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Inversion-based deblending using Radon transform

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Summary

We compare the denoising and inversion based deblending methods using Radon transform. Radon transform can focus seismic data into a sparse model to separate signals, remove noise, or interpolate missing traces. Therefore, Radon transforms are a suitable tool for either the denoising based or the inversion based deblending methods. Denoising based deblending methods treat interferences as noise in common receiver gathers. Blending interferences in common receiver gather, they exhibit random structures due to the dithering of the source firing times. On the other hand, the inversion based deblending methods treat blending interferences as a signal, and we can model this signal by incorporating the blending operator to formulate an inversion problem. We compare both methods using a robust inversion algorithm with sparse regularization. Data examples show that the inversion based deblending can produce more accurate signal separation for highly blended data.

Theory

We can model the blended data from the single-source data. For example, if we let **D** represents the data of all single sources in the time-space domain arranged into a data cube and represents the two-dimensional blended sources data, then

$$\mathbf{b} = \mathbf{\Gamma}\,\mathbf{D}, \tag{1}$$

where $\mathbf{\Gamma}$ represents the blending operator that contains the source information such as firing times and spatial locations (Berkhout 2008). Therefore, blended data b can be separated by compensating for the source firing delays and subdividing of the data into single-source segments. This operation is commonly known as pseudo-deblending. The pseudo-deblending is equivalent to applying the adjoint of the blending operator $\mathbf{\Gamma}$ to the blended data b such that

$$\widetilde{\mathbf{D}} = \mathbf{\Gamma}^{\mathbf{T}}\,\mathbf{b}, \tag{2}$$

where $\widetilde{\mathbf{D}}$ is the pseudo-deblended data cube that contains source interferences. However, source interferences in pseudo-deblended data cube exhibit an incoherent structure in common receiver gathers due to the randomization of the source firing times.

Therefore, a denoising algorithm can attenuate source interferences and achieve deblending. In the denoising based deblending, the deblending problem is posed as the problem of estimating a noise free model m of the common receiver gather by minimizing the cost function (Ibrahim and Sacchi, 2014)

$$J = \left\|\widetilde{\mathbf{D}} - \mathbf{L}\,\mathbf{m}\right\|_1^1 + \mu\,\|\mathbf{m}\|_1^1, \tag{3}$$

where $\mathbf{L}$ is the Stolt-based apex shifted hyperbolic Radon transform (ASHRT) (Trad, 2003; Ibrahim and Sacchi, 2015), and μ the trade-off parameter that controls the weight of the regularization term with respect to the misfit term. We use ℓ_1-norm for the misfit term to avoid the effects of source interferences acting as fitting outliers and producing biased model (Ibrahim, 2015). On the other hand, we can use the blending operator to formulate an inversion based deblending cost function as

$$J = \|\mathbf{b} - \boldsymbol{\Gamma}\, \mathbf{L}\, \mathbf{m}\|_1^1 + \boldsymbol{\mu}\, \|\mathbf{m}\|_1^1 \qquad (4)$$

Both cost functions in equations (3) and (4) can be minimized using Iteratively Reweighted Least Squares (IRLS) algorithm. For more details regarding IRLS, please refer to Daubechies et al. (2010); Trad et al. (2003).

Results

We also tested the deblending methods using numerically blended marine data from the Mississippi Canyon area in the Gulf of Mexico. In this example, the acquisition simulates a single source boat traveling with four times the normal speed. Therefore, four blended shots overlap in the time window of a conventional shot. Moreover, the dithering of the sources is limited to simulate the operational constraints in a marine acquisition. The results of the denoising based and inversion based deblending are shown in Figure 1 and 2, respectively. These, figures show a clear advantage for the inversion based deblending over the denoising based method.

Conclusions

We have implemented an inversion based deblending method that uses robust inversion of Stolt-based Radon transform. We demonstrated that the inversion-based approach is better in deblending, especially in acquisition scenarios where operational constraints limit the dithering of the source firing times. However, the inversion based deblending require more computational resources, especially memory requirements, since it uses the blending operator in the inversion cost function.

Acknowledgements

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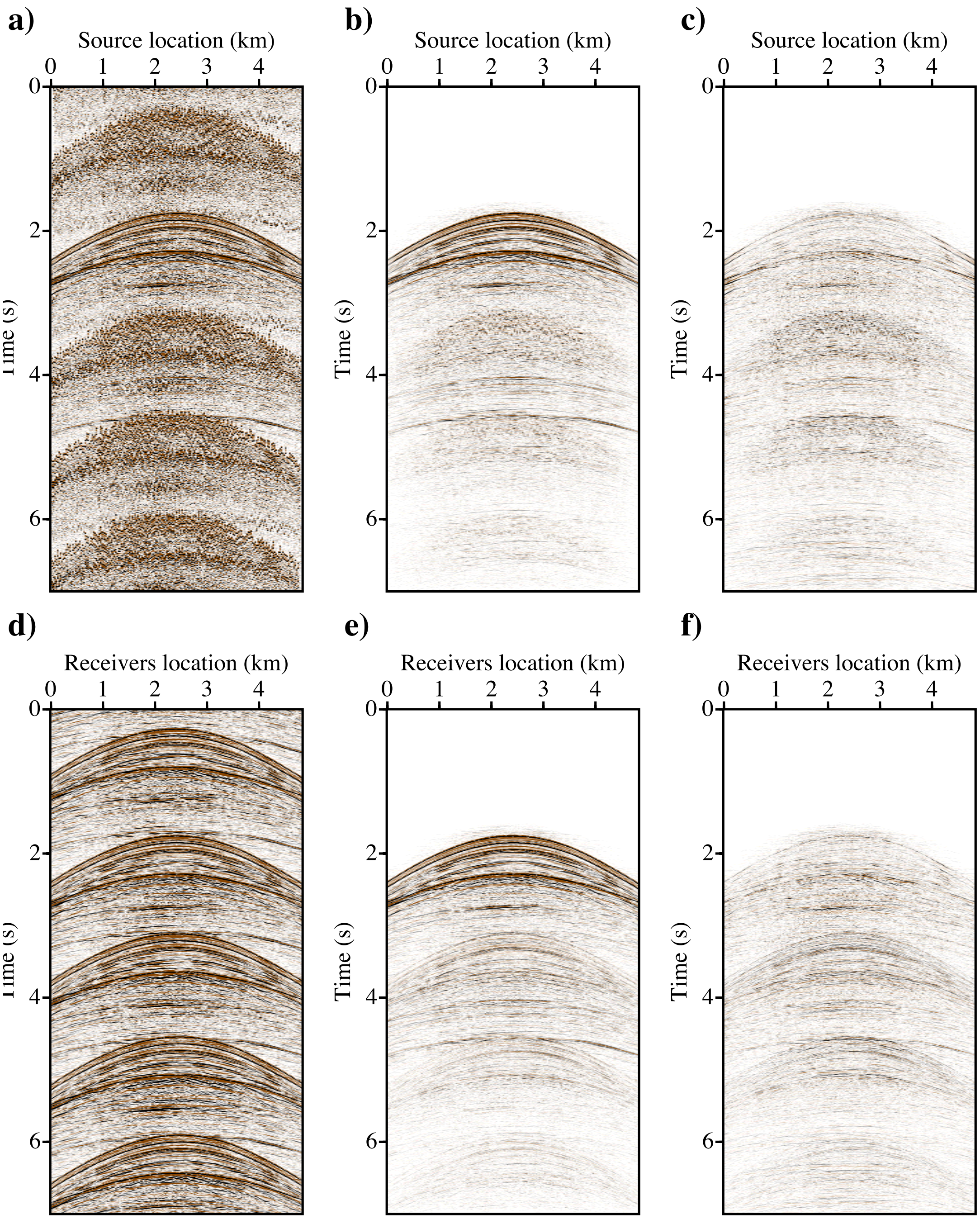

Figure 1: Gulf of Mexico data example deblended using denoising approach. (a) Pseudo-deblended CRG. (b) Deblended CRG. (c) Deblending error of CRG. (d) Pseudo-deblended CSG. (e) Deblended CSG. (f) Deblending error of CSG.

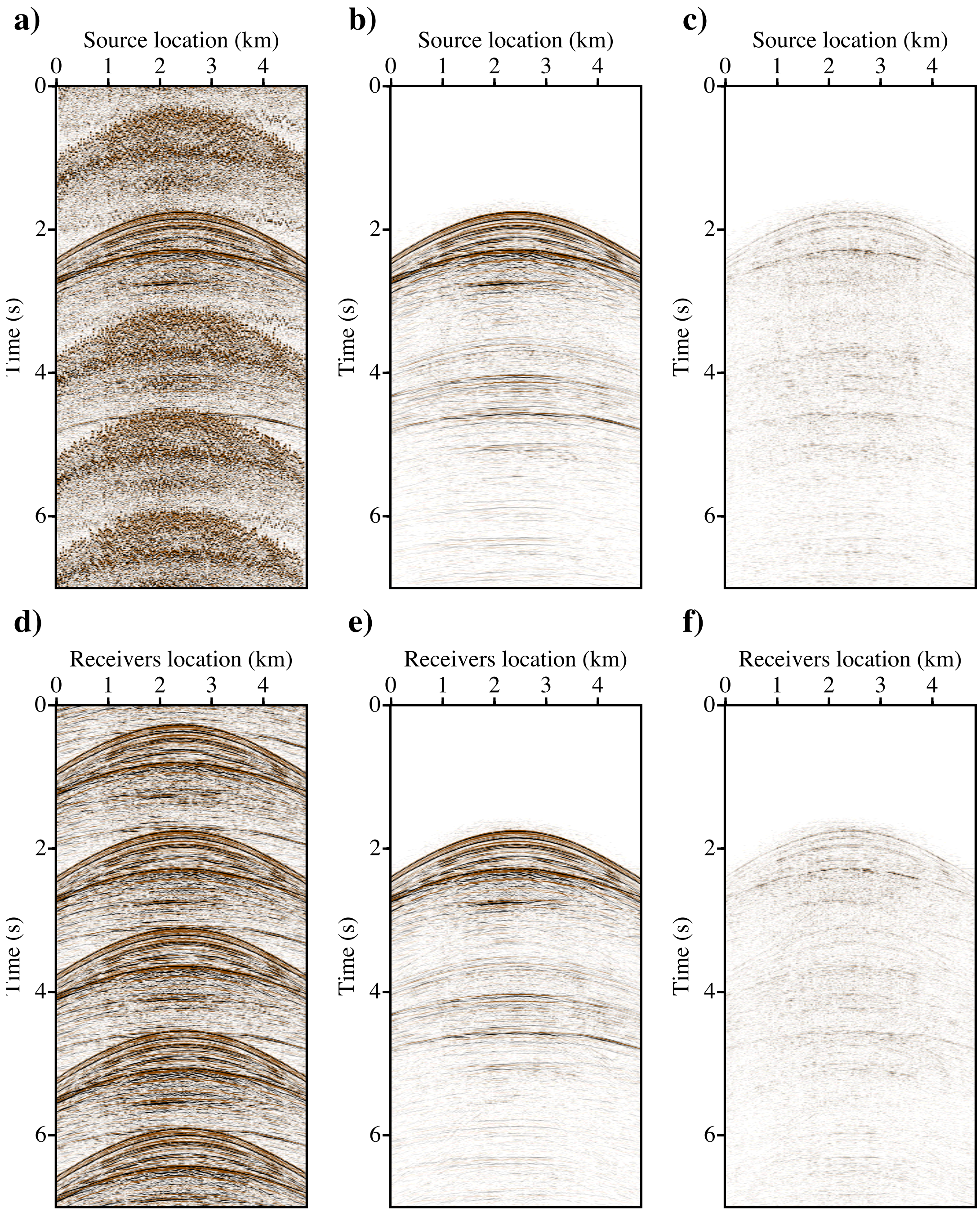

Figure 2: Gulf of Mexico data example deblended using inversion approach. (a) Pseudo-deblended CRG. (b) Deblended CRG. (c) Deblending error of CRG. (d) Pseudo-deblended CSG. (e) Deblended CSG. (f) Deblending error of CSG.

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