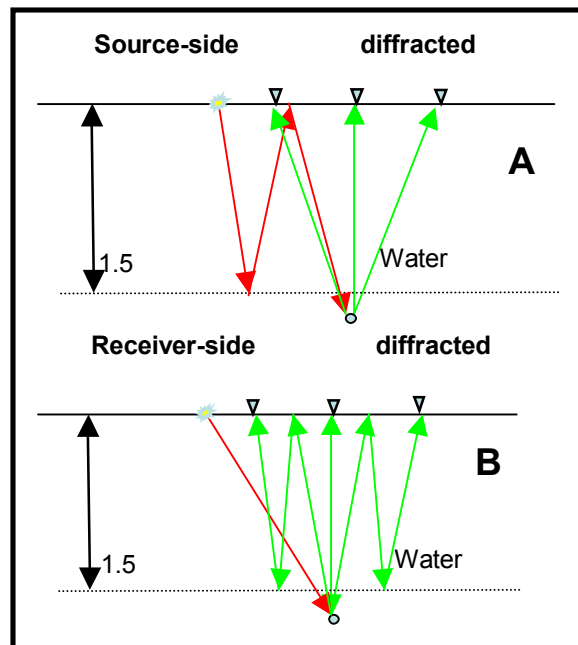


Figure 1. (a) Schematic diagram showing source-side diffracted multiples; (b) Schematic diagram showing receiver-side diffracted multiples.

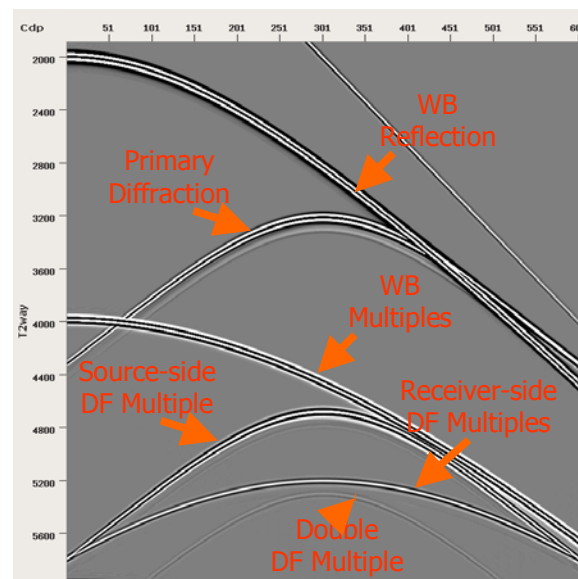


Figure 2. Two-way acoustic modeling result of a shot record using the model shown on the left.

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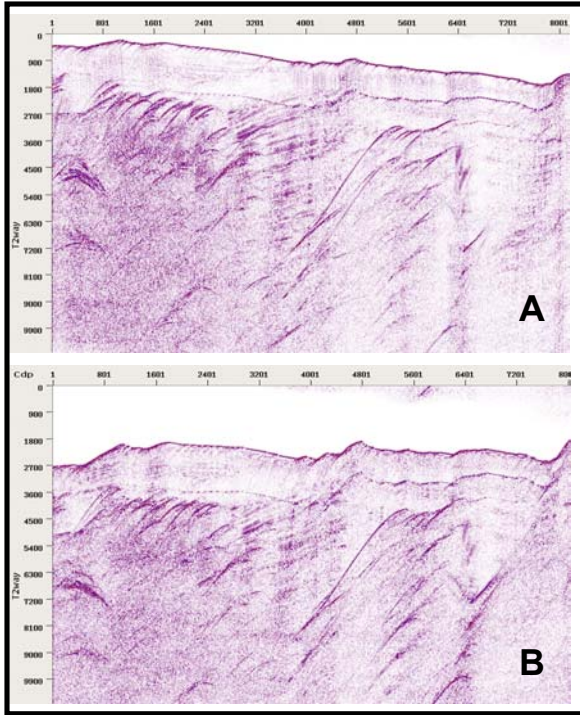


Figure 3. Source-side multiple prediction in common-P domain for BP synthetic data.

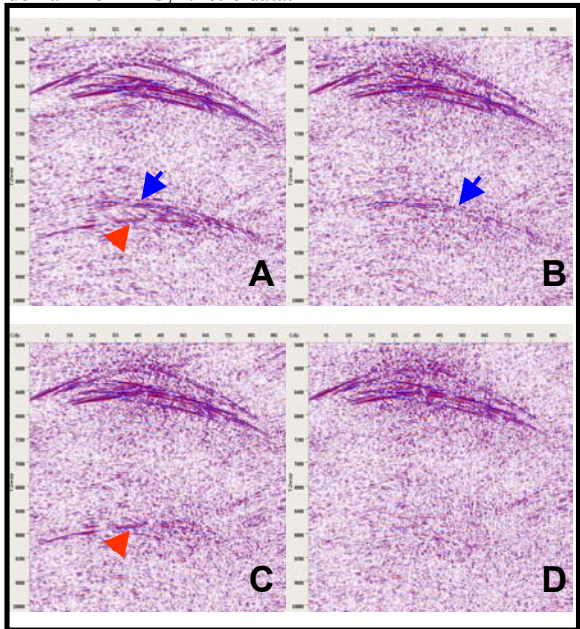


Figure 4. (a) Data with both source-side and receiver-side diffracted multiples; (b) After removing the receiver-side multiples; (c) after removing source side multiples; (d) after removing both source and receiver-side multiples.

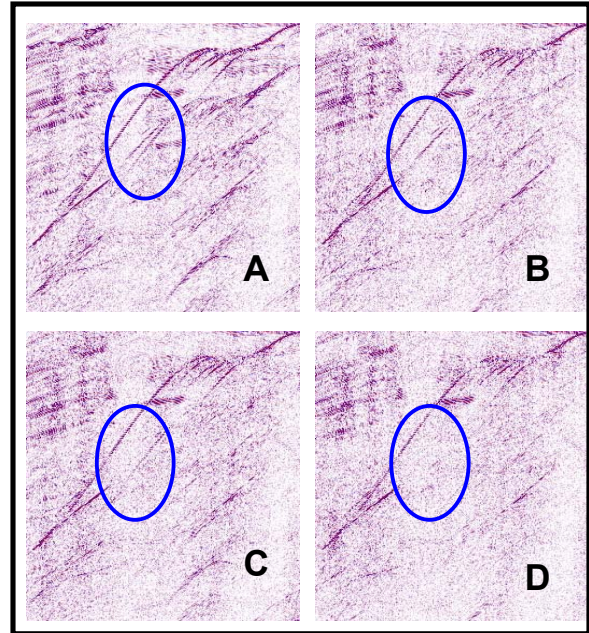


Figure 5. (a) Data with both source-side and receiver-side diffracted multiples; (b) After removing the receiver-side multiples; (c) after removing source-side multiples; (d) after removing both source and receiver-side multiples.

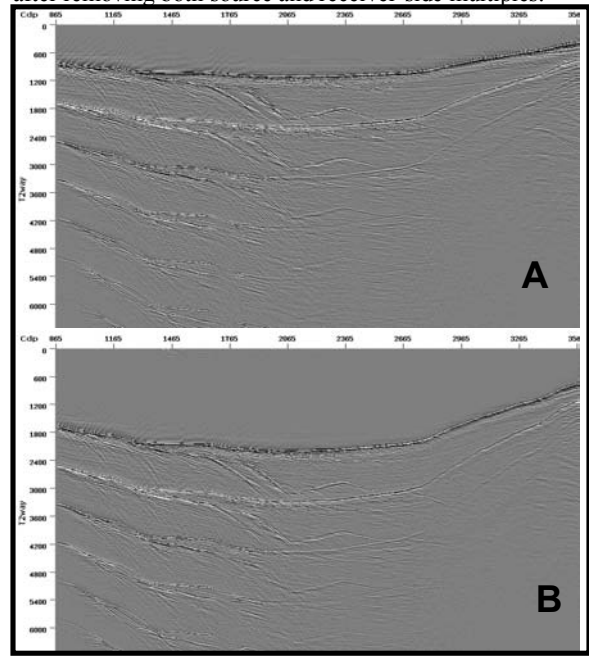


Figure 6. 2D field data example from Greenland: (a) a common-p gather; (b) predicted source-side multiples using the new method for the corresponding common-p gather shown in (a), Note that the new method is able to predict all orders of multiples.

EDITED REFERENCES

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