Stanford Exploration Project, Report 112, November 11, 2002, pages 117–123

Short Note

Damped imaging condition for reverse-time migration.

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INTRODUCTION

Reverse-time migration of shot-profiles (Etgen, 1986) has been proposed (Biondi, 2002) as an alternative to downward continuation methods to perform imaging in complex subsurface environments (e.g., under complex and rugose salt bodies). In these situations, due to the poor illumination given by near-offset ray-paths, all the events present in the data (such as overturned reflections and prismatic reflections) are needed to generate interpretable images.

Not only the kinematic response of the migration is important, seismic data amplitudes also have the potential to provide information on reservoir properties. However, the most common implementation of shot-profile reverse-time migration uses the zero lag of the cross-correlation of the source and the receiver wavefields as imaging condition. This implementation has the advantage of being robust and honoring the kinematics of Claerbout's imaging principle (Claerbout, 1971) but does not honor the dynamics of the problem, resulting in the loss of amplitude accuracy.

I find that a damped imaging condition is more appropriate to obtain accurate amplitudes. I define the imaging condition as the zero lag of the cross-correlation of the source and the receiver wavefields divided by the sum of autocorrelation of the source wavefield and a constant damping factor. The division by the autocorrelation of the source wavefield acts as a normalization by the subsurface illumination.

The damping factor is useful because it avoids division by zero. Unfortunately, it introduces an error in the image amplitudes. I used a mask function that is inversely proportional to subsurface illumination to avoid the use of the damping when it is not needed (space and time variable damping).

Using a shot from a 3D marine seismic dataset acquired in a complex area, I compare three different imaging conditions: cross-correlation, division with constant damping, and division with variable damping. I find that the variable damping imaging condition preserves the amplitudes in areas with good subsurface illumination. In areas with poor subsurface illumination, it does the same job as the constant damping imaging condition.

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DAMPING IN CONVENTIONAL IMAGING CONDITION

Conventional shot-profile migration determines the reflection strength at each subsurface point by taking into account only the source and receiver wavefield at that location. Jacobs (1982) compares two different imaging conditions

$$\mathbf{r} = \sum_{\mathbf{shot}} \sum_{\mathbf{t}} \mathbf{ud}, \tag{1}$$

and

$$\mathbf{r} = \sum_{\mathbf{shot}} \sum_{\mathbf{t}} \frac{\mathbf{ud}}{\mathbf{d^2} + \varepsilon^2}. \tag{2}$$

The first is the most commonly used in the industry. It has the advantage of being robust, but has the disadvantage of not computing the correct amplitudes. The second computes the correct amplitudes (except for a damping factor ε^2), but has the disadvantage of relying on a damping factor that cannot be automatically estimated (Claerbout, 1992).

MASKING THE DAMPING FACTOR

The damping factor is useful because it avoids instability in noisy-signal division but problematic because it biases the image amplitudes. I propose to add a mask function inversely proportional to the subsurface illumination at each point (Rickett, 2001).

$$\mathbf{w} \quad \alpha \quad \frac{\mathbf{1}}{\mathbf{d^2}}. \tag{3}$$

When $\mathbf{d^2}$ has enough energy to contribute to the image, the damping factor ε is set to zero. When factor $\mathbf{d^2}$ is small, the damping factor is kept to avoid zero division. Thus, the imaging condition can be set as

$$\mathbf{r} = \sum_{\mathbf{shot}} \sum_{\mathbf{t}} \frac{\mathbf{ud}}{\mathbf{d^2} + \mathbf{w}\varepsilon^2}, \tag{4}$$

where the damping is now variable in space and time.

RESULTS

A 2D shot from a seismic 3D marine dataset acquired in a complex area was used to test the preceding idea. Figure 1 shows the source wavefield and Figure 2 the receiver wavefield.

I calculated the reflection strength using the three imaging conditions stated in equations (1), (2) and (4). The results are shown in Figures 3-5. We can see that the damped imaging conditions from equation (2) and equation (4) give a more balanced section. Some artifacts, like the shot artifact present in Figure 3, were eliminated in Figure 4 and Figure 5. In general, the continuity of the events was enhanced.

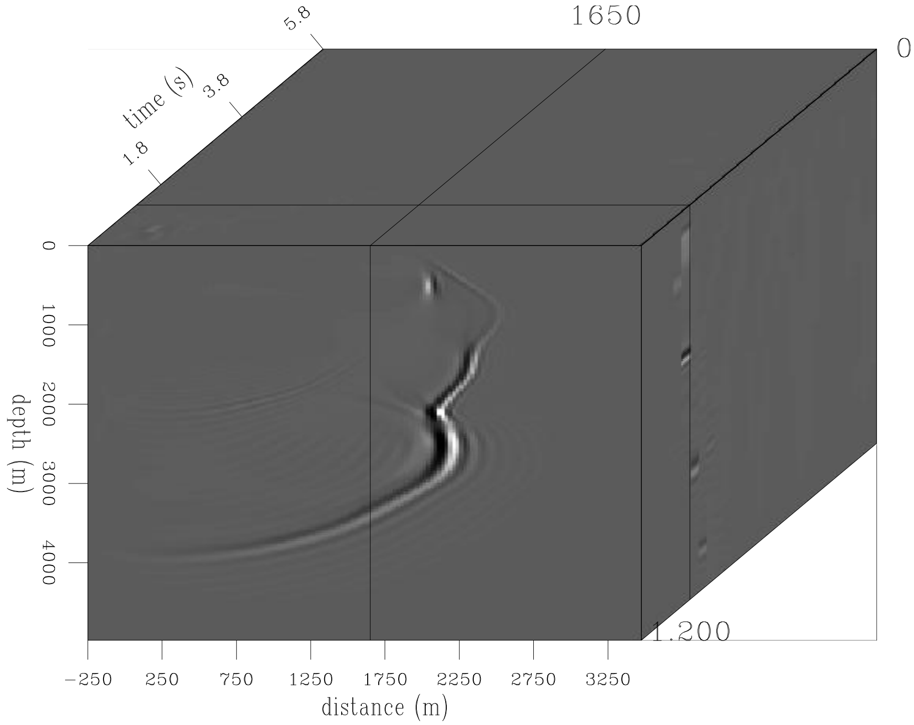

Figure 1: One shot source wavefield. alejandro2-D [ER]

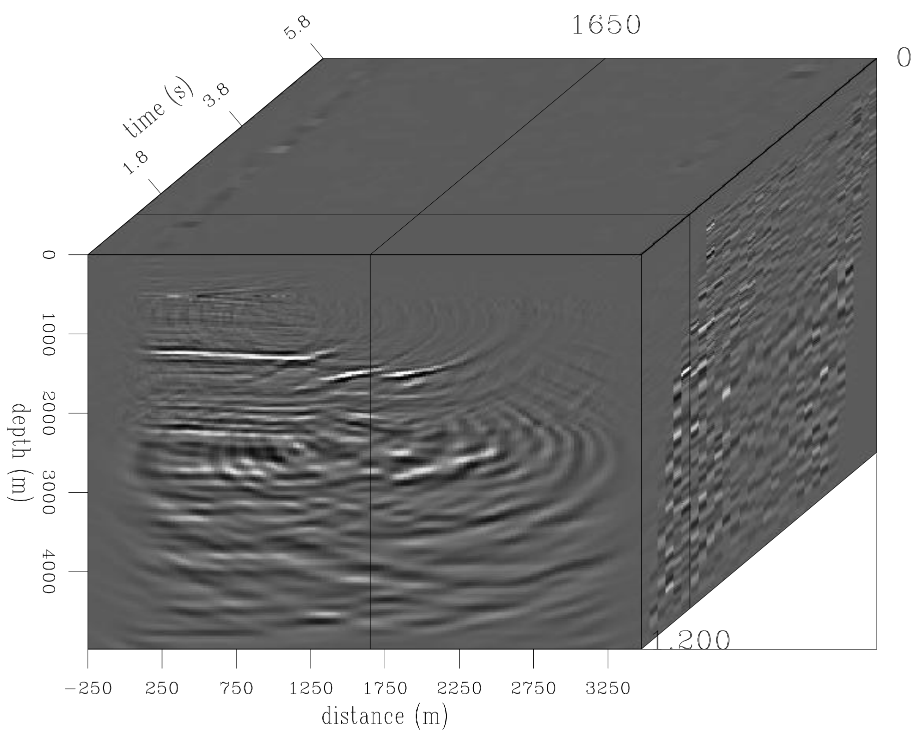

Figure 2: One shot receiver wavefield. alejandro2-U [ER]

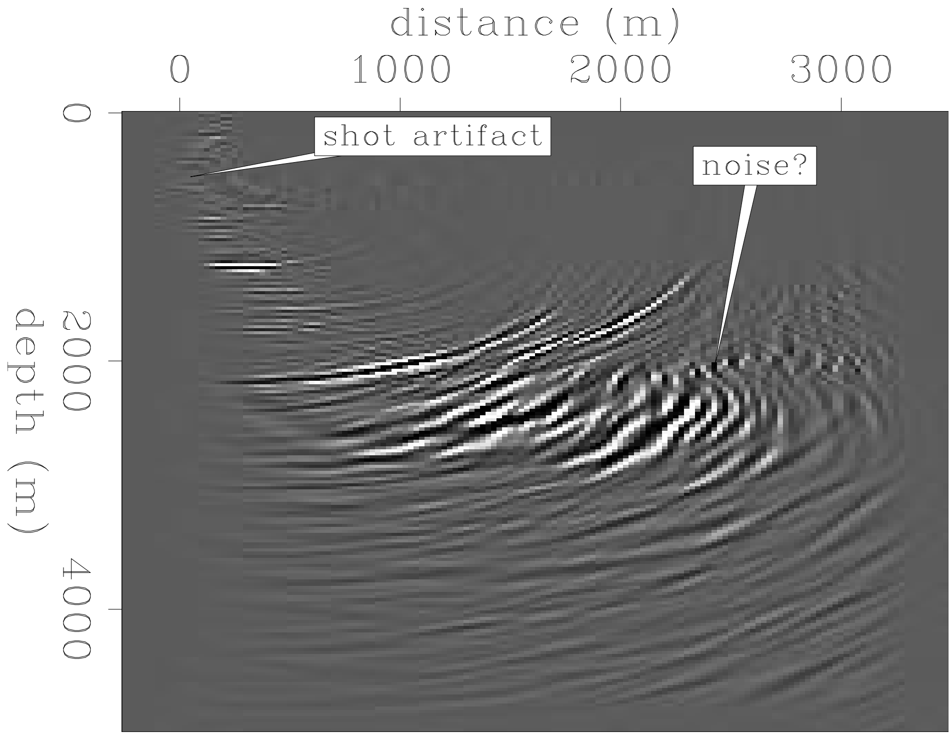

Figure 3: One shot stack using zero lag of the cross-correlation imaging condition as stated in equation (1). alejandro2-Image [ER]

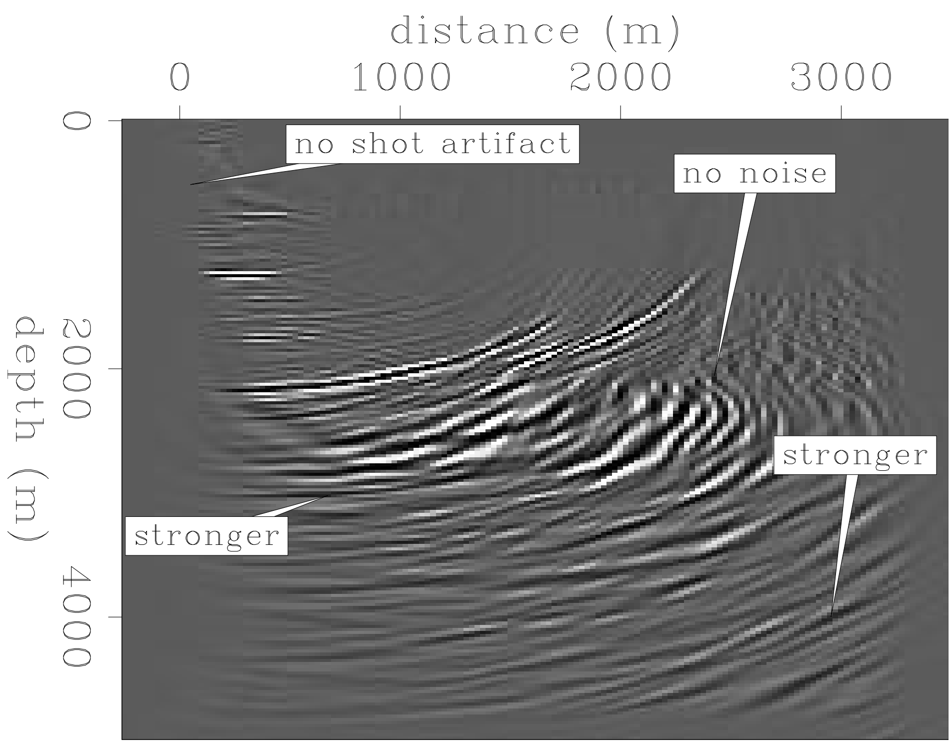

Figure 4: One shot stack using constant damped imaging condition as stated in equation (2). alejandro2-Image_damp [ER]

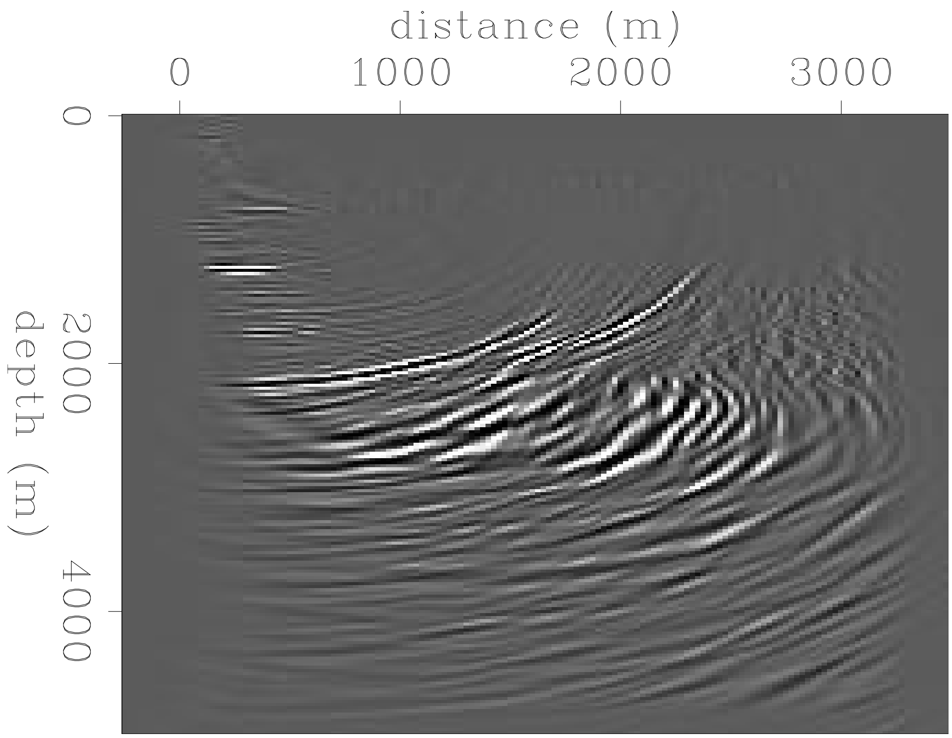

Figure 5: One shot stack using variable damped imaging condition as stated in equation (4). alejandro2-Image_damp1 [ER]

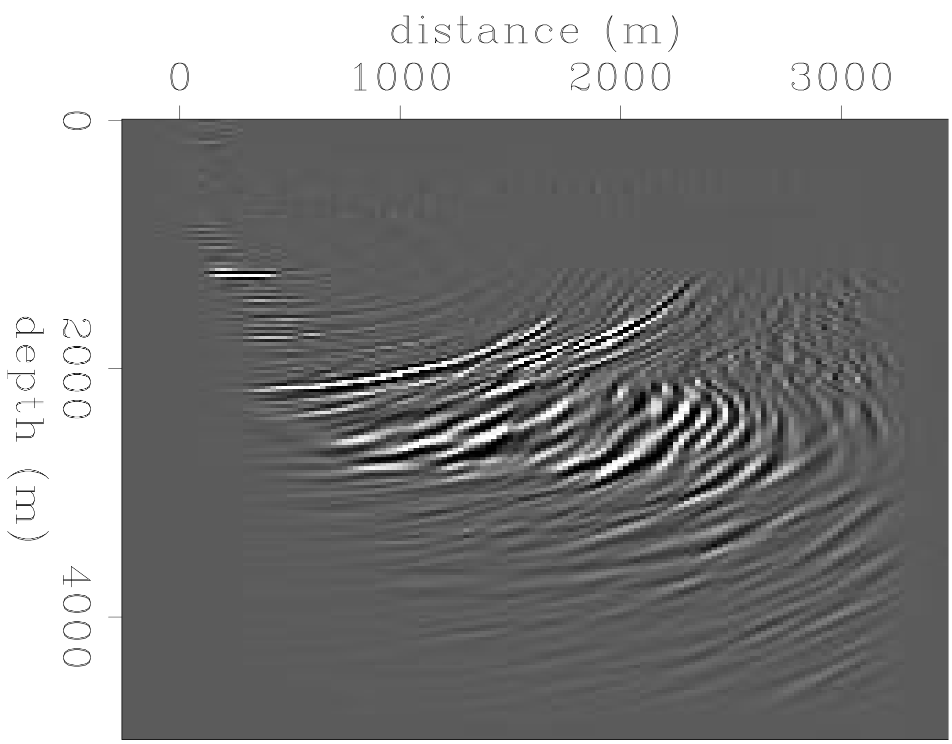

Figure 6: Difference between the constant damping (Figure 4) and the variable damping (Figure 5). alejandro2-diff_damp [ER]

In the two damped images compared in Figure 6, the difference between the images is greatest in the center where the damping was not needed and least in the corners where it is really needed.

A final test for the variable damping imaging condition should be the stack of more shots to form the final image. But issues like the data driven selection of the damping factor still need to be addressed to make it applicable to a full seismic dataset.

CONCLUSIONS

I showed, using a shot from a seismic 3D marine dataset acquired in a complex area, that including a damping factor in the imaging condition can improve the amplitude accuracy of the conventional shot-profile reverse-time migration imaging condition.

The damping factor can be related to reflector illumination, adding the damping factor where it is really needed. Thus a variable damping approach should better preserve the amplitudes than a constant damping approach.

ACKNOWLEDGMENTS

I would like to thank Guojian Shan for generating the data I used in this paper.

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