# Seismic Blending and Deblending in 3D

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## SUMMARY

We propose a new acquisition design based on blended crossline sources. In contrast to existing blended-acquisition designs that only blend in 2D (inline direction and time), this design blends sources in 3D (inline direction, crossline direction and time). Blended crossline sources allow to increase the data quality and/or to reduce the acquisition costs. While most blended-acquisition designs blend two sources, the proposed acquisition design blends up to seven sources. In order to realize this increase in number of blended sources without degrading the data quality, we introduce a 3D deblending method that exploits both the crossline and inline direction to deblend sources. The feasibility of the proposed method is demonstrated on a complex synthetic data example with good results.

## Introduction

In traditional marine acquisition the crossline source direction is very poorly sampled. Increasing the crossline source sampling would be a very costly operation as it requires adding extra sail lines. However, with the development of new blending and deblending techniques (Berkhout, 2008) more advanced acquisition configurations become feasible, that improve the source sampling in the crossline direction without requiring extra sail lines. Thus, blending is beneficial in terms of data quality and acquisition costs. In this abstract we would like to introduce the crossline-source array that blends data in 3D. The design of the crossline-source array is such that it will allow for an improved 3D deblending.

## Blending the crossline-source array

Figure 1 compares a conventional acquisition design (a) to a crossline-source array (b). The crossline-source array acquires the same area (indicated in grey) as the conventional acquisition design but it requires fewer streamers. Note that many variations of the set-up are possible (Reinicke, 2015), e.g. adding more wide-towed streamers would improve the economics as the acquired area would become larger or placing the sources closer together would increase the data quality as the crossline width of the bins becomes smaller.

In order to keep both the inline and crossline source sampling small while maintaining an acceptable vessel speed, the crossline sources must be fired in a blended fashion, i.e. their seismic responses overlap. To be able to use this heavily blended data (the blending factor will be much higher than 2) we need to deblend it before further processing. The design of the crossline-source array allows us to optimize the deblending by introducing a 3D deblending method. Note that the deblending performance can be improved further by using optimized firing-time delays between blended shots (Reinicke, 2015).

## Deblending the crossline-source array

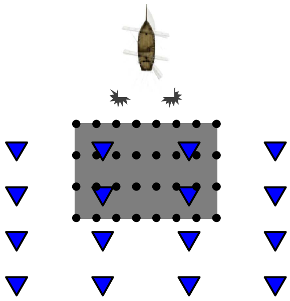
In 3D acquisition the sources and receivers are distributed on a 2D surface. Each data point that is measured by a source receiver pair at a specific time is described by five coordinates: time t, receiver inline and crossline position ($x_r$, $y_r$), and source inline and crossline position ($x_s$, $y_s$).

### *2D Deblending*

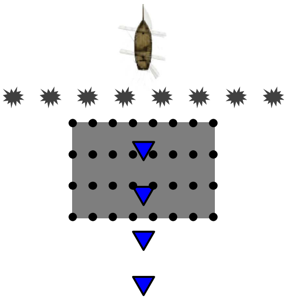
The presented deblending strategy is similar to the 2D deblending method of Mahdad et al. (2011). In their iterative method they build a pseudo-deblended dataset by copying and time-shifting the blended data. In a pseudo-deblended common-receiver gather the signal of the aligned sources is coherent while the interfering sources are incoherent. This incoherent signal is referred to as blending noise. First, they use a coherency constraint in the f-$k_x$ domain to attenuate the amplitude of the blending noise. Second, a sparsity constraint is applied, namely thresholding, in the x-t domain to estimate blending noise. In the next step they subtract the blending noise from the pseudo-deblended data.

### *3D Deblending*

In the case of 3D blended data we suggest the same deblending method as Mahdad et al. (2011) but with a 3D coherency constraint in the f-$k_x$-$k_y$ domain. Other deblending steps are performed analogously to the 2D method.

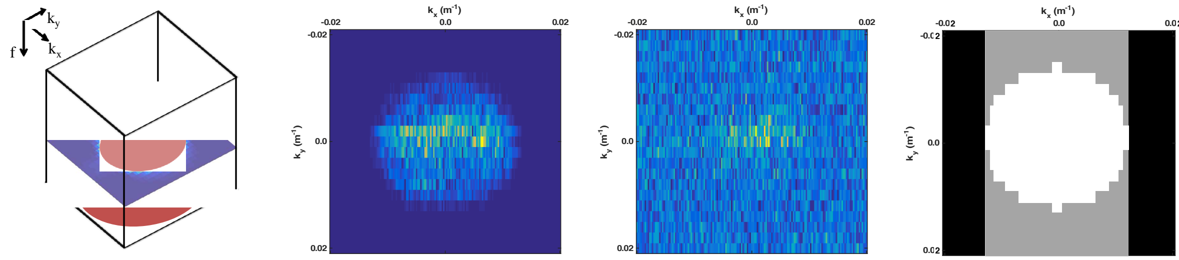


*(a)*



*(b)*

***Figure 1*** *(a) Conventional acquisition design, (b) crossline-source array.*




***(a)*** *3D filter mask* ***(b)*** *Unblended data slice* ***(c)*** *Pseudo-deblended data slice* ***(d)*** *Filter mask slice*

***Figure 2*** *(a) shows a 40 Hz frequency slice of the data in the f-$k_x$-$k_y$ domain. The red cone represents the edge of the 3D f-$k_x$-$k_y$ filter mask. (b) and (c) show a 40 Hz frequency slice of the f-$k_x$-$k_y$ spectrum of the unblended and pseudo-deblended 3D common-receiver gather in Figure 4 respectively. (d) is a 40 Hz frequency slice of the f-$k_x$-$k_y$ mask where the white area equals one and the black and grey area are zero. In case of a 2D f-$k_x$ mask only the black area is zero.*

Assume a pseudo-deblended 3D common-receiver gather, $p_{ps}(t, x_s, y_s)$, as input for the coherency constraint. These data are transformed to the f-$k_x$-$k_y$ domain. There the coherent signal will be inside a cone (see Figure 2a). That this is indeed the case is illustrated when we bring the unblended data of Figure 4a (which we will discuss later) to the f-$k_x$-$k_y$ domain and show a constant frequency slice (Figure 2b). This 2D matrix captures the crossline and inline wavenumbers ($k_x$, $k_y$). The lowest wavefield velocity and the frequency determine an upper limit, $k_{max}$, for the wavenumber, k ($k^2 = (k_x^2 + k_y^2) < k_{max}^2$). Hence, the signal cone is a circle in the $k_x$-$k_y$ domain. The incoherent signal present in the pseudo-deblended data of Figure 4b maps both in- and outside the cone as can be seen in Figure 2c. A 3D filter can be designed to exclude the incoherent signal outside this cone. In Figure 2d one can observe that the 3D filter (black and grey) has the ability to attenuate incoherent noise more effectively than the 2D filter (black only). Reinicke (2015) has demonstrated that therefore, the 3D filter gives better deblending results than the 2D filter, which passes some of the incoherent noise.

**Results on complex synthetic data**

The following data example is extracted from a SEG SEAM dataset. The data are modelled with a source grid of 21 sources along the crossline direction and 81 sources along the inline direction (see Figure 3). The source spacing is 25 m in both directions. Since the presented deblending method is applied in the common-receiver domain it is sufficient to consider a single receiver position; we consider the one that is placed in the left upper corner of the source grid. Figure 4a, Figure 5a, and Figure 6a show an inline slice, crossline slice and time slice of the unblended data respectively.

The sources are fired crossline-wise, i.e. first all sources of crossline one are fired, next, all sources of crossline two, etc. The 21 shots within each crossline are numerically blended in three seismic experiments, i.e. there are seven shots per experiment. Note that a blending factor of seven is very high compared to many current blended acquisition designs that use a blending factor of only two. The firing-time delays between the blended shots are optimized according to Reinicke (2015).

Figure 4 shows inline slices of the unblended, pseudo-deblended, deblended receiver gathers and the error at the inline position $x_s = 250$ m. In analogy Figure 5 illustrates crossline slices at the inline position $y_s = 2000$ m. Figure 6 displays time slices through t = 1.8 s of the data.

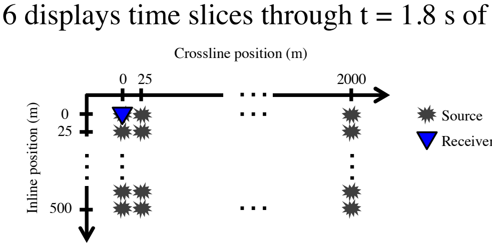



***Figure 3*** *Illustration of the SEG SEAM source grid array. There are 81 sources along the inline direction and 21 sources along the crossline direction. The source spacing is 25 m in both crossline and inline direction. The receiver indicates the position of the receiver gather considered in Figure 4-6.*

A comparison of the unblended and deblended data demonstrates the strength of the 3D deblending method. The quality factor (a measure similar to SNR, Ibrahim and Sacchi, 2015) can be used to rate the deblending performance of our method on the SEAM data with 14.2 dB, a very good result.

## Conclusions

We have successfully demonstrated deblending in the case of a numerically blended crossline-source array configuration, using the SEAM data. The good deblending results demonstrate the feasibility of blending and deblending in 3D.
The benefit of 3D blended acquisition is two-folded; it enhances the data quality and reduces the acquisition costs.
The presented 3D deblending method takes advantage of a coherency constraint of the data in the f-$k_x$-$k_y$ domain, in contrast to 2D deblending methods, which only use coherency constraints in the f-$k_x$ domain.

## Acknowledgements

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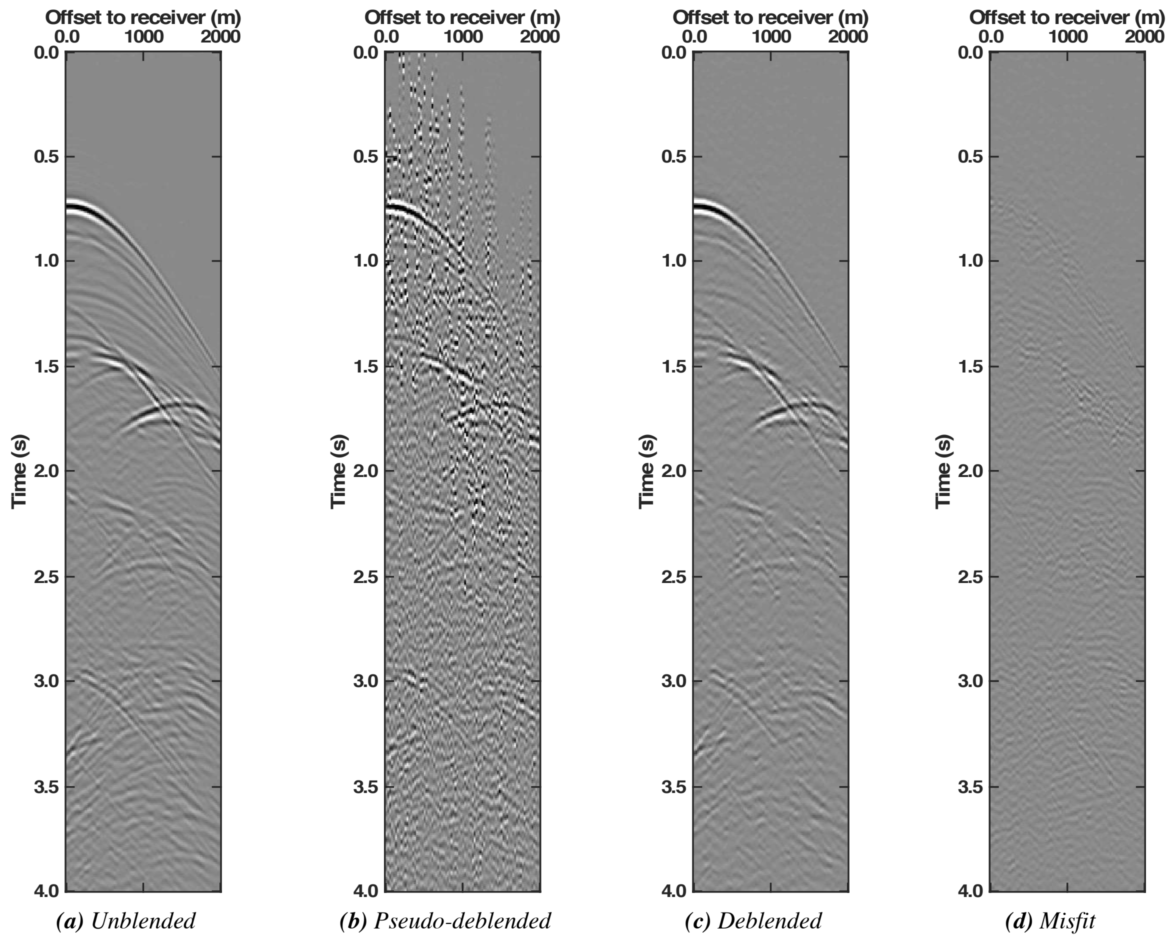
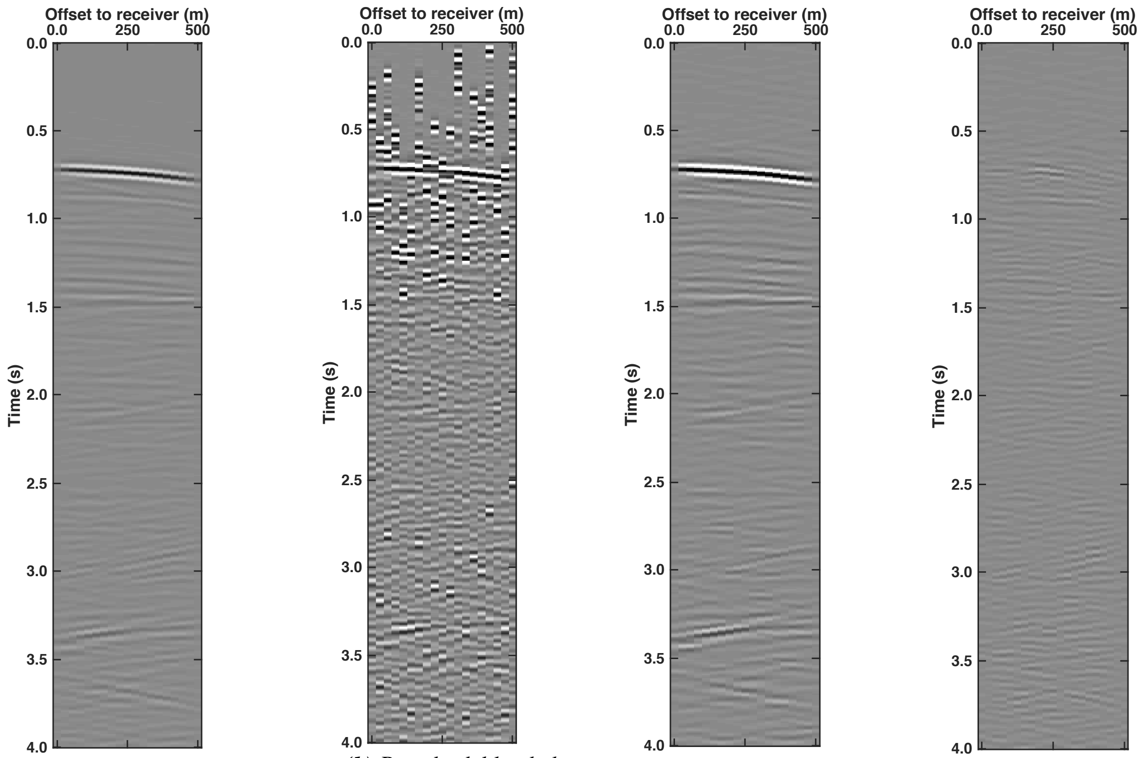


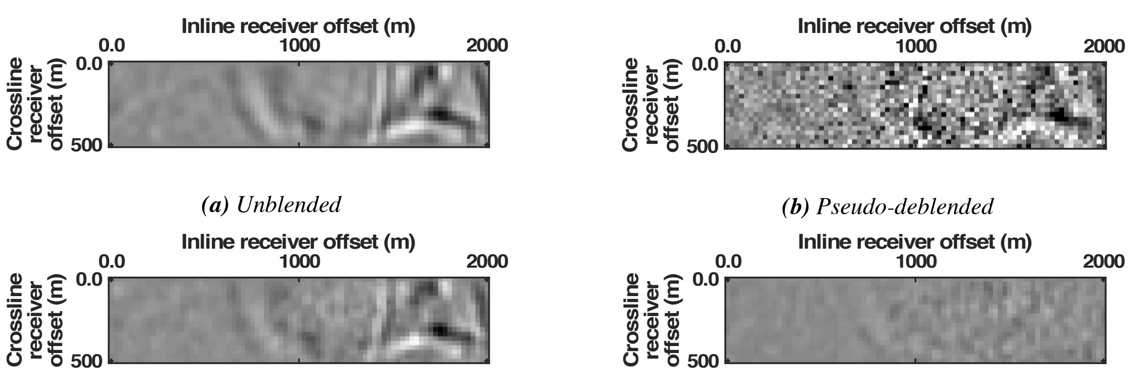

***(a)*** *Unblended* ***(b)*** *Pseudo-deblended* ***(c)*** *Deblended* ***(d)*** *Misfit*

***Figure 4*** *(a) – (d) show inline slices at the inline position $x_S$ = 250 m of the SEG SEAM data. The shown seismic sections are common-receiver gathers.*




***(a)** Unblended* ***(b)** Pseudo-deblended* ***(c)** Deblended* ***(d)** Misfit*

***Figure 5** (a) – (d) show crossline slices at the inline position $y_S$ = 2000 m of the SEG SEAM data. The shown seismic sections are common-receiver gathers.*




***(a)** Unblended* ***(b)** Pseudo-deblended*

***(c)** Deblended* ***(d)** Misfit*

***Figure 6** (a) – (d) show time slices through t = 1.8 s of the data in Figure 4 and Figure 5.*

## References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