Imaging condition for reverse time migration

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Summary

In reverse time migration the imaging condition is estimated by cross-correlating the source wave-field with the receiver wave-field under the basic assumption that the source wave-field represents the down-going wave-field and the receiver wave-field the up-going wave-field. However, for large impedance contrasts and complex geological structures the wave-fields cannot be separated efficiently. In these cases the cross-correlation leads to low frequency artifacts. The imaging condition can be improved by dividing the cross-correlated image of each shot by the receiver illumination. This method is simple, it does not introduce phase shifts and it requires little additional computation, because the receiver illumination can be directly computed from the receiver wave-field.

Introduction

The imaging condition of reverse time migration is estimated by cross-correlating the source wave-field (S) and receiver wave-field (R) summed over the sources s (Biondi and Shan, 2002)

$$I(z,x) = \sum_s \sum_t S_s(t,z,x) R_s(t,z,x)\,, \qquad (1)$$

where z and x denote depth and the horizontal axis, respectively, and t is time. This imaging condition is sufficient for media with small impedance contrasts and simple geological structures.

Imaging condition with cross-correlation

Figure 1 shows for the simple case of one horizontal reflector that the source wave-field and the receiver wave-field will both consist of a down-going part and an up-going part in the upper medium, which leads to a low frequency artifact in the image. For the simple case of one source and one receiver both wave-fields show the same geometrical spreading and the artifact appears symmetrical between source and receiver.

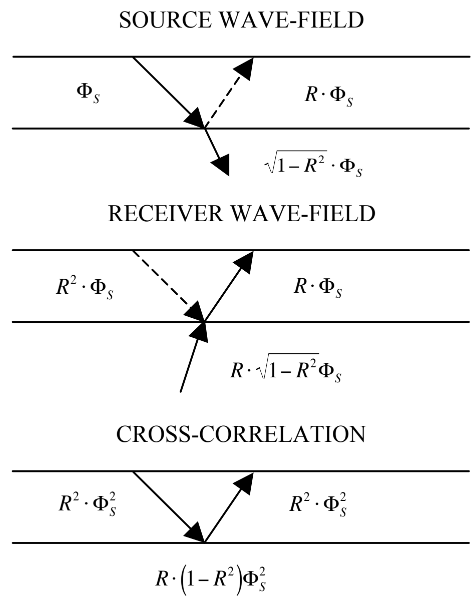

Figure 1: (a) Source wave-field, (b) receiver wave-field and (c) cross-correlation of source wave-field and receiver wave-field. The solid lines denote the ideal case, where up-going and down-going waves can be separated. Φ_S is the source function and R is the reflection coefficient between the two media.

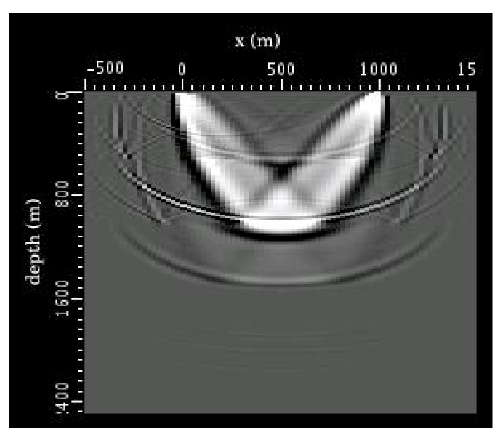

Figure 2: Imaging condition by cross-correlating source and receiver wave-field (equation 1) for a layered medium (source at x=0, receiver at x=1000). The artifact appears symmetrical between source and receiver.

Other imaging conditions

For small impedance contrasts the cross-correlation is a good approximation for the imaging condition. However, for large impedance contrasts the low frequency artifact becomes stronger and distorts the image. Figure 2 shows the migrated image for synthetic data from a layered medium with one source and one receiver. The artifact is distributed symmetrically between source and receiver and becomes strongest close to the reflector.

To suppress the artifacts, the image of the cross-correlation may be divided by the source illumination (Claerbout, 1971)

$$I(z,x) = \sum_s \frac{\sum_t S_s(t,z,x) R_s(t,z,x)}{\sum_t S_s^2(t,z,x)} \qquad (2)$$

or by the receiver illumination

$$I(z,x) = \sum_s \frac{\sum_t S_s(t,z,x) R_s(t,z,x)}{\sum_t R_s^2(t,z,x)} \,. \qquad (3)$$

Figure 3 shows that the image can be enhanced in both cases while the artifact is shifted to the receiver and to the source side, respectively.

In practice, reverse time migration is not applied for each receiver separately, but for all receivers in one shot-gather at the same time. In this case the geometrical spreading of the source wave-field and the receiver wave-field is different and the cross-correlation of the two becomes generally non-symmetrical (Figure 4). Dividing the cross-correlation by the source illumination (equation 2) suppresses the artifact close to the source, but it does not enhance the image above the strongest reflector (Figure 5a). Dividing by the receiver illumination (equation 3) suppresses the artifacts better and it enhances the deeper reflectors (Figure 5b).

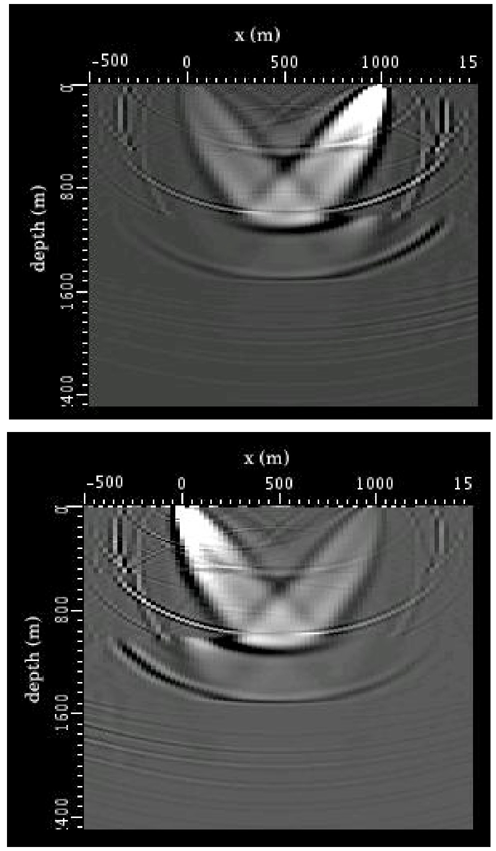

Figure 3: (a) Imaging condition from equation (2) and (b) imaging condition from equation (3).

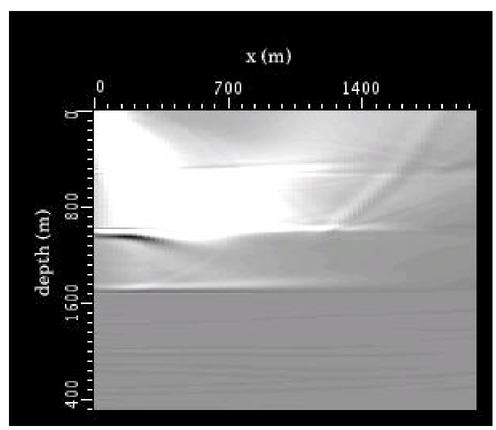

Figure 4: Imaging condition by cross-correlating source and receiver wave-field (equation 1) for a layered medium (source at x=0, 80 receivers between x=0 and x=2000). The artifacts are stronger close to the source.

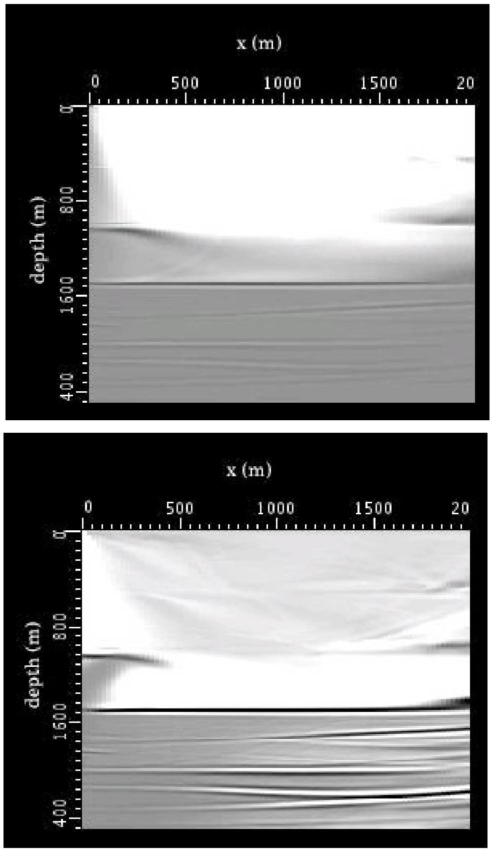

Figure 5: Layered medium (source at x=0, 80 receivers between x=0 and x=2000). (a) Imaging condition from equation (2). and (b) imaging condition from equation (3).

2004 BP velocity benchmark model

With the synthetic 2004 BP velocity benchmark model (Billette and Brandsberg-Dahl, 2005) we illustrate the effect of the different imaging conditions for reverse time migration in challenging geological environment. Figure 6 shows the results by estimating the imaging condition with the cross-correlation of the source wave-field and the receiver wave-field. 20 shot gathers were individually migrated, cross-correlated and summed. The image shows a strong artifact near the surface due to strong impedance contrasts and complex geological structures. The reflectors below the strong impedance contrast are well estimated by the imaging condition.

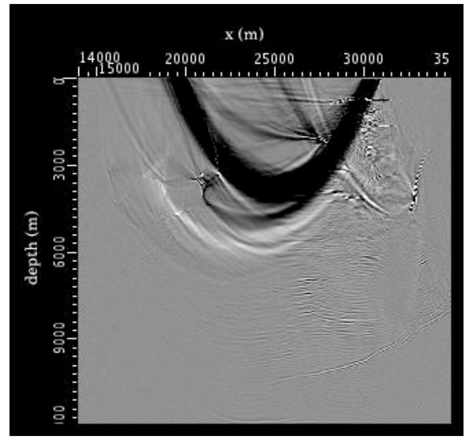

Figure 6: Imaging condition by cross-correlating source and receiver wave-field for 20 shots from the synthetic 2004 BP data.

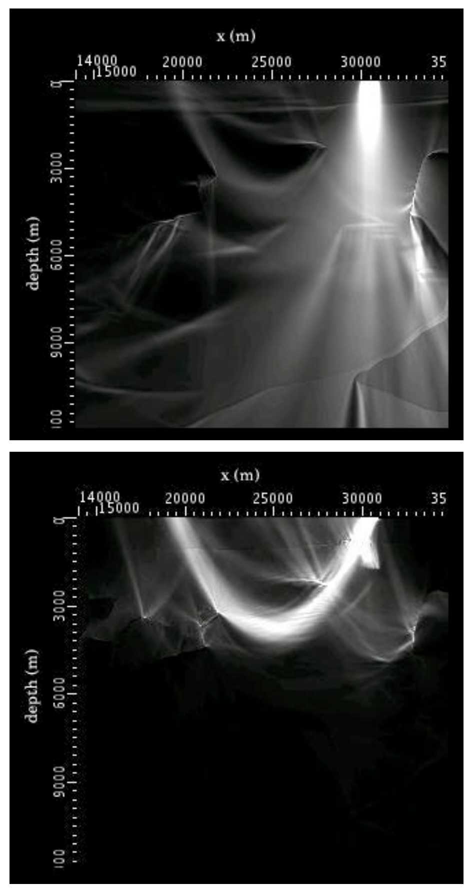

Figure 7: (a) Source illumination and (b) receiver illumination for 20 shots from the synthetic 2004 BP 2004.

Figure 7a shows the source illumination and Figure 7b shows the receiver illumination for the same 20 shots. Similar to the case for flat layers, the geometrical spreading of the two illuminations is very different. The source illumination covers the subsurface almost uniformly whereas the receiver illumination shows most of the energy at the location, where there are strong artifacts.

Normalizing the cross-correlation by the source illumination for every shot reduces the artifacts close to the source, but it enhances the artifacts close to the receiver (Figure 8). Normalizing by the receiver illumination reduces the artifacts in the whole image very effectively and preserves the lower reflections (Figure 9).

Conclusions

The imaging condition for reverse time migration is generally estimated by cross-correlating the source wave-field with the receiver wave-field. For large impedance contrasts and complex geological structures, the imaging condition can be improved by normalizing with the receiver illumination. This method eliminates artifacts and preserves reflectors at the same time. It requires little additional computation, because the receiver illumination can be computed directly from the receiver wave-field.

References

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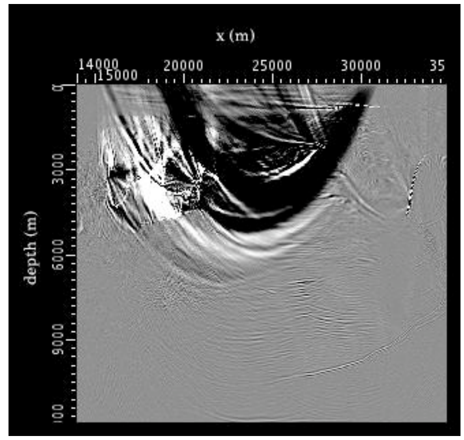

Figure 8: Imaging condition from equation (2) for 20 shots from the synthetic 2004 BP data.

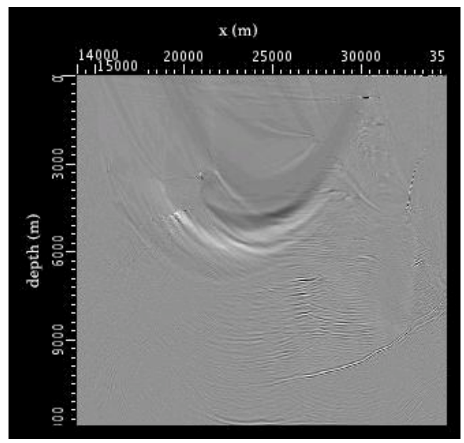

Figure 9: Imaging condition from equation (3) for 20 shots from the synthetic 2004 BP data.

EDITED REFERENCES

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