G043

General Surface Multiple Prediction (GSMP) - A Flexible 3D SRME Algorithm

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SUMMARY

Ideal 3D SRME has geometric requirements for its input data that are not met by marine streamer surveys. Consequently, one must either precondition the field data to meet the requirements, or modify the algorithm to match the data. In this paper, we present a new method in the latter category. Our algorithm has many desirable features: it is applicable for any survey geometry and geology, accounts properly for trace azimuth, does not require preconditioning of the field dataset, and predicts diffracted multiples more accurately than other approximations to the ideal 3D SRME algorithm. Analysis of multiples predicted by the algorithm shows that they closely match actual multiples.
Introduction

Ideal 3D surface-related multiple elimination (SRME) is a theoretically correct, data-driven process in which seismic traces are manipulated to predict surface multiples (van Dedem and Verschuur, 2001). For each input trace, selected pairs of traces are convolved to obtain a 3D volume called a multiple contribution gather (MCG) (Figure 1). Stacking an MCG then produces the predicted multiples for the targeted input trace. For good-quality results, the areal extent of each MCG must span a region that contains all of the downward reflection points (DRPs) for the surface multiples in the target trace. Also, each MCG must be regularly sampled in each spatial direction with no aliased dips (Dragoset et al., 2006).

Unfortunately, the spatial distribution of traces in a marine streamer survey does not allow these conditions to be met. In particular: 1) The narrow crossline recording aperture means that traces required for accurate multiple prediction when crossline dip is large often are not recorded. 2) 3D SRME requires non-aliased spatial sampling in four coordinates: inline and crossline source position and inline and crossline receiver position. Usually, only the inline receiver position sampling is adequate. 3) Cable feathering, imperfect boat steering, near-offset gaps, obstruction avoidance, and infill cause irregular sampling of the data.

In recent years, a number of ideas for overcoming obstacles to 3D SRME have been tried. van Dedem and Verschuur (2001) suggested using sparse parametric inversion to overcome spatial sampling limitations. Baumstein et al. (2005) created regularized and densely sampled shot records by a DMO/inverse DMO process. Moore and Bisley (2004) described a method of overcoming the limited crossline aperture of conventional marine surveys by approximately converting multiple predictions made by 2D SRME into those that would be made by 3D SRME.

The limitations of these and other approaches to 3D SRME affect the quality of predictions. Although adaptive subtraction algorithms attempt to compensate for imperfectly predicted multiples, they, too, have limitations. Thus, a need for better methods of 3D SRME remains. Furthermore, the recent proliferation in multi-, rich-, and wide-azimuth (WAZ) marine surveys creates a challenge. Having a single approach to 3D SRME that can handle all survey types with aplomb would be desirable. In this paper, we present a new approach to 3D SRME, called 3D general surface multiple prediction (3D GSMP), which we believe has minimal limitations and is appropriate for all acquisition geometries and geological conditions.

Technical description

Conceptually, the 3D GSMP algorithm is simple, and is closely related to the theoretically ideal algorithm described previously. For each target trace, the geometry of the MCG is defined based on aperture, sampling, and cost requirements, but without reference to the available input data. Unlike in Figure 1, the aperture and grid are aligned with the target trace. Computation of the MCG then requires convolutions of traces that generally will not exist in the recorded dataset. When such a trace is required, the 3D GSMP algorithm simply selects
the nearest available trace and applies differential moveout correction to compensate for the difference in offset between the available and desired traces. No correction is made for differences in midpoint or azimuth. This process is a simple form of interpolation, and means that regularization and extrapolation of the recorded data are not required prior to 3D GSMP.

The definition of “nearest” is flexible, but typically involves minimizing an error term that is a weighted sum of the squared differences in midpoint location, offset, and azimuth between the recorded and desired traces. For a narrow-azimuth survey, the azimuth weight is generally small or zero, because the sampling of the input data is not sufficient to support trace selection based on azimuth. In contrast, the broad range of azimuths provided by WAZ surveys is readily exploited by GSMP. Consequently, the MCGs are more accurate, especially for large crossline apertures.

Although conceptually simple, the 3D GSMP algorithm requires careful implementation to make it efficient. To compute the multiples for a given target trace, we must firstly determine which input traces contribute to the MCG, and secondly must extract those traces efficiently from the recorded dataset. The first task can be accomplished relatively efficiently even for large datasets using, for example, kd-trees. The second task essentially requires random I/O to the input data, and making this I/O efficient is a key part of the 3D GSMP implementation.

**Performance**

3D GSMP is designed to be, in a sense, optimal given the sampling of the recorded data. Given ideally sampled data, the algorithm becomes the theoretically correct algorithm. Errors in the predicted multiples are due entirely to the nearest neighbor approximation. In practice, as with ideal 3D SRME, there will also be errors related to the limited aperture and sampling of the MCG. Those errors can be minimized by appropriate choice of processing parameters.

Use of the nearest trace rather than the desired trace creates timing and amplitude errors in the MCG. Typically, these errors have zero mean, because the errors in midpoint, offset, and azimuth are equally likely to be in either direction. The errors, therefore, create timing jitter in the MCGs. When the MCG is stacked, this timing jitter creates wavelet distortion, especially at the higher frequencies, which appears as noise in the multiple model. The coherent part of the model is, however, correct. This is in contrast to most other 3D SRME algorithms, which suffer from systematic timing errors because of the approximations that are made.

Figure 2 shows an example of the timing errors associated with a real rich-azimuth geometry for a diffracted multiple. 3D GSMP predicts the multiple accurately, albeit with some additional noise. These plots were produced without reference to the recorded data, and therefore, serve as a prediction as to how well 3D GSMP will perform on a given multiple for a given geometry. See the figure captions for more details.

![Figure 2: Comparison of ideal (left) and predicted (center) traveltimes in the MCG for a diffracted multiple. The difference (right) shows that the travelt ime error has zero mean. The green square and triangle show the source and receiver locations, respectively. The multiple corresponds to a source-side diffractor on a planar water bottom, with the diffractor at the origin. The correct DRP is, therefore, one-third of the way from the origin to the receiver location, and corresponds to the minimum travelt ime.](image-url)
Field data example
We have applied 3D GSMP to seismic datasets from numerous locations around the world. One example is shown in Figure 4. The water depth for this survey varied rapidly from about 1000 m to 2500 m in the direction orthogonal to the target line shown. Although 2D SRME predicts the multiples well in a few areas, qualitatively, the overall prediction quality appears poor. The multiples predicted by 3D GSMP, however, seem to be a much better match to the actual multiples. This is quantitatively confirmed by cross correlations of the predicted multiples with the original seismic traces (Figure 4d and 4e). The cross correlations are computed for a cascade of short time windows, whose start times track the shape of the water bottom. A perfect prediction produces a cross correlation that includes a band-limited spike located at zero lag. The 2D SRME cross correlations exhibit areas where the lag is not zero (indicating prediction errors due to 3D effects) as well as areas of poor correlation (indicating no match between the predictions and the actual multiples). In contrast, the 3D GSMP cross correlations are uniformly excellent.

Conclusion
3D GSMP is a simple, yet elegant and practical approach to 3D SRME. It does not require geometric preconditioning of the data, yet provides full control over the spatial sampling and areal aperture of the MCGs. The algorithm is suitable for all geologic conditions and all streamer geometries, including rich-, wide-, and multi-azimuth surveys. Multiples are predicted using the true acquisition geometry, rather than a regular or nominal geometry. Cross correlation analysis demonstrates that multiples predicted by 3D GSMP closely match actual multiples.

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References

Figure 4: Near common offset field dataset. a) Input data. b) Multiples predicted by 2D SRME. c) Multiples predicted by 3D GSMP. d) Cross correlations for 2D SRME. e) Cross correlations for 3D GSMP. The black arrow in d) indicates a correlation peak at a non-zero lag, which is indicative of 3D effects.