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Coherent noise reduction by progressive greedy Radon transform

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Summary

We propose a time domain super high resolution Radon transform for coherent noise reduction by solving a prioritized linear inverse problem based on continuous amplitude bands. The importance of Radon model elements is determined by the amplitude of the adjoint model computed iteratively from the data residuals. Within each iteration, model elements are grouped into several amplitude bands. Local optimization is performed to adjust the adjoint model so that it can fit the input data. Elements within the higher amplitude band are solved earlier than those within the lower amplitude band. The resulting Radon model has higher resolution than that generated by conventional methods. We validate the algorithm using both synthetic and real data examples.

Introduction

The key to the success of applying the Radon transform for noise attenuation is to increase the resolution of the Radon model. When the energy of seismic events is better focused, it is easier to separate primaries from multiples and other coherent noise in the tau-p domain. Conventional methods based on least-squares regularization (e.g. Hampson, 1986) usually give low resolution results. When the moveout difference between primaries and multiples is small, it is difficult to design a cut-off moveout parameter to effectively remove multiples without harming primaries. When the Radon transform is regularized by minimizing the $\boldsymbol{L_1}$ norm, or Cauchy norm, of the model the resolution is greatly increased (Sacchi and Ulrych, 1995). More recently Ng and Perz (2004) proposed a super high resolution Radon transform by prioritizing the energy of the *p* trace. The main drawback of this method is the lack of time-variant energy prioritization. When the velocities of the multiple generators are time-variant, the result may be sub-optimal. Wang and Ng (2009) proposed a greedy Radon transform, which can handle time-variant energy distribution, to further enhance resolution. However, in later iterations, the thresholding mechanism is less effective in generating groups of elements with outstanding amplitude. Also the model-masks for each iteration can generate sharp boundaries, which lead to an unstable inversion. In this paper, we improve the greedy Radon transform by solving a series of least-squares problems within continuous amplitude bands. No gaps between model elements are left after each iteration so that there are no sharp boundaries existing in the final solution.

Theory

Seismic data after NMO correction can be modeled used the parabolic Radon transform by

$$\boldsymbol{d} = \boldsymbol{Lm}, \tag{1}$$

where $\boldsymbol{d}$ is the seismic data, $\boldsymbol{m}$ is the tau-p domain Radon model, and $\boldsymbol{L}$ is the time domain Radon transform operator. Given seismic data, we need to solve for a Radon model that can fit the seismic data.

This can be done by minimizing the following cost function:

$$\boldsymbol{J}(\boldsymbol{m}) = \|\boldsymbol{d} - \boldsymbol{Lm}\|^2 + \mu\boldsymbol{R}(\boldsymbol{m}), \qquad (2)$$

where $\boldsymbol{R}$ is a regularization function used to enforce some features in the model. μ is a trade-off parameter to determine the amount of regularization. A greater value of μ will increase the impact of model regularization at the price of worse data fitting. Conventional regularization like $\boldsymbol{L_2}$ norm gives a smooth or low resolution result. $\boldsymbol{L_1}$ norm and Cauchy norm methods can generate much higher resolution results. As we show in this paper, regularization in the global model domain may not efficiently remove the crosstalk between model elements. On the other hand regularization of the model by solving problems in a prioritized subspace performs better at separating seismic events. We call this a progressive greedy Radon transform. The original greedy Radon transform tries to design a model-mask for the strongest events from the data residuals at the beginning of each iteration. In contrast, our new method solves all model elements within a series of amplitude bands, leaving no gaps in the model space. The method can provide stable solutions with super high resolution. There is no formal regularization term for this method. We think that it may be called a prioritized $\boldsymbol{L_1}$ norm.

Examples

We first validate the idea using a synthetic dataset. The data contains many flat primaries and three multiples with small residual moveouts. One may think that some of the overlapping events are just primaries with amplitude and phase change with offset. Multiples with small moveout are very challenging to conventional Radon transforms. As shown in Figure 1b, the multiple model computed by the $\boldsymbol{L_2}$-norm method is severely contaminated by leaked primaries. The problem is alleviated in the solution of the $\boldsymbol{L_1}$-norm method (see Figure 1c). The proposed method (Figure 1d) gives the best result with least primary leakage.

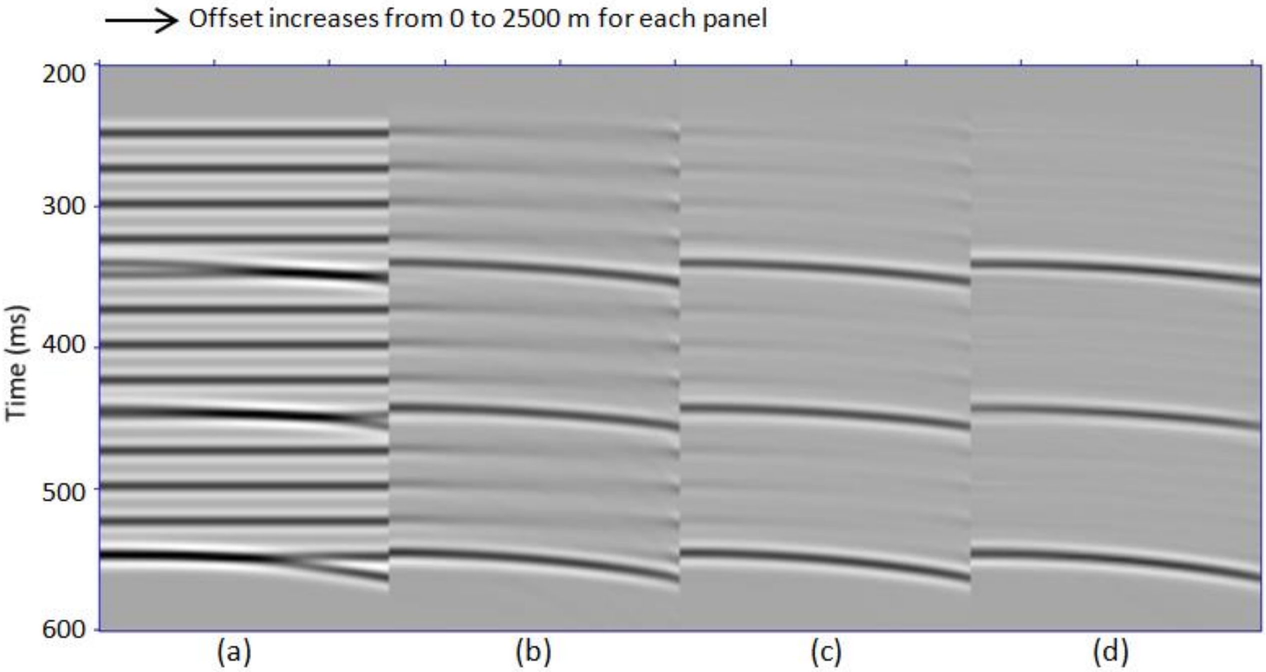

Figure 1: Comparison of Radon multiple attenuation with different regularization. (a) Input gather. (b) Multiples computed by $\boldsymbol{L_2}$-norm method. (c) Multiples computed by $\boldsymbol{L_1}$-norm method. (d) Multiples computed by the new method (prioritized $\boldsymbol{L_1}$ norm).

To explain the difference of the models for these methods, we examine data in the tau-p domain using Radon models computed for these three methods (see Figure 2). It is clear that the new method provides a result with the highest resolution so that multiples are best separated from primaries. However, the conventional $\boldsymbol{L_2}$-norm method and $\boldsymbol{L_1}$-norm method have more smeared events. When the muted model is transformed back to data domain, the leaked weak primaries become more evident (as shown in Figure 1b and Figure 1c) because the inverse transform is a decompressing procedure.

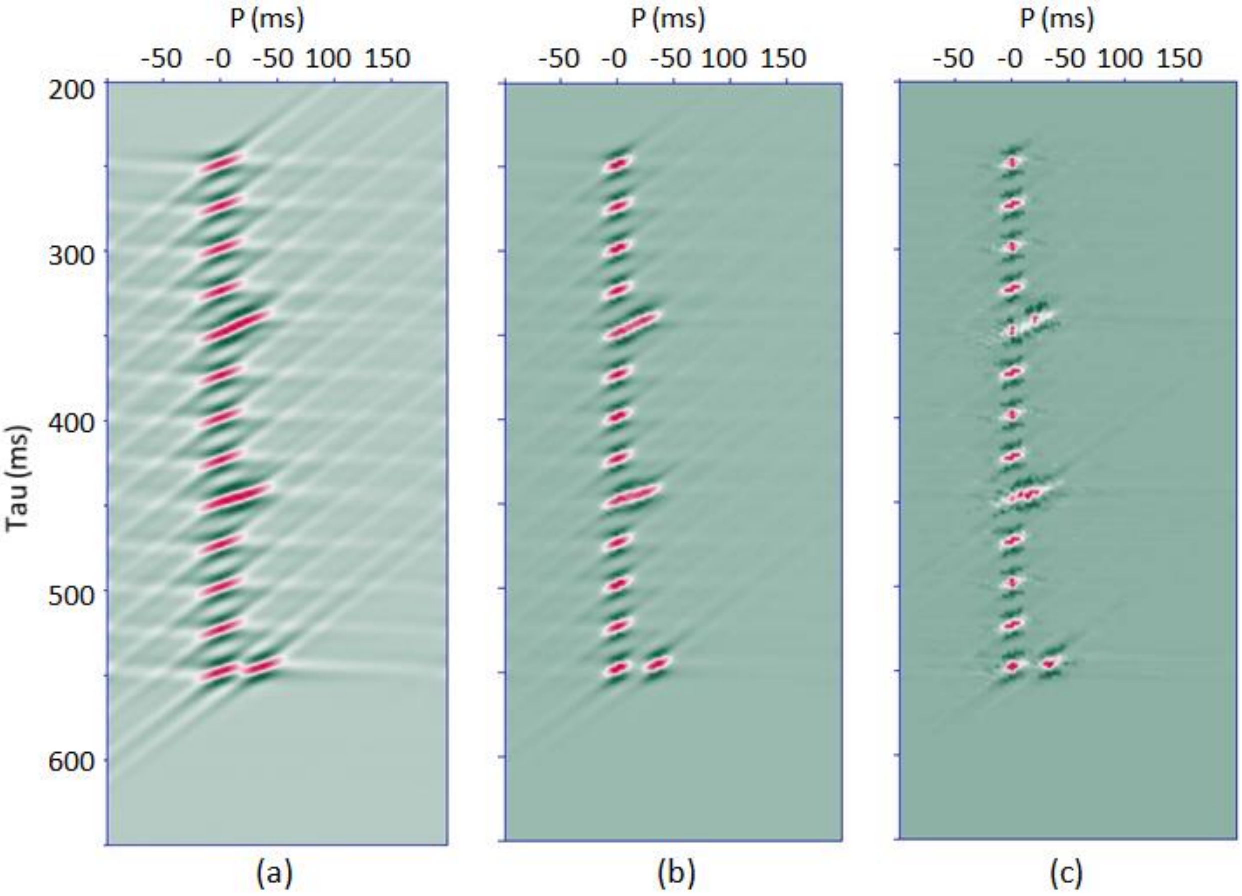

Figure 2: Comparison of tau-p domain Radon models from different methods. (a) $\boldsymbol{L_2}$-norm method. (b) $\boldsymbol{L_1}$-norm method. (c) New method. Note that all panels are plotted using the same clipping percentage.

We also test the new method with a real dataset from the Western Canadian Basin. As shown in Figure 3, the algorithm successfully removes multiples without touching primaries. Primaries look more consistent after multiple attenuation. Note that coherent noise other than multiples may also be suppressed if its moveout is greater than the user specified cut-off moveout parameter. This explains why the shallow linear noise is also removed in Figure 3b. An implementation of the progressive greedy Radon transform using the localized linear Radon kernel can be a tool to attack linear noise (e.g., ground roll and refractions etc). The optimization work is onging, and we will include more results with practical applciations.

Conclusions

In seismic processing it is not a trivial task to remove the multiple energy and coherent noise without touching the primary energy. We have developed a super high resolution Radon transform to reduce coherent noise based on the moveout diffence between noise and primaries. The signal leakage is minimized compared with conventional methods because of the better model focusing and signal separation. Both synthetic and real data tests show that the algorithm can effectively remove multiples and preserve primaries at the same time. As this is an amplitude friendly approach this method can be successfully utilized as a tool for data conditioning for future post-stack and prestack inversion work.

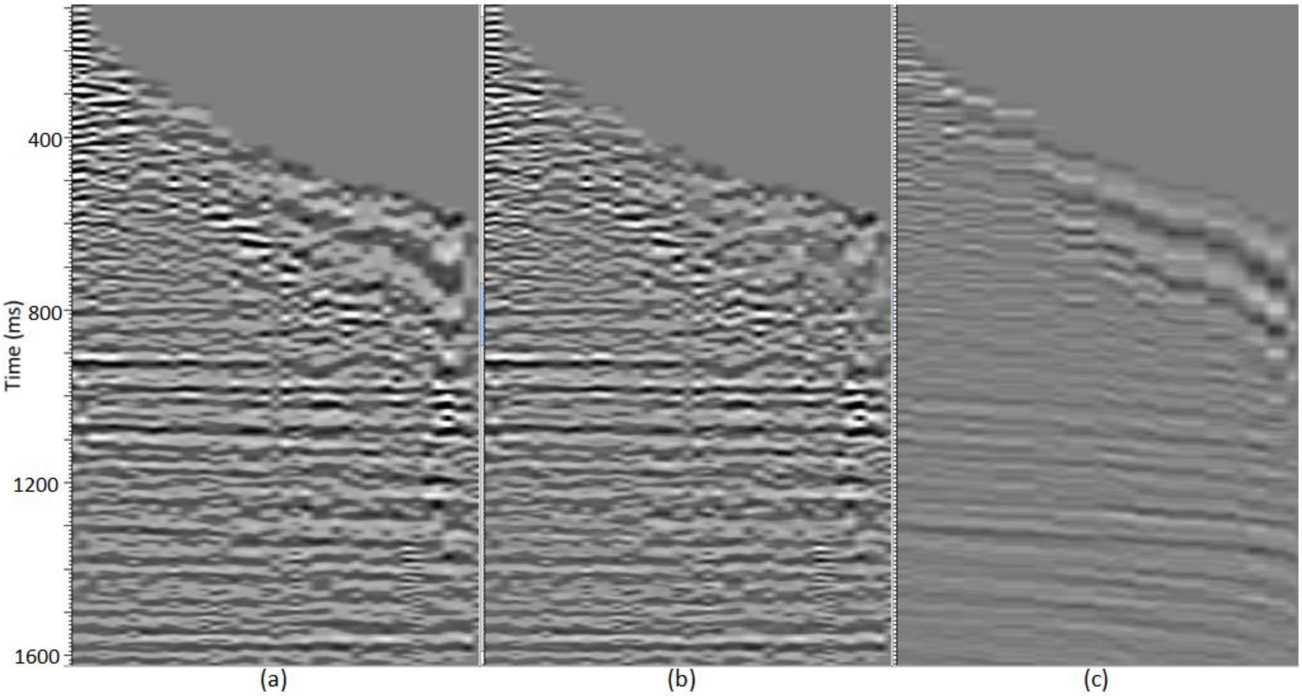

Figure 3: A test of progressive greedy Radon transform on a real dataset. (a) Input gather. (b) Output gather. (c) Difference of (a) and (b).

References

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