Effective seismic interference elimination enabled by multi-component data from marine acquisitions
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Summary
We present a fast and effective method to detect and eliminate seismic interference from 3D marine data measured by four-component (4C) streamers.

The interference elimination method we propose acts on each shot record independently from the others, relying on the pressure wavefield being reconstructed (and simultaneously deghosted) on a 2D grid, densely sampled in both the inline and the crossline directions. Such reconstruction is enabled by matching-pursuit-based signal processing techniques proposed recently in the literature that have the capability to explicit the information in the multicomponent measurements. Without these measurements, the reconstruction capability is seriously compromised by the strong crossline aliasing.

We show that the interference can be easily isolated and removed from the data, with a high degree of signal preservation, after the data are reconstructed on a dense grid of receivers. When supported by vector based seismic interference detection, this technique has the potential of being automated and applied directly during the acquisition timeframe.

Introduction
Seismic interference experienced during marine acquisitions is a common problem for the seismic industry. We present effective ways to eliminate it from marine seismic data measured by streamers that record the full particle velocity vector (Vx, Vy and Vz) in addition to the pressure wavefield.

The vector information describes the polarization of the seismic events, which in water gives important clues on the directionality of the wavefield, and hence it enables a more robust detection and elimination of seismic interference related events (Rentsch and Brouwer, 2011). Several methods can be applied to achieve this in different domains (Warner et al, 2004; Gulunay et al., 2004; Yu, 2011).

One approach in particular relies on the reconstruction of common-shot measurements on ideal grids of receivers, finely sampled in both the inline and the crossline directions. In fact, it has been shown that the particle velocity measurements enable the explicit reconstruction of the wavefield overcoming the severe spatial aliasing that usually affects the crossline direction (Vassallo et al. 2010, Özbek et al. 2010). After the wavefield is reconstructed on a dense 2D grid and the seismic interference is detected, as well as its direction of arrival, a simple directional filter in the common shot domain can effectively and quickly separate the desired signal from the interfering ones; this could even be accomplished within the acquisition timeframe. We tested our method on real data acquired by multicomponent streamers and we present the concepts and the results achieved in the presence of strong seismic interference affecting the recorded shots.

Multicomponent tests in the presence of seismic interference
Extensive tests were carried out in the North Sea with an advanced streamer platform for making multicomponent measurements, able to measure the pressure (P) as well as the full particle velocity vector (Vx, Vy and Vz). In these experiments, six segments of streamer were towed, each of them being 500m long. During some of the tests, another seismic survey was conducted in close proximity; this generated significant seismic interference on some of the shots, even causing some delays in the acquisition. The interference was initially regarded as a processing challenge, but it gave us a great opportunity to test a multi-component SI azimuthal detection technique as well as multicomponent reconstruction techniques in the presence of extreme aliasing in the crossline direction and significant wavefield complexity.

Figure 1: Polarization-based azimuth estimate for several adjacent shots (top panel). Azimuth is measured in degrees relative to positive inline. Bottom panel: Comparison between the measured azimuth and the analytical azimuth obtained from logged radar positions of the other acquisition.
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The Vx and Vy were used to determine a time and space variant azimuth via polarization analysis as described in Robertson et. al, (2007). Furthermore, we were able to log the radar position of the vessel causing the SI, allowing us to compare the measured azimuth from the data to the analytical azimuth based on sensor positions and the radar logs. Because the arrival time of the interference changes from shot to shot (see top panel Figure 1) we searched for coherent signal with azimuths different from the azimuthal range consistent with our own source and receiver geometry and calculated trace by trace the median azimuth of such coherent but out of plane events. The comparison between the measured and analytical interference azimuths holds very well (bottom panel) and shows that out of plane seismic interference can be detected and its azimuth correctly determined.

Note that the measured interference was often coming from a direction almost orthogonal to the multicomponent streamers, with an azimuth close to 80° with respect to positive inline of our spread and very high incidence angles relative to the vertical. The nature of the interference was a very strong and compact series of events, with very high apparent velocity along the inline direction of each streamer, but heavily aliased in the crossline. Figure 2 shows the example of a shot gather of the pressure wavefield measured in the presence of such interference. In this example, all streamers were towed at 17.5 m depth and at 75 m nominal crossline spacing. Both the inline and the crossline views (top left and right) are shown in Figure 2, with a t² gain. The interference is clearly recognizable between 1.5 s and 3 s. The aliasing in the crossline is obvious in the region affected by the interference already in the time-space crossline view (Figure 2, top right), but it is even clearer in the panels on the bottom, showing slices of the 3D frequency-wavenumber transform of the data in the time window affected by the interference. Here, the replicas of the crossline spectrum overlap the region of the signal significantly, as it is clearly visible in the f-kx slice (bottom right). It is also interesting to observe how these replicas affect significantly the f-ky slice (bottom left).

In conventional marine acquisition measuring only the pressure component, no processing technique could safely remove this type of seismic interference without affecting the signal while operating on single shot gathers. The velocity vector measurements, on the other hand, provided additional information to allow the reconstruction of this wavefield and consequently the seismic interference interpretation and elimination on a dense grid of receivers free of spatial aliasing.

Multicomponent-based wavefield reconstruction and seismic interference elimination

The Generalized Matching Pursuit technique (GMP, Özpek et al. 2010) is a technique able to extract from the multicomponent measurements the information to reconstruct (and deghost) the 3D wavefield on a regular dense grid, and it can do this even in the presence of severe spatial aliasing. We applied GMP to the pressure wavefield shown in Figure 2, jointly used with its crossline gradient, derived from the crossline particle velocity measurement (Vy), and with its vertical gradient, derived from the vertical particle velocity measurement (Vz). The results of

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GMP are shown in Figure 3. The severe aliasing in crossline was resolved correctly and the seismic interference appears as a compact series of coherent events propagating at low apparent velocity in the crossline direction. In particular, looking at the crossline slice of the 3D spectrum (Figure 3, bottom right), the effects of the de-aliasing performed by GMP are evident: the replicas have disappeared. The signal can now be correctly interpreted in the F-kx slice as well (Figure 3, bottom left), establishing that most of the energy shown in the same panel in Figure 2 is actually due to the crossline spectral replicas that affect the signal bandwidth. It is clear from Figure 3 that the

Figure 3: Pressure reconstructed by GMP on a regular grid of receivers; Top left: inline view of virtual streamer at about 130m crossline offset; Top right: crossline view at 250m inline offset; Bottom: frequency-wavenumber 3D transform of volume of data in the time window between 1.5s and 3s: frequency/inline wavenumber (f,kx) slice at k_y=0 (left) and frequency/crossline wavenumber (f,k_y) slice at k_x=0 (right).

Figure 4: Pressure reconstructed by GMP on a regular grid of receivers after a directional filter is applied to eliminate the seismic interference; Top left: inline view of virtual streamer at about 130m crossline offset; Top right: crossline view at 250m inline offset; Bottom: frequency-wavenumber 3D transform of volume of data in the time window between 1.5s and 3s: frequency/inline wavenumber (f,kx) slice at k_y=0 (left) and frequency/crossline wavenumber (f,k_y) slice at k_x=0 (right).
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Seismic interference can now be easily isolated from the signal of interest. Hence, once the data are reconstructed on a dense grid, a simple directional filter should be able to eliminate the most of the seismic interference on a shot-by-shot basis, without affecting the signal.

Figure 4 shows the data after the application of a directional filter to eliminate the interference from the dataset of our example. The elimination appears very successful and the signal seems unaffected.

To further evaluate the results, we produced the stack of the acquired line before and after the elimination of seismic interference; both results are shown in Figure 5 (a) and (b), respectively. In particular, a diffracted event is very well recognizable in Figure 5 (b) after 2.5 s: the same event is hard to identify in the stack showed in Figure 5 (a), being completely covered by interfering noise. In Figure 5 (c) we show the stack of the removed interference. We note that there is no coherent seismic energy, which confirms the effectiveness of our approach enabled by the multicomponent measurements, and suggests that the signal is well preserved while the interference is correctly removed from the data.

Conclusions

Thanks to four-component measurements and to the wavefield reconstruction to a dense grid enabled by such measurements and techniques such as GMP, the seismic interference can be correctly interpreted and efficiently eliminated on a shot-by-shot basis with relatively simple procedures, like the application of directional filters. For instance, the directionality of the filter can be determined by applying automatic vector polarization analysis techniques to the velocity measurements. When the direction of the interference is clearly different from the direction of the main signal, simple, robust and effective seismic interference elimination can be successfully achieved, as illustrated by the example on real data.

Acknowledgments

We thank Tony Curtis, Smaine Zeroug, Phil Kitchenside and Johan Robertsson for helpful and inspiring discussions. We also would like to thank WesternGeco management for permission to publish this paper.

Figure 5: Inline stacks of pressure. a) Measured pressure in presence of seismic interference, (b) pressure after seismic interference elimination, (c) stack of the interference that has been detected and eliminated: no residual of signal appears to be there.
EDITED REFERENCES

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REFERENCES


