Eliminating imaging artifacts in two-way migrations using pre-stack gathers

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Abstract

Two-way wave-based migration methods like reverse time migration (RTM) have become established methods in areas of complex geology. However, RTM is also known for producing low frequency artifacts, where sharp velocity contrasts are present. We show that the imaging condition applied with time-shift gathers offers an excellent opportunity to remove artifacts based on properties of wave propagation.

Introduction

Thanks to advances in computer technology wave-based methods like shot profile migration and reverse time migration (RTM) (Baysal et al., 1984; Whitmore, 1983) have become established methods during the last decade. However, RTM is also known for producing low frequency artifacts, when sharp velocity contrasts are present. These artifacts are created by the unwanted cross-correlation of head waves, diving waves, and backscattered waves, which are not included in the imaging condition. There are different alternatives for attenuating these artifacts:

1. Wave-field propagation approaches where the wave equation is modified to attenuate reflections at the velocity contrasts (e.g., Baysal et al., 1984; Fletcher et al., 2005).
2. Imaging condition approaches in which only the energy created by reflections is kept in the final image (e.g., Yoon et al., 2004).
3. Post-imaging condition approaches in which the artifacts are filtered after imaging on each shot or the stacked image (e.g., Guitton et al., 2007). The filtering can be done on subsurface offset or angle gathers (e.g., Biondi and Shan, 2002; Sava and Fomel, 2003).

Based on our experience, the third method of post-imaging conditions shows significant advantages over the other two approaches. Although the second approach of using reflected energy only in the imaging condition sounds appealing, the methodology does not produce satisfactory results in complex subsurface. It is also well known that the non-reflective wave equation used for the first approach does not perform well for high angles of incidence. One of the strongest arguments favoring the third method is of course the integrity of the migration, because no event has been suppressed, modified or has been removed from the migration.

Time-shift imaging condition

The time-shift imaging condition is defined (Sava and Fomel, 2006)

$$I(\underline{x},\tau)=\sum_t R(\underline{x},t+\tau)\cdot S(\underline{x},t-\tau), \qquad (1)$$

where *I* is the image, and *R* and *S* are the receiver wave-field and the source wave-field, respectively. $\underline{x}$ the spatial coordinate, *t* is time and τ is a scalar describing the time shift between the source and the receiver wave-field prior to imaging. To obtain time-shift gathers the migrated images from all shots are stacked spatially. The relationship between time-shift τ and position in depth *z* is

$$z=z_0-\upsilon\cdot\tau, \qquad (2)$$

where *v* is the local migration velocity at depth z_0. After Fourier transforming depth and time-shift, we can easily filter events, which are not accounted for by the imaging condition:

- Events with positive slopes,
- Events with apparent velocities lower or higher than the migration velocity.

For dipping reflectors the relationship between time-shift τ and the position in depth becomes

$$z=z_0-\upsilon\sqrt{1+z_x^2+z_y^2}\cdot\tau, \qquad (3)$$

where z_x and z_y denote the structural dip in *x* and in *y*, respectively. Hence, the maximum velocity for the fan filter becomes

$$v_{\max}=v(z_0)\sqrt{1+z_x^2+z_y^2}, \qquad (4)$$

which is equal or greater than the maximum migration velocity *v*.

Single shot gather

In this first example we want to illustrate the effectiveness of the filter with the time-shift imaging condition. The velocity model exists of one thin flat layer with 1,333 m/s velocity in a background with 2,000 m/s velocity, respectively. Figure 1 shows the migrated image of one single shot. We can observe the strong artifacts for reflection angles close or beyond the critical angle. For illustration, Figure 2 shows a few time-shift gathers. After transforming these gathers into the Fourier domain, the actual reflection can easily be identified. Hence, the unwanted contributions can be eliminated in the Fourier domain by applying a fan filter (Figure 3). Figure 4 shows the result after applying the fan filter to all CDP locations and by extracting the zero time-shift trace afterwards. Almost all artifacts could be eliminated.

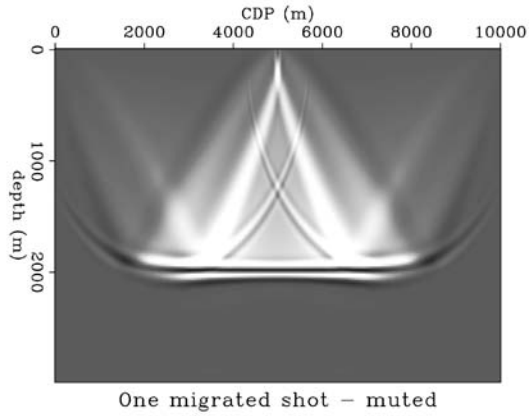


Figure 1: The migrated image of one single shot. The model consists of one thin flat low velocity layer. Please note the strong artifacts beyond the critical angle.

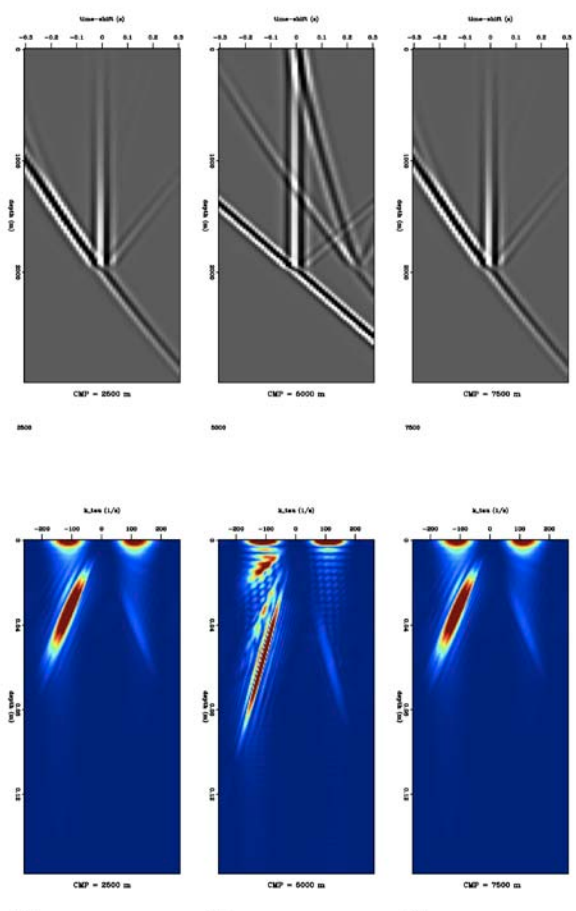


Figure 2: For illustration, time-shift gathers (top) and their Fourier transforms (bottom). The actual reflections can easily be identified.

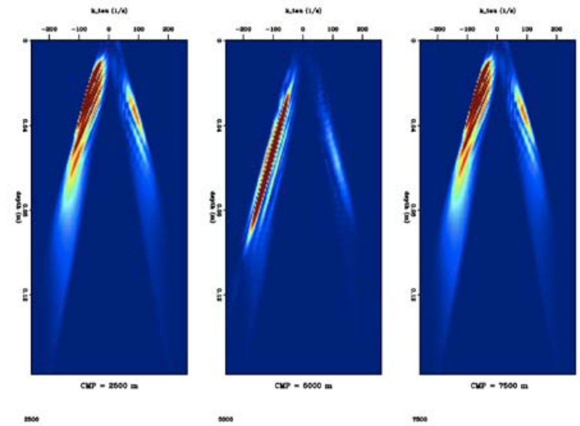


Figure 3: Similar to Figure 2: The artifacts have been eliminated with a fan filter defined by the migration velocities and the structural dip.

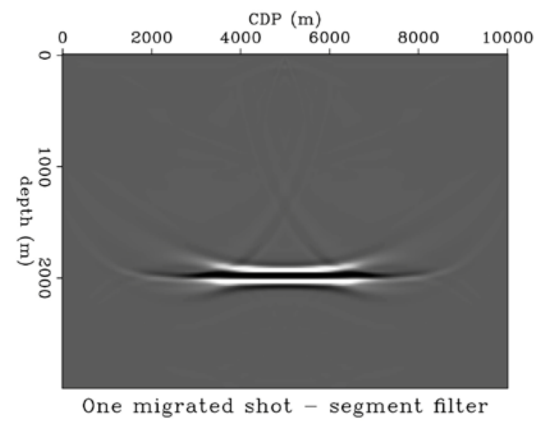
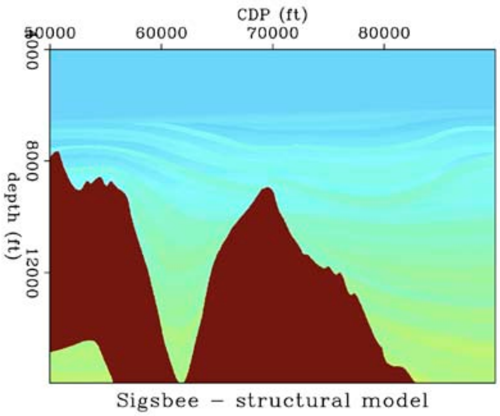


Figure 4: Similar to Figure 1: The migrated image of one single shot after applying fan filters with the time-shift imaging condition. Almost all artifacts have been eliminated.

Sigsbee2B

The second example is from the Sigsbee2B synthetic data (Pfaffenholz et al., 2002). This data contains a particular challenging area, where a deep canyon between steep salt flanks is filled with sediments (Figure 5, top). The migrated images show exceptionally strong artifacts at these locations (Figure 5, bottom). Figure 6 shows the image derived with a 2D low-cut filter. Similarly, Figure 7 shows the result of the time-shift imaging condition filter. Only the filter based on the time-shift imaging condition can preserve the continuity of the salt, and it can eliminate the low artifacts effectively.



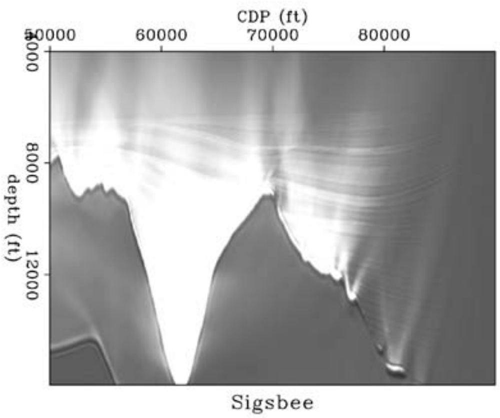


Figure 5: Sigsbee synthetic data: Velocity model (top) and migrated image (bottom). Please note the strong artifacts in the deep salt canyon.

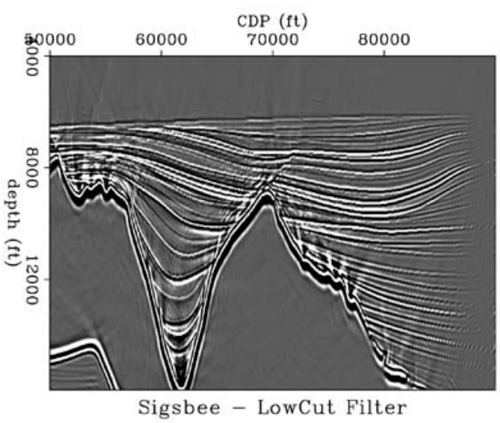


Figure 6: Similar to Figure 5, migrated image after applying a low-cut 2D filter. Please note the remaining low frequency artifacts.

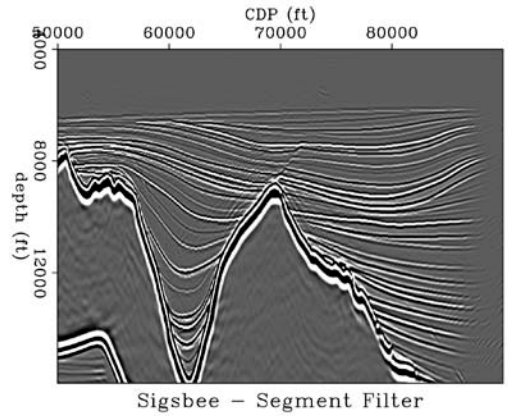


Figure 7: Similar to Figure 5, migrated image after applying the time-shift imaging filter.

Conclusions

The imaging condition applied with time-shift gathers offers an excellent opportunity to remove artifacts based on properties of wave propagation. The filters can be applied as a post-imaging process, and it therefore preserves all input data. Compared to regular noise filters the filtering with time-shift gathers yields superior zero time-shift images.

Acknowledgments

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