GeoConvention 2015
GEOSCIENCE
new horizons
Telus Convention Centre • 4-8 May 2015 • Calgary, AB Canada

From surface to interbed - a cascaded processing flow for land demultiple

Juefu Wang, CGG, and Shaowu Wang, CGG

Summary

We present an effective processing flow to suppress both surface-related multiples and internal multiples for land data. We show that the two kinds of multiples can be removed using similar methods. In the preprocessing stage, the data are corrected to a smoothed surface and harsh noise attenuation is applied to precondition the data. Then, convolution-based operators are used to predict two kinds of multiples. Finally, a two-step adaptive subtraction is applied to remove the multiples from the input. A field data example with vertical seismic profile (VSP) tie shows the robustness of our processing flow. A comparison of horizon guided convolution and the inverse scattering series (ISS) technique shows that the two multiple prediction methods can provide similar results if we limit the range of the multiple generators for the latter method.

Introduction

Multiples can be divided into two classes, surface-related and internal, based on the boundary where seismic waves are reflected downward. Surface-related multiples must have at least a portion of the ray path in which the seismic wave is reflected downward at the surface, and internal multiples should have all downward reflections in the subsurface. Conventional model-based methods like the Radon transform rely on the velocity difference between primaries and multiples to separate the signal from coherent noise. When the velocity difference is small, it is difficult for model-based methods to remove the multiples. On the other hand, data-driven methods like surface-related multiple elimination (SRME) (Berkhout and Verschuur, 1997) and interbed multiple elimination (IME) (Jakubowicz, 1998) do not require subsurface velocity information to predict multiple models. Because they only predict multiples, there is no need to separate primaries and multiples in another domain. The multiples are removed by matching the predicted multiple model to the original input.

Surface-related multiple elimination is a well-established method in marine processing, but it is less popular in land processing due to the characteristics of land data, including low signal-to-noise ratio, poor spatial sampling, and statics. Wang and Wang (2013) showed that SRME can be effectively applied to land data, but land data require special attention in data preconditioning and adaptive subtraction to address the noise and statics issues.

Internal multiples are more difficult to remove than surface multiples because they are usually weaker than surface-related multiples and the moveout difference from the primaries is smaller. In addition, methods like IME require the identification of multiple generators for data muting, which can be a challenge for multiples generated by complex layers. Here we focus on data with relatively simple multiple generators. For more complex data, the method of inverse scattering series (Weglein et al, 1997; Hung and Wang, 2012) can be a better solution but with much higher computational cost. We show that IME should be used in a target-oriented manner, and conservative subtraction should be applied to protect primaries. To make a practical use of the ISS method, we adopt a 1.5D version of the algorithm, in which we assume seismic data do not change much laterally. Our tests show that the simplified algorithm can be effectively applied to data with mild structure.

Method

Surface-related multiples can be simulated by convolving two seismic traces with relaying ray paths. Figure 1 shows one possible ray path of a first-order multiple. To compute the multiple trace corresponding to the displayed source and receiver, we need to sum up the contributions of all combinations of common shot traces and common receiver traces using a summation aperture because we don't know the exact location of the reflection point.

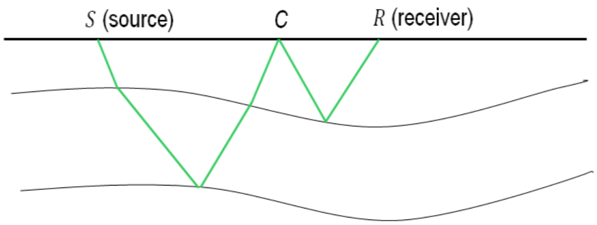

Figure 1: Theory of surface-related multiples (Berkhout and Verschuur, 1997). The multiples for one pair of source and receiver can be calculated by summing up contributions related to all possible relaying ray paths, and each contribution is equal to the convolution of two traces corresponding to two relaying ray paths. The figure shows that one multiple contribution between *S* and *R* is calculated by convolving the trace from *S* to *C* and the trace from *C* to *R*.

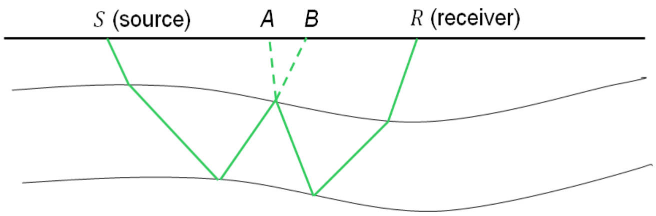

Figure 2: Theory of internal multiples (Jakubowicz, 1998). The multiples for one pair of source and receiver can be calculated by summing contributions related to all possible convolution and cross-correlation combinations. One contribution between *S* and *R* can be calculated by convolving traces from *S* to *B* with the trace from *A* to *R* and then cross-correlating with the trace from *A* to *B*.

Internal multiples can be modeled by first convolving two traces with ray paths that are not necessarily relaying and then correlating with a third trace (Figure 2). In essence, the correlation process removes the overburden influence above the multiple generating reflector. Mathematically, the operator reduces the travel time of the model predicted by the convolution process.

The ISS method (Weglein et al., 1997) is similar to Jakubowicz's method except that the method tries to compute multiples related to all generators. The 1.5D ISS integral formula (Pan and Innanen, 2014) for model prediction is

$$\text{(1)} \qquad m(k_g,\omega)=\int_{-\infty}^{\infty} dz\, e^{ik_z z} b_1(k_g,z) \int_{-\infty}^{z-\epsilon} dz' e^{-ik_z z'} b_1(k_g,z') \int_{z'+\epsilon}^{\infty} dz'' e^{ik_z z''} b_1(k_g,z''),$$

where m is the multiple model, k_g is the lateral wavenumber, k_z is the vertical wavenumber, and b_1 is the depth-dependent wavefield, which can be easily calculated by a standard phase-shift operator. The first and the third term in Equation (1) performs convolution in the frequency and wavenumber domain (FK) and the second term performs the cross-correlation for generators at all depths. In detail, we need to compute the convolution of wavefield below the generator at each depth and then the travel time is corrected by the generator. The strength of the multiple is scaled by the amplitude of the generator. By assuming 1.5D, we can apply the algorithm to each CMP gather without constructing common shot gathers and common receiver gathers, which greatly reduces the computational cost.

Figure 3 outlines our land demultiple processing flow using SRME and IME. The statics correction in the pre-processing stage is required because the process makes it easier to apply noise attenuation algorithms and regularize the data using local interpolation methods in the data preconditioning stage. Performing the statics correction in reference to a smoothed surface helps to stabilize the model prediction (Wang and Wang, 2013), and travel time errors can be removed by applying a two-step least-squares subtraction. In the first step, a CMP-based filter is applied to remove background travel time errors. In the meantime, the wavelet of the model is matched to that of the input data. In the second step, adaptive filtering using data from higher dimensions (inline, crossline, offset and time) is applied to remove residual travel time errors and phase mismatch. The amplitude is also optimally matched in this step.

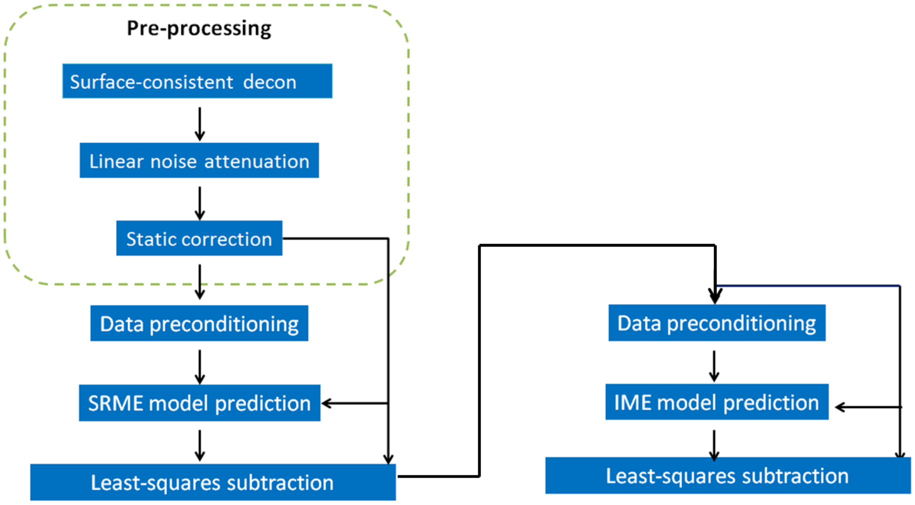

Figure 3: Processing flow for data-driven land data demultiple. The pre-processing stage follows the conventional land data processing flow. The statics correction is applied in reference to a smoothed surface. For both SRME and IME, the data need to be preconditioned prior to model prediction. In the least-squares subtraction stage, each CMP multiple gather is filtered individually to match the input gather and remove the background travel time errors. Then, it is adaptively filtered in higher dimensions to match the input. Finally, the matched model is subtracted from the input.

Field data example

We applied the two demultiple methods to a real dataset with strong surface-related multiples and some noticeable internal multiples. Figure 4 compares the stacks of the input and the output after SRME, IME and ISS. In Figure 4b, the surface-related multiples marked by the red arrows in Figure 4a have been successfully removed. In the area where multiples overlap with primaries (marked with a yellow arrow), the primaries become sharper and more consistent with the VSP data. Figure 4c shows that the internal multiples (marked with green arrows in Figure 4b) have been suppressed effectively by the IME method. The result of the ISS method (Figure 4d) is very similar to that of the IME method.

In this test, we are particularly interested in comparing the performance of the two internal multiple prediction methods. Figure 5 compares the multiple models computed by these two methods. Overall they look similar, but the 3D IME result looks more coherent. This is reasonable because the 3D algorithm uses nearby data within the summation aperture instead of using a single CMP gather, and it properly handles lateral structural change. An important feature of the ISS algorithm is that we don't need to pick any horizons. This is especially helpful when there are many generators and it is difficult to decide which generators to use for multiple prediction.

Conclusions

We present a robust land processing flow by cascading SRME with IME/ISS to remove surface-related multiples and internal multiples, respectively. Our method can handle noisy data by preconditioning the data prior to model prediction. Travel time errors introduced by static correction can be effectively removed by a two-step least-squares subtraction. We have successfully applied the method to a land field dataset, and the result matches well with VSP data. Comparison between 3D IME and 1.5D ISS shows that 1.5D ISS can also be a practical solution for mildly structured data.

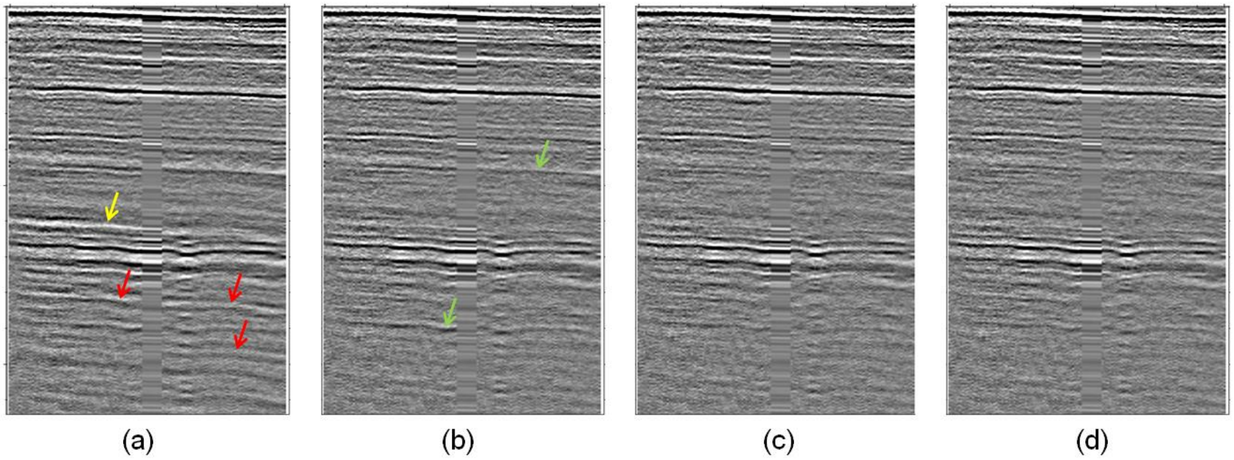

Figure 4: Stack comparison of input and de-multiple output with VSP tie in the middle of the section. (a) Input stack. (b) Output after SRME. (c) Output after SRME and IME. (d) Output after SRME and ISS.

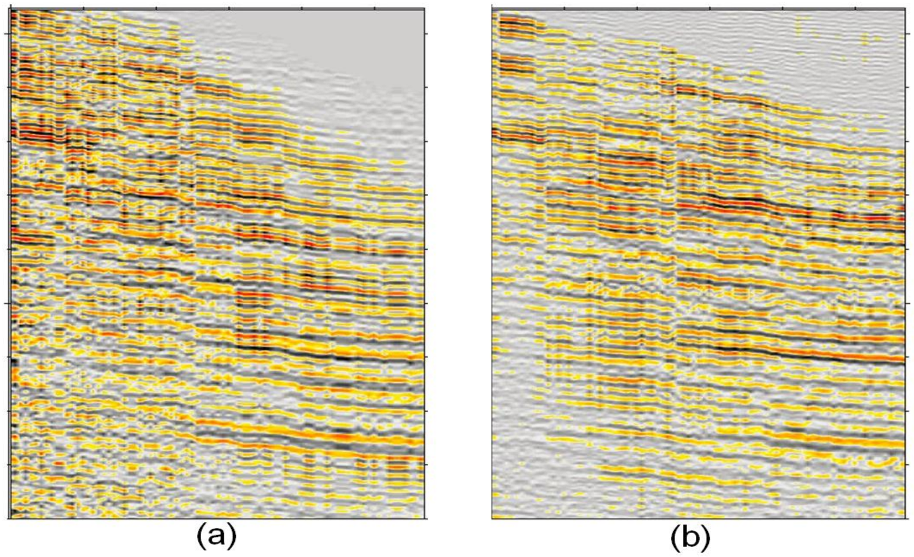

Figure 5: Comparison of internal multiple models (one CMP gather) from different methods. (a) 1.5D ISS. (b) IME.

Acknowledgements

We thank CGG for allowing us to publish this paper, and we also thank Dr. Kris Innanen for helping us to understand the concept of inverse scattering series.

References

Hung, B. and M. Wang, 2012, Internal demultiple methodology without identifying the multiple generators: 82nd Annual International Meeting, SEG, Expanded Abstracts, 1-5.

Berkhout, A. J. and D. J. Verschuur, 1997, Estimation of multiple scattering by iterative inversion, Part I: theoretical consideration: Geophysics, **62**, 1586-1595.

Pan, P. and K. Innanen, 2014, Numerical analysis of 1.5D internal multiple prediction: 84th Annual International Meetng, SEG, Expanded Abstracts, 4135-4138.

Wang, J. and S. Wang, 2013, Practical strategies for data-driven land multiple attenuation: 83rd Annual International Meeting, SEG, Expanded Abstracts, 4101-4105.

Weglein, A. B., F. A. Gasparotto, P. M. Carvalho and R. H. Stolt, 1997, An inverse-scattering series method for attenuating multiples in seismic reflection data: Geophysics, **62**, 1975-1989.