More processing in the radial trace domain

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Abstract

The radial trace (R-T) domain has been shown to be useful for coherent noise attenuation and other seismic wavefield separation operations. The reason is that the mapping trajectories of the R-T transform can be readily fitted to various linear components of the recorded wavefield in the conventional X-T domain, especially coherent noise. This allows these components to be efficiently represented in the R-T domain, and thus easily separated. Various techniques can be used to affect the actual wavefield component separation in the R-T domain. Overall, the most successful method for attenuation of coherent noise is to apply an operation to the data in the R-T domain which isolates the noise and 'models' it as well as possible. The noise can then be transformed back to the X-T domain and subtracted from the original seismic data. Various R-T domain operations, both single and multi-trace can be used to model the noise and are described here. Scaling the noise before subtraction, and iterating the model-and-subtract sequence can both improve results.

A useful intrinsic property of the R-T transform is that it rearranges the samples of an input seismic data gather in such a way that the raypath geometry associated with the new traces corresponds more nearly to the geometry implicit in the standard convolutional model. This means that for deconvolution as well as demultiple operations, the R-T domain should be more appropriate than the X-T domain in which the data were originally recorded. Preliminary results suggest that this is the case.

Introduction

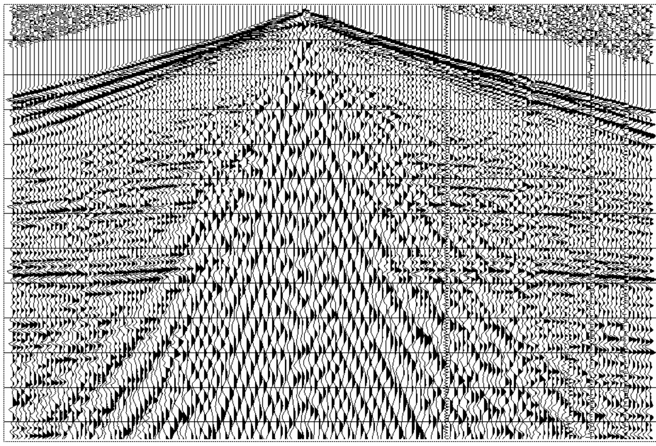
Radial trace domain techniques for attenuation of coherent noise in seismic data were introduced by Henley (1999, 2000a, 2000b, 2003), based on earlier work by Claerbout (1975, 1983), who introduced the radial trace (R-T) transform primarily for use in migration and related imaging algorithms. The R-T transform works well in noise attenuation because the geometry of the mapping operator (linear trajectories radiating from a common origin) is very similar to that of most kinds of coherent noises, allowing them to be efficiently represented in the R-T domain and thus easily separated from the parts of the wavefield which are not so efficiently mapped. Not only do most coherent noises collapse into a few traces in the R-T domain, but their apparent frequency content is shifted significantly lower, as well. This provides further isolation relative to the characteristics of the reflection components of the wavefield, which are hardly altered by the R-T transform. While noise attenuation can be done by simply rejecting the noise components in the R-T domain, a more flexible and effective approach is to enhance or 'model' the noise components in the R-T domain, then subtract these components in the original X-T domain. Both the noise modeling and the subtraction aspects of this technique can be separately optimised. In this work, several operations are tested for their effectiveness in isolating and modeling the coherent noise components of the R-T wavefield, and the X-T domain wavefield subtraction operation is examined briefly.

Most efforts to increase the temporal resolution of seismic data are based on some form of deconvolution, which usually assumes the standard convolutional model. This model is essentially a 1-dimensional one in which seismic energy is transmitted and reflected along a single raypath at normal incidence to reflecting interfaces. Since few seismic traces are acquired at normal incidence, the convolutional model is violated to some degree by most traces. Significantly, as noted by Claerbout and later by Taner (1980), when a seismic wavefield is transformed to the R-T domain, each trace in the new domain represents energy which shares a common downgoing raypath and parallel upgoing raypath segments. This means that transmission and reflection coefficients at each interface will share the same angle of incidence, and that comparable raypath segment travel times for single and multiple reflections will be equal. Since this is the fundamental constraint imposed by the common raypath aspect of the convolutional model, R-T domain traces should provide better deconvolution results, especially when relative amplitudes of reflections are important. A brief comparison of deconvolution results in X-T and R- T domains is presented here.

Modelling coherent noise in the R-T domain

The R-T transform provides separation of coherent noise from reflection signal by both velocity and frequency, and both characteristics can be used to 'model' or estimate the noise from the R-T transform of an input seismic trace gather. Relative trace amplitudes in the R-T domain can be selectively altered to emphasize those radial traces which contain mostly coherent noise, but an easier approach is to apply to all the R-T traces operators which discard energy in the seismic frequency band and retain only the lowest frequencies occupied exclusively by coherent noise in the R-T domain. An obvious choice for such an operator is a single trace low-pass filter; but many other operators, both single and multi-trace, can be conceived. To illustrate noise modeling, Figure 1 shows a single raw shot gather from the Blackfoot seismic survey, and Figure 2 shows the coherent noise estimated by applying a single trace low-pass filter in the R-T domain. Figure 3 shows the result of subtracting this noise estimate from the raw shot. As can be seen, there is still a relatively high level of residual noise, indicating the potential for finding a better noise modeling process. A number of schemes have been tested, and, as an example, Figure 4 shows the result of subtracting a noise estimate obtained using a multi-trace K-F filter in the R-T domain. This result is clearly superior to that shown in Figure 3, but it requires more computational effort.

Another way to improve the model-and-subtract technique is to optimise the scaling applied to the noise estimate before subtraction, or to iterate the entire sequence to remove diminishing remnants of coherent noise. Both approaches have shown promise for increasing the amount of noise removed, but iterating three or four times is the simplest and most practical approach.



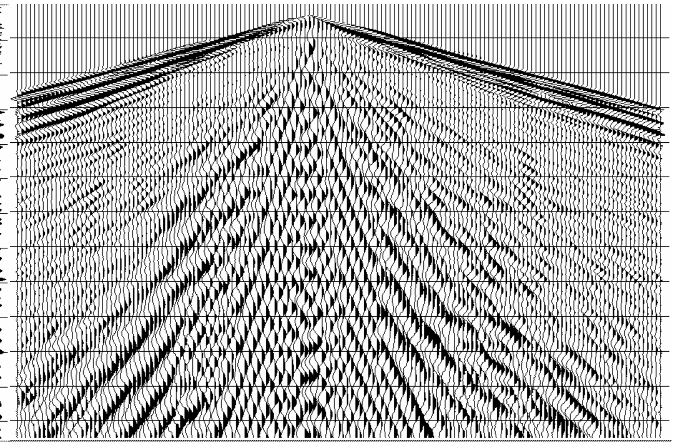
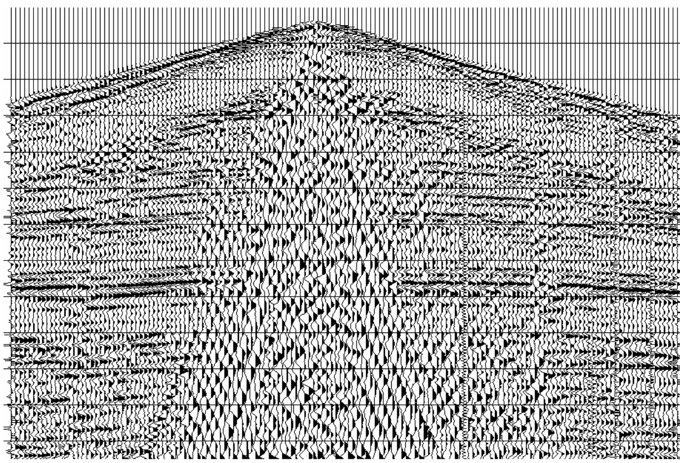


Figure 1.—Raw shot gather from Blackfoot 3C seismic survey showing several modes of coherent noise.

Figure 2.—Coherent noise estimated from shot gather in Fig. 1 using low-pass filter in R-T domain.



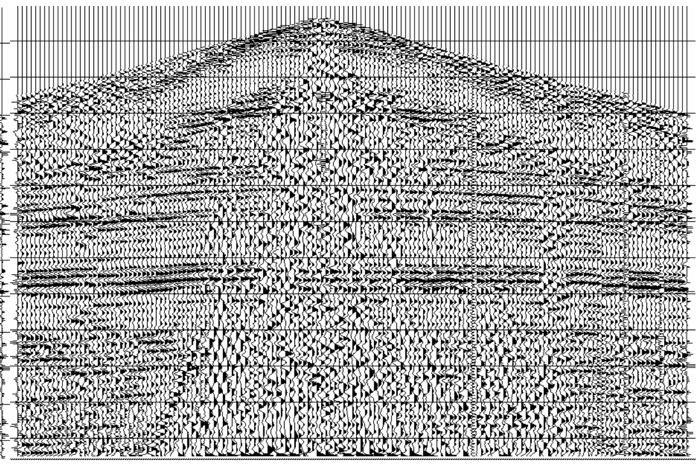


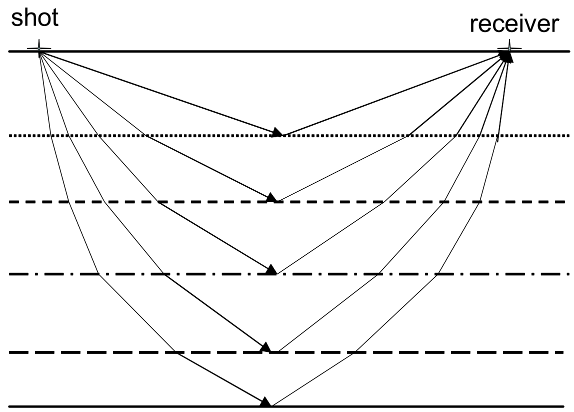
Figure 3.—Coherent noise estimate in Fig. 2 subtracted from the raw gather in Fig. 1. Note residual coherent noise.

Figure 4.—Coherent noise estimated by multi-trace K-F filter in R-T domain subtracted from raw gather in Fig. 1. Much less residual noise.

Deconvolution

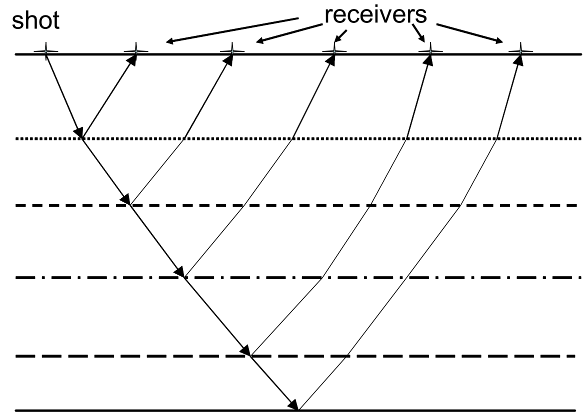
The standard convolutional model is 1-dimensional…that is, it assumes that seismic energy transmits and reflects from interfaces along a single normally incident raypath, so that the seismic wavelet reflected from each interface has been affected only by preceeding interfaces, not by effects due to different travel paths. In actual practice, however, the raypaths followed by seismic energy during data acquisition are shown in Figure 5. According to this schematic, seismic reflections recorded on a single trace have no raypaths in common; in fact, raypath segments in the same layer are not parallel, indicating unequal transit times and incidence angles. The only exception to this occurs when the receiver coincides with the source, which rarely happens in actual surveys. When a conventional shot gather is mapped into R-T space, however, the data on a single R-T domain trace then correspond to the raypaths shown in Figure 6. In this schematic, downgoing energy traverses the same raypath segments for all reflections, and the upgoing raypath segments are parallel in all layers, making the transit times and incidence angles through each layer equal for all reflections beneath that layer. This is consistent with the assumptions inherent in the simple convolutional model, so deconvolution should be expected to be more appropriate in this domain. A similar argument was used by Taner (1980) to motivate the R-T domain implementation of long-period multiple removal from marine data.

Figure 7 shows a portion of the Blackfoot shot gather of Fig. 1 after being deconvolved in the X-T domain by the Gabor nonstationary deconvolution algorithm (Margrave et al, 2002a, 2002b), while Figure 8 shows the same data deconvolved in the R-T domain by Gabor deconvolution (with the same parameters). Of particular note is the fact that the deconvolution in the R-T domain extracts shallow reflections at greater amplitude, relative to deeper reflections, and extends the reflections to larger offsets than X-T domain deconvolution. The deconvolution in the R-T domain greatly attenuates the direct arrival sequence, as well, revealing what may be backscattered energy from surface irregularities. In close-up Figures 9 and 10, the focus is on reflection events which appear to manifest 'ringing' in the X-T domain, but not in the R-T domain. This ringing may simply be pegleg multiples which are tuned over the particular range of offsets. Because of the more rigorous adherance to the convolutional model in the R-T domain, the deconvolution algorithm is more successful in removing the multiple energy. An additional feature of these figures is a single trace which exhibits mostly 60 Hz energy on the raw shot gather. While the deconvolution procedure whitens this trace somewhat in the X-T domain, it is still primarily dominated by 60 Hz. The R-T domain deconvolution, on the other hand, leaves no evidence of the 60 Hz, but returns a low amplitude trace which nevertheless correlates with some of the reflections on the section.



Geometry of a trace in X-T domain

Figure 5.—Schematic showing the many different raypaths associated with reflections on a single trace of a shot gather



Geometry of a trace in R-T domain

Figure 6.—Schematic showing the common downgoing raypaths as well as parallel upgoing raypaths associated with reflections on a radial trace.

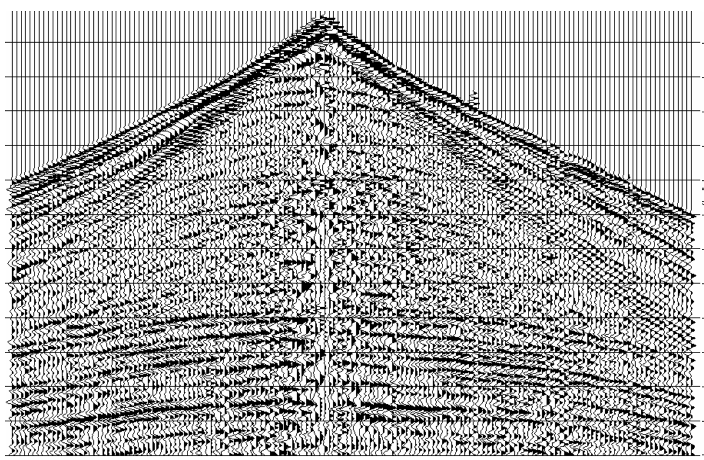


Figure 7.—Blackfoot gather deconvolved in the X-T domain. Shallow reflections masked by direct arrivals and too low in amplitude relative to deeper reflections.

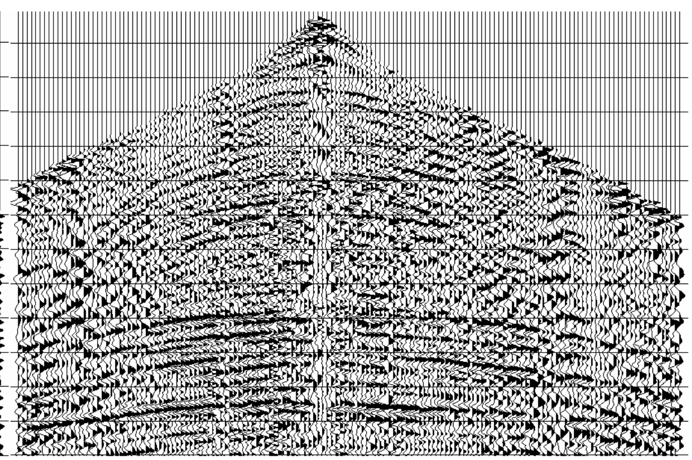


Figure 8.—Blackfoot gather deconvolved in the R-T domain. Shallow reflections visible to greater offsets, stronger in amplitude relative to deeper reflections.

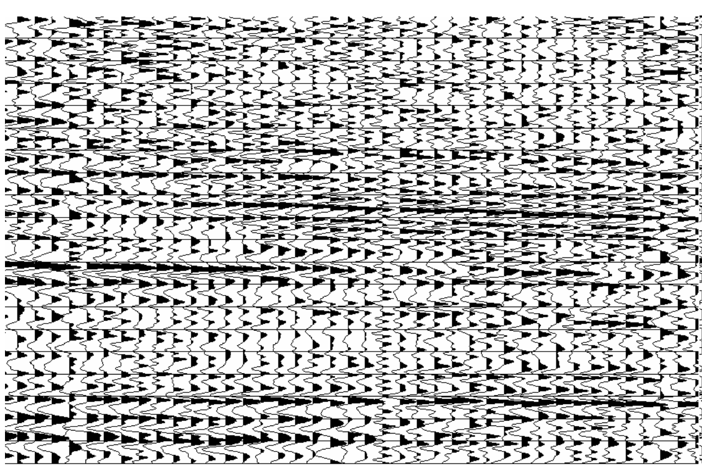


Figure 9.—Possible pegleg multiples and 60 Hz noise trace not properly deconvolved after X-T deconvolution.

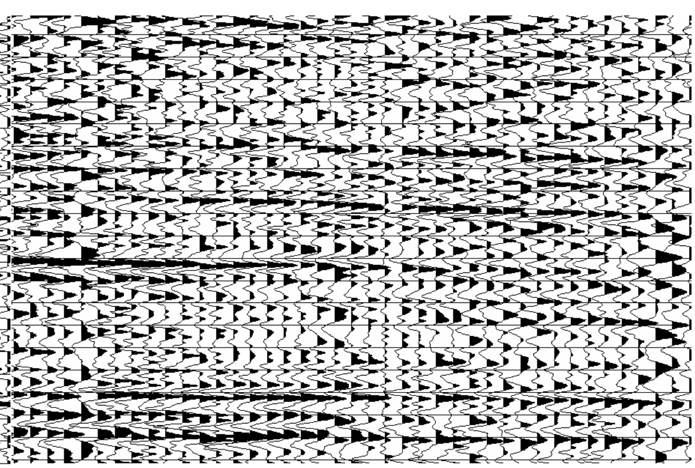


Figure 10.—No pegleg multiples after R-T domain deconvolution, and 60 Hz noise trace at least partially deconvolved.

Conclusions

As shown in the examples, improvements can be made to the basic R-T domain coherent noise attenuation technique by focusing on both the noise modeling and the noise subtraction aspects of the method. Some improvements on the basic technique have been demonstrated such as multi-trace noise modeling in the R-T domain and iteration of the basic model-and-subtract sequence.

Seismic data in the R-T domain are better suited to deconvolution because the corresponding raypath geometry more nearly satisfies the assumptions of the convolutional model. Significant differences between deconvolution in the X-T domain and deconvolution in the R-T domain have been demonstrated.

Acknowledgements

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