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Spectrum-preserving internal multiple elimination and its application to a 3D land dataset

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Summary

We improve the conventional internal multiple prediction algorithm by replacing the correlation operator with a phase shift operator using user picked horizons as guidance. As a result, the amplitude spectrum is not altered in the correlation step, which makes it easier to apply matched filtering after the multiple model is computed, and the computational cost is reduced because there is no need to construct the correlation trace. We validate the method with a 2D synthetic dataset and an onshore 3D dataset. We use a VSP corridor stack to further validate our demultiple methodology.

Theory

Demultiple is an important step in seismic data processing because untreated multiples can be misinterpreted as primaries, and they can lead to bad drilling decisions. When the velocity difference between primaries and multiples are noticeable, the multiples can be effectively removed by conventional model-driven methods like Radon transform (e.g., Hampson, 1987; Sacchi & Ulrych, 1995). Otherwise, data-driven methods like Surface Related Multiple Elimination (SRME) (Berkhout and Verschur, 1997), and Internal Multiple Elimination (IME) (Jacubowitz, 1998)) are preferred. The former is used to remove surface-related multiples, and the latter is to remove internal multiples. It has been showed that these methods can be adapted to attenuate multiples in land data (Wang and Wang, 2013; Wang and Wang, 2014). One of the challenges to IME is the degraded frequency contents due to convolution and correlation operators required in the modeling process, compared with convolution only in SRME. In addition, the multiple generator (the correlation trace) may be contaminated by random and coherent noise, which limits the accuracy of the obtained multiple model.

In this paper, we propose an alternative way to correct the multiple model to the surface with less computational cost and better quality. Given user-defined horizons and NMO velocities, we analytically compute the travel time of the generator and design a phase-shift operator in the frequency domain to correct the travel time of multiple contributions. The amplitude is corrected in the matched filtering stage.

The IME algorithm can be understood as SRME followed by a travel time correction. Mathematically, each multiple contribution can be formulated as a convolution between a common shot trace and a common receiver trace and then correlating with a third trace connecting a receiver of the common shot gather and a source of the common receiver gather (see Figure 1).

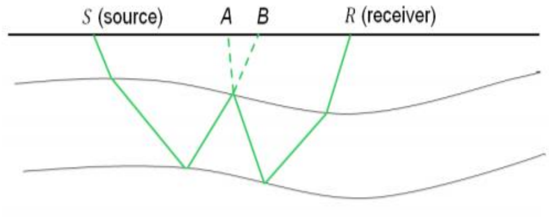


Figure 1: Theory of internal multiple elimination (Jacubowitz, 1998). A multiple contribution can be calculated by convolving a common shot gather trace (from *S* to *B*) with a common receiver gather trace (from *A* to *R*) and then correlating with a third trace (from *A* to *B*).

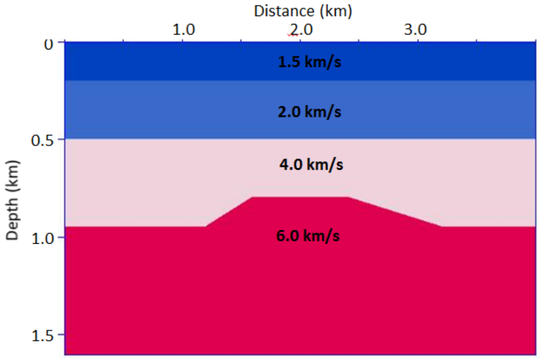


Figure 2: Velocity model for generating the synthetic data.

In the space and temporal frequency domain, the multiple model can be expressed as

$$M(S,R,\omega) = \sum_{Ai=1}^{n} \sum_{Bj=1}^{n} \left(D(S,B,\omega) \cdot D(A,R,\omega) \cdot D^{*}(A,B,\omega)\right),. \tag{1}$$

where M is the frequency domain multiple model for the seismic trace corresponding to a source at *S* and a receiver *R*, $D(S,B,\omega)$ is the data from *S* to *B*, $D(A,R,\omega)$ is the data from *A* to *B*, and $D^{*}(A,R,\omega)$ is the conjugate of the data from *A* to *B*, all in the space and temporal frequency domain.

By ignoring the amplitude term in $D^{*}(A,B,\omega)$, Equation 1 can be changed to

$$M(S,R,\omega) = \sum_{Ai=1}^{n} \sum_{Bj=1}^{n} \left(D(S,B,\omega) \cdot D(A,R,\omega) \cdot e^{-i\omega t_{AB}}\right), \tag{2}$$

where t_{AB} is the travel time from *A* to *B*, which can be calculated based on the horizon travel time and the NMO velocity of the midpoint between A and B. There is no need to construct the data corresponding to the event from *A* to *B*. Instead only the travel time from *A* to *B* is required in Equation 2. Therefore the computational cost for data interpolation is reduced.

If we want to model internal multiples generated by more than one horizon, we can repeat applying Equation 2 for all horizons. One shortcoming of the proposed method is that we assume the amplitude of the generator is time invariant. Therefore we need to tune up the amplitude by sequentially subtracting multiple models from the input data, from shallow to deep. Alternatively, it may be beneficial to apply simultaneous subtraction using all multiple models. In this paper we only show the result for a single major generator to validate the proposed method.

Equation 2 can be extended to 3D cases by summing multiple contributions over a surface instead of a line. The cost of 3D IME grows exponentially when the size of summation aperture increases. In practice we often limit the crossline contributions to reduce the computational cost particularly when the geology is not complex.

In the real world, it is rare to record data exactly on the multiple summation grid. To construct the data for the algorithm, we simply find the nearest trace considering different dimensions including inline, crossline, azimuth and offset and apply partial moveout correction to fit each summation grid point.

Synthetic example

To test the method, we prepare a velocity model with slightly complex structure (see Figure 2), where density is set to a constant for simplicity. The data is generated by a finite-differencing method. A Ricker wavelet with dominant frequency of 25 Hz was used in the simulation. The surface boundary condition is applied to absorb surface multiples. Therefore we can only observe primaries and internal multiples. We also observe some artifacts due to imperfect boundary absorbing conditions.

Figure 3 shows the shot gather at the center location (distance=2.0 km) and the predicted multiple models using two different methods. It can be seen that the new method generates a cleaner and sharper model than the conventional method. The artefacts in the conventional method were introduced by correlating with the generator (the first event) that has gone through linear noise attenuation in the preprocessing stage and imperfect internal data muting in the model prediction stage. The new method is less affected because what we need from the generator is only the travel time as indicated in Equation 2.

(a) (b) (c)

Figure 3: Raw multiple model comparison of two IME methods. (a) Input shot gather. (b) Multiple model computed using the conventional method (Jacubowitz, 1998). (c) Multiple model computed using the proposed method.

The new method provides a sharper multiple model because the wavelet is only degraded once in the convolution process. In contrast, the wavelet is degraded twice in the conventional method due to one convolution and one cross-correlation as shown in Equation 1. The amplitude spectrum comparison (Figure 4) confirms our observation. Not surprisingly, the frequency contents of both methods degrade compared with the input. The new method preserves low and high frequencies better than the conventional method. Theoretically the quality of the amplitude spectrum given by the new method should be similar to that of the SRME method.

Field data example

We also test the algorithm with a land 3D dataset. Figure 5 compares stacks before and after IME demultiple. The blue curve highlights the generator that serves to reflect back events below (annotated with a green brace) and generate a series of short period multiples around the target zone, which poses a challenge to interpreters who want to map the reservoir. It can be seen that IME has suppressed significant amount of internal multiples from the input, although there are still residuals. It is still a challenging problem to completely eliminate multiples from seismic data without touching primaries when they overlap closely.

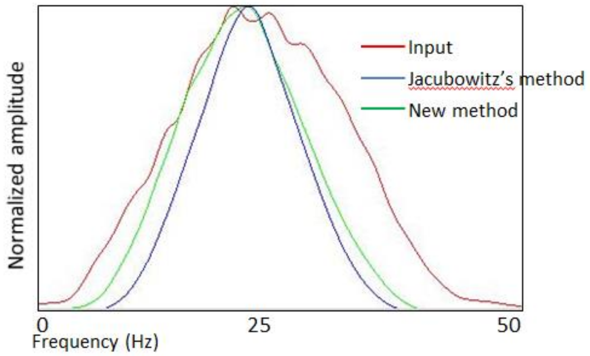
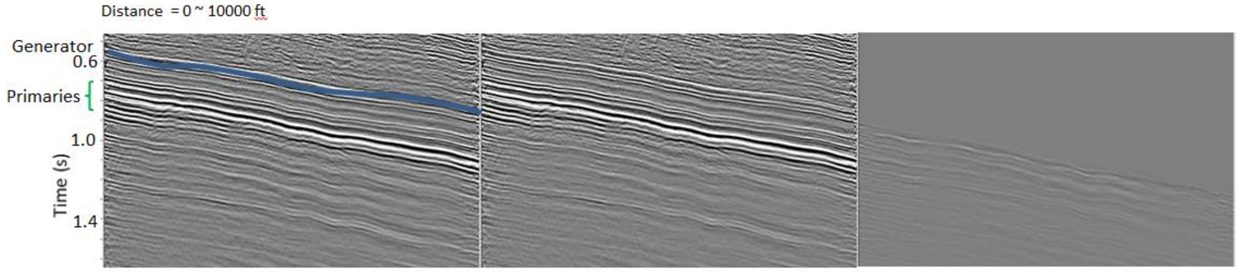


Figure 4: Amplitude spectrum comparison of different IME methods.

The gather comparison in Figure 6 shows that the estimated multiples have small moveout, which makes it difficult for Radon transform to separate them from primaries. Fortunately with a data driven method like IME we can still predict the multiple model and suppress multiples by adaptive subtraction. It is clear that we effectively remove most of the multiples and preserve primaries nicely.



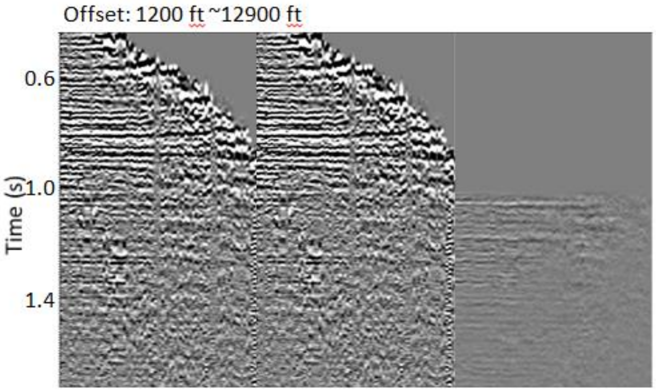
(a) (b) (c)

Figure 5: Stacks before and after IME demultiple. (a) Input stack. (b) Output after IME. (c) Difference.

To quantify our proposed IME process, we tie the stacks with a VSP stack in different stages of processing. Figure 7 shows that with a cascaded data driven demultiple flow we greatly improves the match with the VSP corridor stack. Similar to marine data, in this example surface related multiples are stronger than internal multiples. However, the subtle improvement after IME is equally important because the target zone is seriously contaminated by internal multiples.

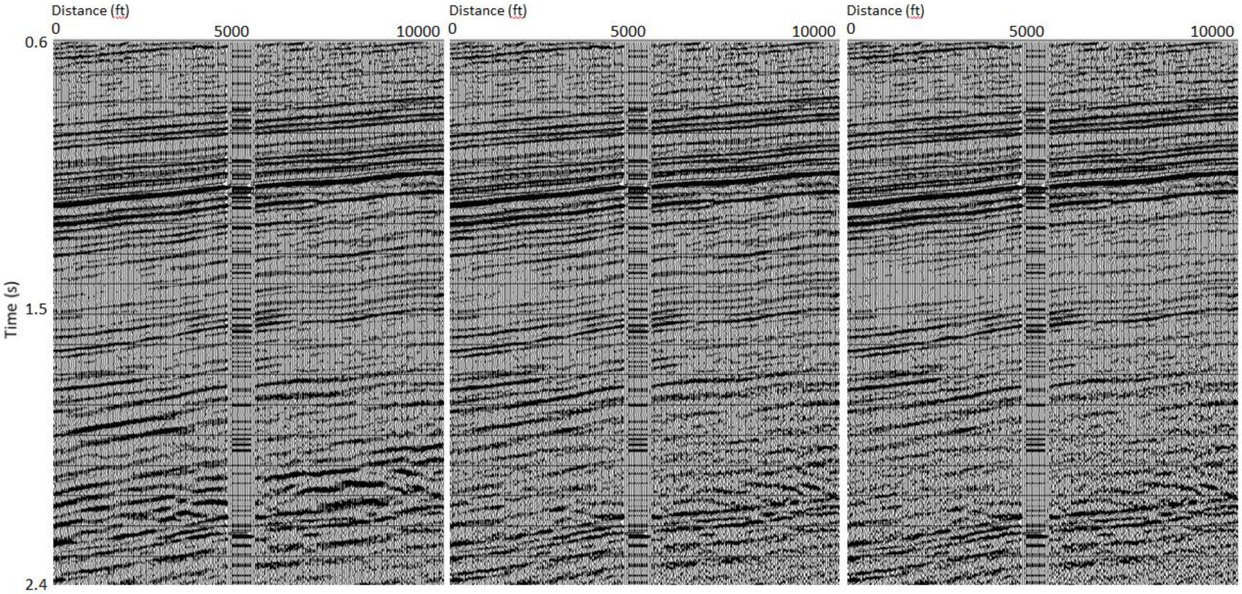
Conclusions

We have proposed a new IME algorithm that is fast and preserving frequency contents better than the conventional method. The resulting multiple model is cleaner compared with that of the existing method. Both synthetic and real data examples show that the method can be a practical solution to removing internal multiples. Good adaptive subtraction method is required to further improve the result of data-driven demultiple methods.



(a) (b) (c)

Figure 6: A CDP gather before and after IME. (a) Input. (b) Output. (c) Difference.



(a) (b) (c)

Figure 7: VSP tie of stacks in different demultiple stages. The VSP corridor stack is shown in the middle of the section in each plot. (a) Input stack. (b) Stack after SRME. (c) Stack after IME.

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