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Sparse inversion based deblending in CMP domain using Radon operators

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Summary

Deblending of simultaneously sourced data is often represented as denoising in the receiver domain. By posing the deblending operation in an inversion scheme, we can achieve a refitting of the original data without the loss of events. To do this we combine the blending operator with an additional focusing operator and treat both as a single combined operator for least squares inversion. To aid in focusing of the Radon model we implement the inversion using sparse priori through minimization of the L1 norm. To avoid the increased computational cost associated with proper focusing in the receiver domain using apex shifted Radon, we implement the deblending framework in the CMP domain. The CMP domain allows us to use a simpler Radon operator than would be required for focusing in the receiver domain.

Introduction

Simultaneously sourced acquisition is a method to reduce the time spent in the field collecting data by firing multiple sources together with small delay times such that signals interfere with each other. This is in contrast to traditional acquisition which tries to avoid source crosstalk. In blended acquisitions, sources are allowed to interfere while they are later separated in processing thus reducing time spent in the field. The simultaneously fired shots are fired with a small randomized delay time between each other (Berkhout, 2008), taking advantage of random delay times of each source through a process called pseudo deblending. Pseudo deblending copies and moves blended shot frames into their own data panels mimicking a conventional survey. After pseudo deblending is applied, the shots to be separated show up as coherent events while the crosstalk from other shots show up as randomized blending noise. Deblending through the use of the blending operator (Berkhout, 2008) has originally be applied through the denoising methods (Hou et al., 2012), with inversion based (Mahdad et al., 2011) methods being explored only recently. Many different deblending approaches include using compressive sensing techniques (Lin and Herrmann, 2009), direct separation in the shot domain using Stolt apex shifted Radon (Trad et al., 2012), the use of the Stolt operator as a denoising method in the receiver domain (Ibrahim and Sacchi, 2015) (Ibrahim and Sacchi, 2014), a thresholding approach in the FK domain using an inversion scheme (Stanton and Wilkinson, 2018), and a proposed deblending using migration-demigration operators (Trad, 2015, Ibrahim et al., 2018). This paper introduces inversion based deblending in the CMP domain as a high-speed approach using a relatively simple Radon focusing operator.

Theory

The blending operator is a key step in the proper separation of shots as it contains information in the shot scheduling of the data, including the source locations as well as delay times. The blending operation is commonly represented as Γ, The blended data $\boldsymbol{D_{bl}}$ can then be represented through a combination of the unblended data $\boldsymbol{D}$ and the blending operator Γ (Berkhout, 2009):

$$\mathrm{D_{bl}} = \Gamma \mathrm{D}. \#(1)$$

With the adjoint operation shown below:

$$\widetilde{\mathrm{D}} = \Gamma^{\mathrm{H}} \mathrm{D_{bl}}. \#(2)$$

Where $\widetilde{\mathrm{D}}$ is the pseudo-deblended data, and Γ^{H} is the adjoint blending operator commonly known as the pseudo deblending operator. Due to the poorly posed nature of the blending operator, no direct inverse can be determined as an infinite number of solutions exist.

To aid in the inversion of the blending data a coherency constraint must be implemented alongside the blending operator to re-define the ill posed inverse problem. The coherency constraint we will be using is the hyperbolic Radon transform (Thorson and Claerbout, 1985):

$$\mathrm{u}(\mathrm{p}, \tau) = \int_{\mathrm{h_1}}^{\mathrm{h_2}} \mathrm{d}\left(\mathrm{h}, \mathrm{t} = \sqrt{\tau^2 + \mathrm{p}^2 \mathrm{h}^2}\right) \mathrm{dh} \,. \#(3)$$

By implementing the inversion within the CMP domain instead of the common receiver domain allows us to avoid the need for the use of the apex shifted Radon transform (Trad et al., 2004) and instead use a non-apex shifted transform.
We then combine both the Blending operator and the Radon operator into a single operator for our inversion objective function(Claerbout, 1992) allowing us to solve for the sparsest Radon model that fits the entire dataset, explaining all events that occur in the data.

$$\left|\left|\mathrm{D_{bl}} - \Gamma \mathrm{Rm}\right|\right|_{\mathrm{p}}^{\mathrm{p}} + \mu \left|\left|\mathrm{m}\right|\right|_{\mathrm{q}}^{\mathrm{q}}. \#(4)$$

Where p and q are integer values that computes the approximate L_p or L_q norm solution. Mainly L_p corresponds to the residual norm and L_q corresponds to the model norm. Where with p=q=2 corresponds to the least squares solution, setting q=1 minimizes for the sparsest model and setting q=1 minimizes for the robust solution.

Examples

The purpose of this paper is to examine the quality of results generated through inversion based deblending in the CMP domain. The inversion of the data will be performed using the sparse constraints or $L_2 - L_1$ norms for the data and model weights respectively. The inversion scheme is tested on a number of data sets, blended either numerically or through finite-difference itself. The two tests shown in this paper are a Marmousi model example and a real dataset acquired from the Gulf of Mexico. The marmousi model was blended through finite difference using a blending schedule of 5 simultaneous shots with 60 supershots totaling 300 shots. The firing delay was randomized between 0-200 samples through finite difference. The Gulf of Mexico example was blended numerically using continuous listening, with 90 shots blended using a 60% listening time overlap.

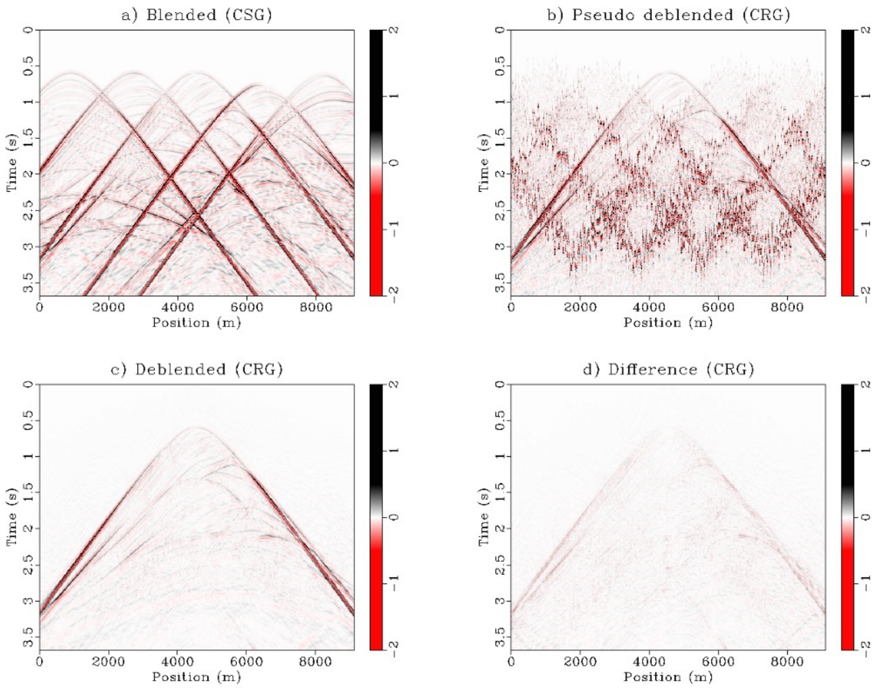

Figure 1. Marmousi receiver domain results: Deblending in the CMP domain plotted in the receiver domain. Shot domain blended data in a), pseudo-deblended receiver domain data in b), deblended data in c) and the difference between true solution in d).

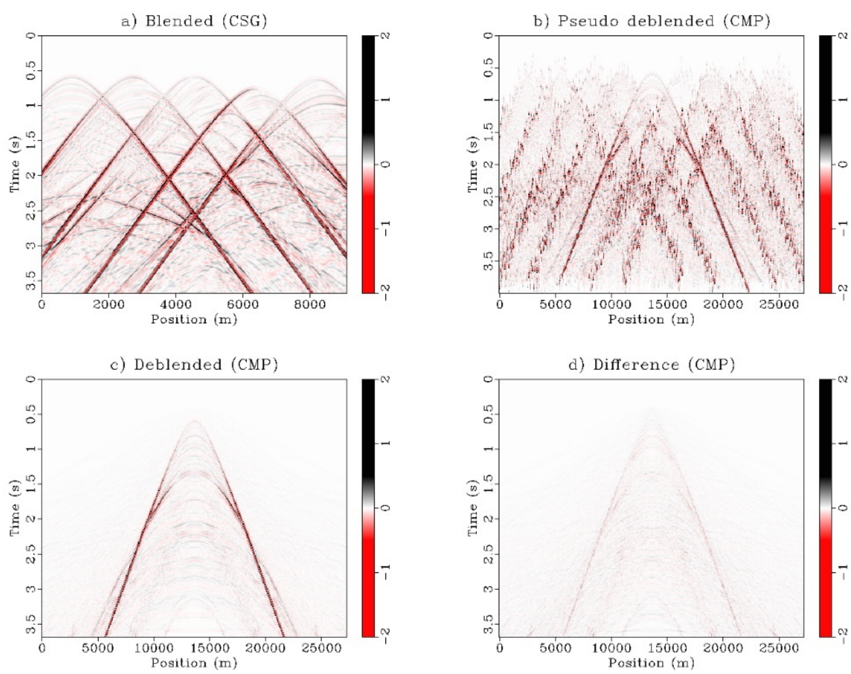

Figure 2. Marmousi CMP domain results: Shot domain blended data in a), CMP domain pseudo-deblended data in b), deblended data in c) and the difference between a) and c) in d).

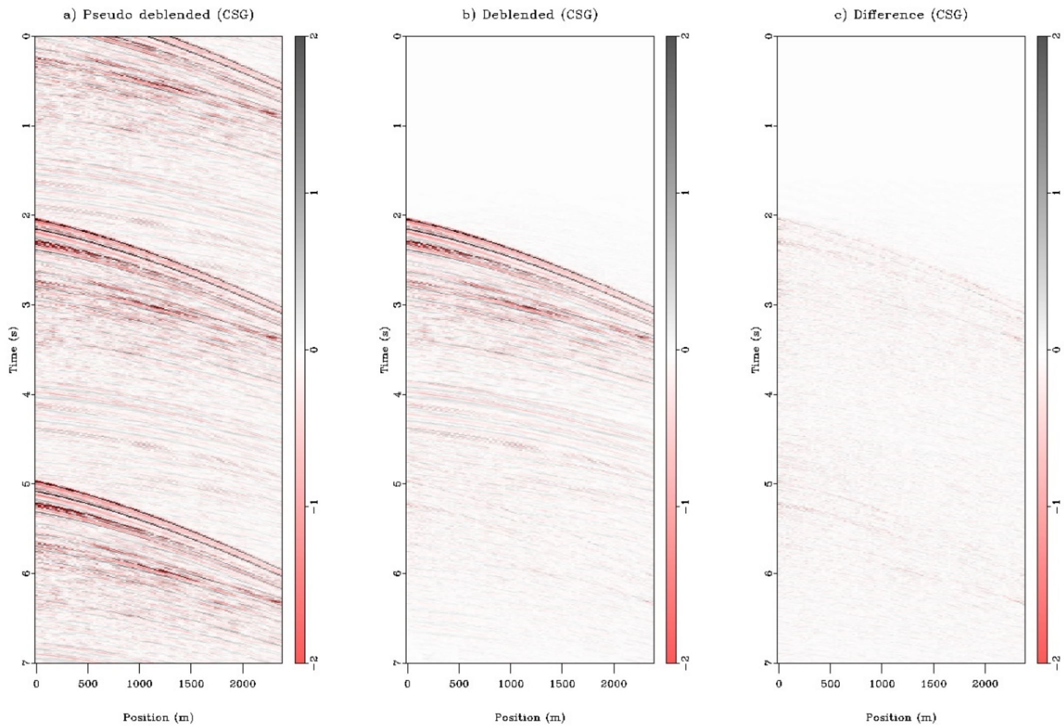

Figure 3. The Gulf of Mexico shot domain results: Blended data in a), deblended data in b), and the difference in c).

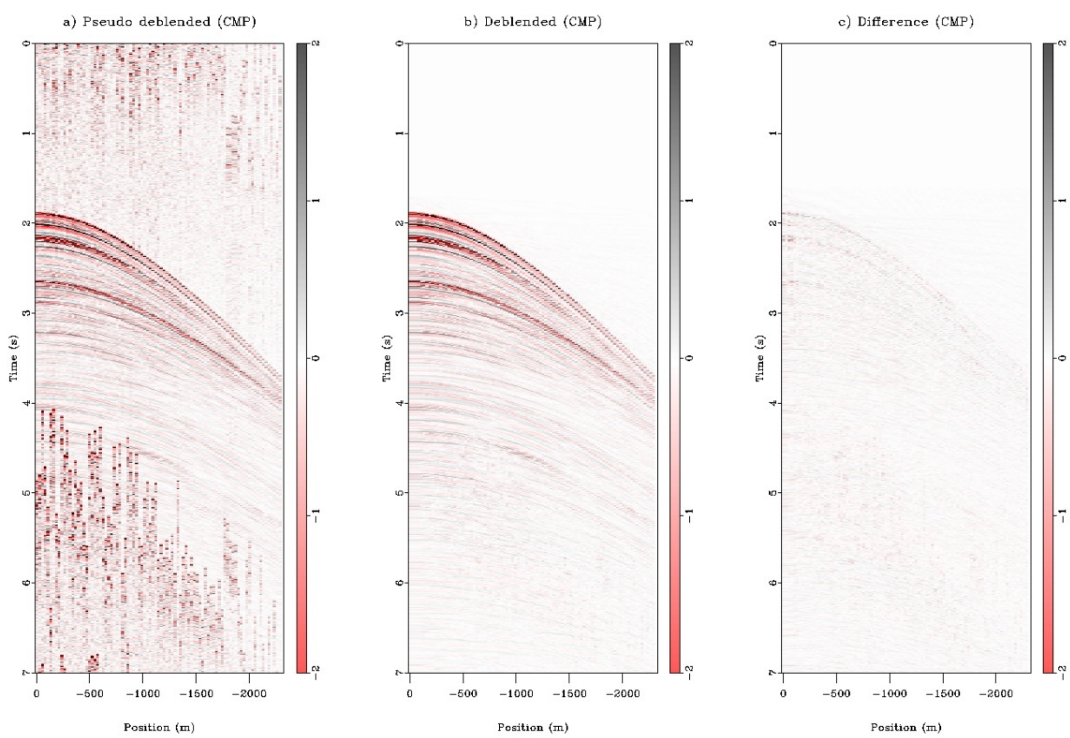

Figure 4. The Gulf of Mexico CMP domain results: Pseudo-deblended data in a), deblended data in b), and the difference in c).

Conclusion

Blending noise from source crosstalk in simultaneously sourced acquisition can be remapped through an inversion based deblending scheme. By fitting the entire data set instead of denoising common receiver gathers low amplitude events are preserved. The implementation of the Radon transform as a coherency constraint on the blending operator in the CMP domain allows for more efficient processing of the inversion.

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