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Multiples Attenuation for Variable-depth Streamer Data, Shallow and Deep Water Cases

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SUMMARY

Processing the variable-depth streamer acquisition has recently become possible, with a new joint deconvolution algorithm (Soubaras, 2010). In this particular acquisition, called BroadSeis, the receiver depth regularly increases with offset, which allows a wide diversity of receiver ghosts and so increases dramatically the possible frequency bandwidth, in both low & high-frequencies sides. Compared to conventional flat-streamer data, processing BroadSeis data implies a major change: the receiver ghosts are rigorously taken into account. In conventional processing, both source and receiver ghosts are included in a wavelet that is assumed to be consistent from offsets to offsets. On the contrary, with a BroadSeis dataset, the receiver ghosts change from near offsets to far offsets and so cannot be included in a wavelet. This breaks an implicit assumption of many processing steps such as Surface Related Multiple Elimination (SRME). These receiver ghosts will then be removed from the final image with a pre-stack or post-stack joint deconvolution. Of course, the receiver ghost preservation is a constraint for some programs developed for conventional processing. One of the key challenges, presented in this paper, is how to deal with de-multiples techniques and Variable-depth streamer data, in both deep & shallow-water environments.
Introduction

Processing the variable-depth streamer acquisition has recently become possible, with a new joint deconvolution algorithm (Soubaras, 2010). In this particular acquisition, called BroadSeis, the receiver depth regularly increases with offset, which allows a wide diversity of receiver ghosts and so increases dramatically the possible frequency bandwidth, in both low & high-frequencies sides, from 2.5 Hz to source notch. Compared to conventional flat-streamer data, processing BroadSeis data implies a major change: the receiver ghosts are rigorously taken into account. In conventional processing, both source and receiver ghosts are included in a wavelet that is assumed to be consistent from offsets to offsets. On the contrary, with a BroadSeis dataset, the receiver ghosts change from near offsets to far offsets and so cannot be included in a wavelet. This breaks an implicit assumption of many processing steps such as Surface Related Multiple Elimination (SRME). These receiver ghosts will then be removed from the final image with a pre-stack or post-stack joint deconvolution. Of course, the receiver ghost preservation is a constraint for some programs developed for conventional processing. One of the key challenges, presented in this paper, is how to deal with de-multiples techniques and Variable-depth streamer data, in both deep & shallow-water environments. Several BroadSeis datasets were acquired across the world, among which two examples will be presented, in Central North Sea and West of Shetlands.

De-multiple techniques with BroadSeis data in Deep-water environment

In shallow water environments (< 150m), SRME method is known not to be well adapted for short-period multiples reflections: due to the lack of near-offsets, the recorded water-bottom reflections, used by SRME, are often not good enough or missing. Other common de-multiple methods such as Tau-P deconvolution and Shallow water de-multiple (SWD, Hung et al, 2010) have been tested on BroadSeis data. The predictive deconvolution in Tau-P domain is frequently used for attenuating short-period multiples, mainly from a relatively flat and shallow water bottom. For BroadSeis data, this method could also be applied in both shot and receiver domain, but the main risk is to affect receiver ghosts with a periodicity close to that of the water layer. The key point is to keep a gap long enough to preserve the receiver ghosts (Figure 1a).

![Figure 1](image)

**Figure 1** a) Autocorrelation of a BroadSeis shot gather on a window: offset 0-1400 m, Time 0-3s, showing the ghosts varying along the offset. b) SWD prediction operator derived from conventional data. c) SWD Prediction operator derived from Variable-depth streamer data (same shot location)

The Shallow water de-multiple method uses the water layer related multiples from the data in order to reconstruct the missing water bottom primary reflections. The prediction operators, used to compute a short-period multiples model, are derived from the nearest offsets, where the wavelets are close to those of conventional zero-phase wavelets (Figures 1b & 1c). In practice, SWD allows to remove efficiently the short-period multiples, with results equivalent to those expected on conventional data. These de-multiple methods were tested on a BroadSeis 2D line in Central North Sea. Different trials were done by combining different tools and the best result was finally achieved by combining Shallow water de-multiple, predictive deconvolution in Tau-P domain and SRME (Figure 2): The water-layer multiples are handled by SWD & Tau-P predictive deconvolution, and SRME tackles free-surface multiples that have longer periods. In this case, the water bottom has to be muted prior to generate the SRME model.
De-multiple techniques with BroadSeis data in Deep-water environment

The de-multiple technique commonly used in a deep-water environment is the 2D, or 3D, surface-related multiple elimination (Berkhout and Verchuur 1997). By applying SRME on conventional data, where both source & receiver ghosts have already been included in a wavelet, the modelled multiples are close to the input data multiples. A key issue appears with BroadSeis data, because of the receiver ghosts: Variable receiver depth creates visible differences in wavelet, from near to far offsets. By convolving traces with different wavelets, the standard SRME method produces multiple models with mismatched wavelets, actually different from input data, and the differences vary from offset to offset (Figure 3 & 4).

Figure 3 Results of standard and new SRME on a synthetic variable-depth streamer dataset

a) Input synthetic wavelet with a receiver ghost at a given depth 30m, and its corresponding spectrum
b) Mismatched multiple wavelet produced by the standard SRME
c) Correct Multiple wavelet created by the new SRME
Even if this particular problem can be partially solved through a wavelet adjustment - with already a significant effectiveness - this method was developed for conventional data and cannot handle properly the multiples wavelet variations. Indeed, the standard SRME method leaves a lot of residual multiples, and the low frequency multiples provided by the Variable-depth streamer acquisition cannot be properly addressed. That's why some algorithmic modifications were introduced to improve the multiples model prediction by normalizing the receiver ghosts. This new SRME technique allows creating multiples model with correct wavelets on the full frequency bandwidth. Once the multiples model matches perfectly with the input data, the multiples model adjustment could be even more accurate and efficient.

This new technique was successfully applied on 2D and 3D datasets and has consistently produced better results than standard SRME (Figures 5 & 6). The example below, from a BroadSeis dataset in West of Shetlands, illustrates the results of Standard SRME and New SRME in common offset / channels planes corresponding to three different receiver depths (7.8, 20 and 30 m). In order to compare properly the multiples model predictions, the same adaptive subtraction parameters were applied in both cases.

**Figure 4** Multiples wavelet variations on three offset planes corresponding to 7.8, 20 and 30 meters cable-depths, on a BroadSeis dataset in West of Shetlands.

**Figure 5** From left to right : a) Input offset Plane corresponding to 20 meters cable-depth b) Multiples model generated with standard SRME c) Multiples model generated with New SRME

**Figure 6** From left to right : a) Input offset Plane corresponding to 20 meters cable-depth b) Result with adaptive subtraction of the multiples model generated with standard SRME c) Result with adaptive subtraction of the multiples model generated with New SRME
Figure 7 Results of Standard SRME and New SRME on stacks (post-stack deghosting). a) Deghosted stack without SRME b) Deghosted stack with standard SRME c) Deghosted Stack with new SRME.

The receiver ghost normalization method could be theoretically extended to any de-multiple technique producing a multiples model which could be adapted and subtracted to the input data. This method is currently being tested with other standard de-multiple techniques, such as: SWD, Convolutional inter-bed de-multiple or Radon de-multiple.

Conclusions

Processing BroadSeis data introduces new challenges, mainly due to the receiver ghosts which have to be preserved and used in the Joint deconvolution for the final image. A key challenge is how to deal with de-multiples techniques and receiver ghost preservation. Some existing de-multiple methods like Shallow-water de-multiple, Tau-P predictive deconvolution can significantly attenuate multiples with results equivalent to those expected on conventional data. Nevertheless, these techniques were developed for conventional flat-streamer data. That's why some algorithmic modifications are currently being tested and introduced, such as a new SRME for example, to improve the de-multiple effectiveness for BroadSeis data.

References

