

## **Illumination effects in reverse time migration**

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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 artefacts and illumination effects. Illumination effects can be efficiently removed by dividing the cross-correlated image by the receiver illumination and by the source illumination. This method is simple, it does not introduce phase shifts and it requires little additional computation, because the both illuminations can be directly computed from the source wave-field and from the receiver wave-field, respectively.

## Introduction

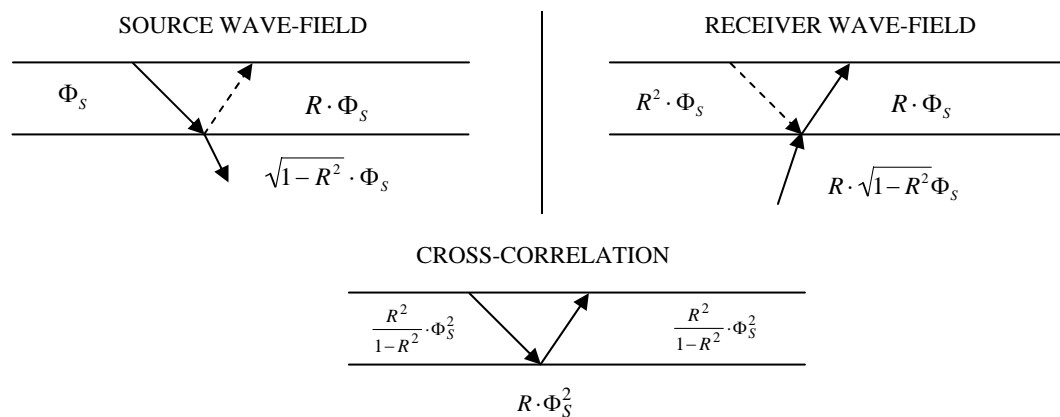
The imaging condition of reverse time migration is estimated by cross-correlating the source wave-field ( $S$ ) and receiver wave-field ( $R$ ) summed over the sources  $s$  (Biondi and Shan, 2002)

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

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 artefact 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.



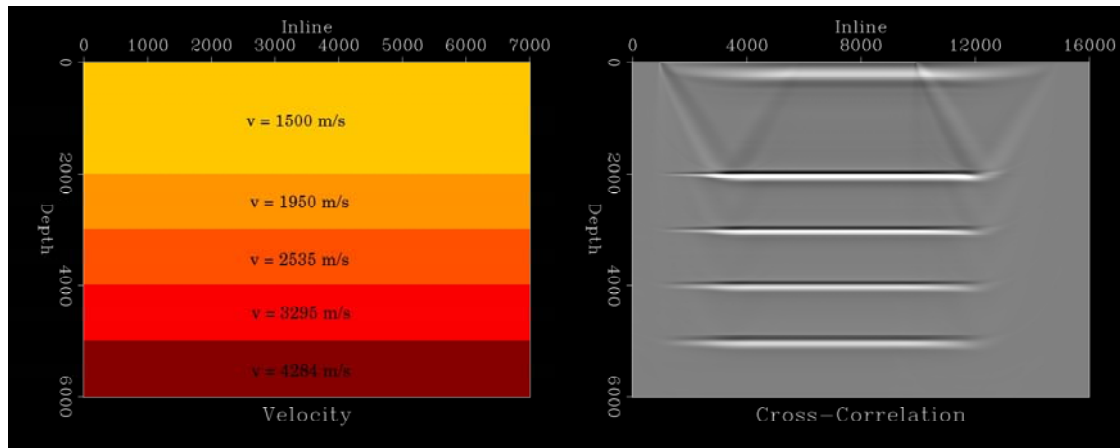
**Figure 1:** (a) Source wave-field, (b) receiver wave-field and (c) cross-correlation of source wave-field and receiver wave-field. The solid lines in (a) and (b) denote the ideal case, where up-going and down-going waves can be separated.  $\Phi_s$  is the source function and  $R$  is the reflection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

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.

## Other imaging conditions

For small impedance contrasts and simple geological structures the cross-correlation is a good approximation for the imaging condition. However, with larger impedance contrasts the low frequency artefact becomes stronger (Kaelin and Guitton, 2006; Guitton et al., 2007) and with more complex geological structures the reflectivity in the migrated image is non-stationary. Figure 2 shows the migrated image for synthetic data from a layered medium with identical reflection coefficients. The image was generated with 100 shots and 201 receivers for each shot. The artefact is distributed symmetrically between source and receiver and becomes strongest close to the surface and at the first reflector. Figure 2 also shows that the reflectivity

of the individual interfaces decreases with depth and does therefore not represent true reflectivity of the velocity model.



**Figure 2:** Velocity model (left) and migrated image (right). Imaging condition by cross-correlating source and receiver wave-field (equation 1) for a layered medium (100 sources between 1000 m and 9000 m; 201 receivers with 20 m spacing). The artefacts are strongest close to the source. The reflection coefficient of all layers is constant in the velocity model, but the reflectivity in the migrated image decreases with depth.

To suppress the artefacts and to recover the true reflectivity, the image of the cross-correlation may be divided by the source illumination (Claerbout, 1971)

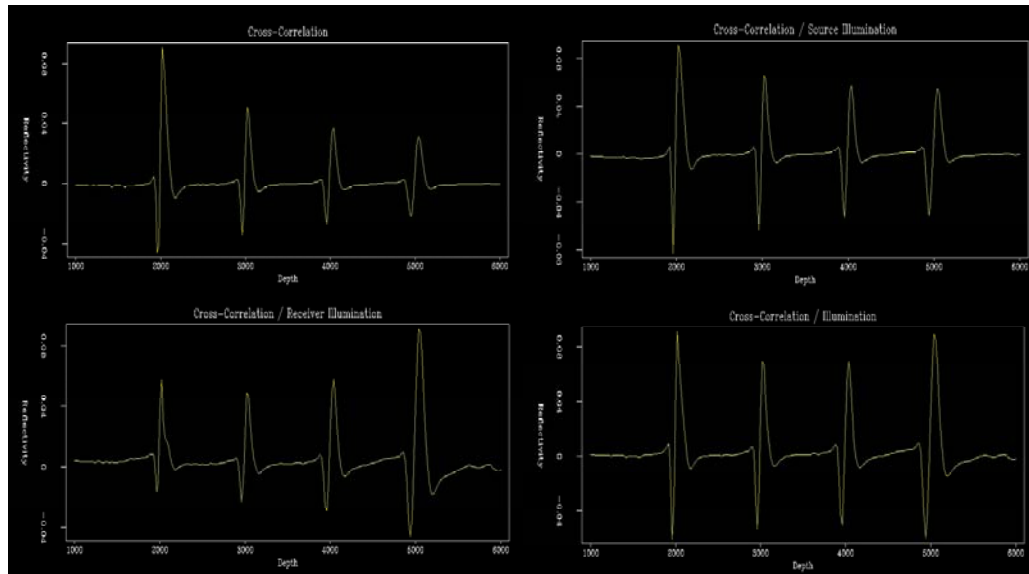
$$I_S(z, x) = \frac{\sum_s \sum_t S_s(t, x, z) \cdot R_s(t, x, z)}{\sum_s \sum_t S_s^2(t, x, z)}, \quad (2)$$

or by the receiver illumination

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

Figure 3 shows the reflectivity of the layered model (Figure 2) by applying the cross-correlation (Figure 3a). Dividing the cross-correlation by the source illumination alone puts too much weight on the shallow reflectors (Figure 3b), whereas dividing by the receiver illumination alone puts more weight on the deep reflectors (Figure 3c). The combination of the two latter imaging conditions yields equal reflectivity for all reflectors (Figure 3d)

$$I(z, x) = I_S(z, x) + I_R(z, x). \quad (4)$$



**Figure 3:** (a) Imaging condition is the cross-correlation (equation 1), (b) the cross-correlation imaging condition normalized by the source illumination (equation 2), (c) the cross-correlation imaging condition normalized by the receiver illumination (equation 3) and (d) a combination of the two latter imaging conditions (equation 4).

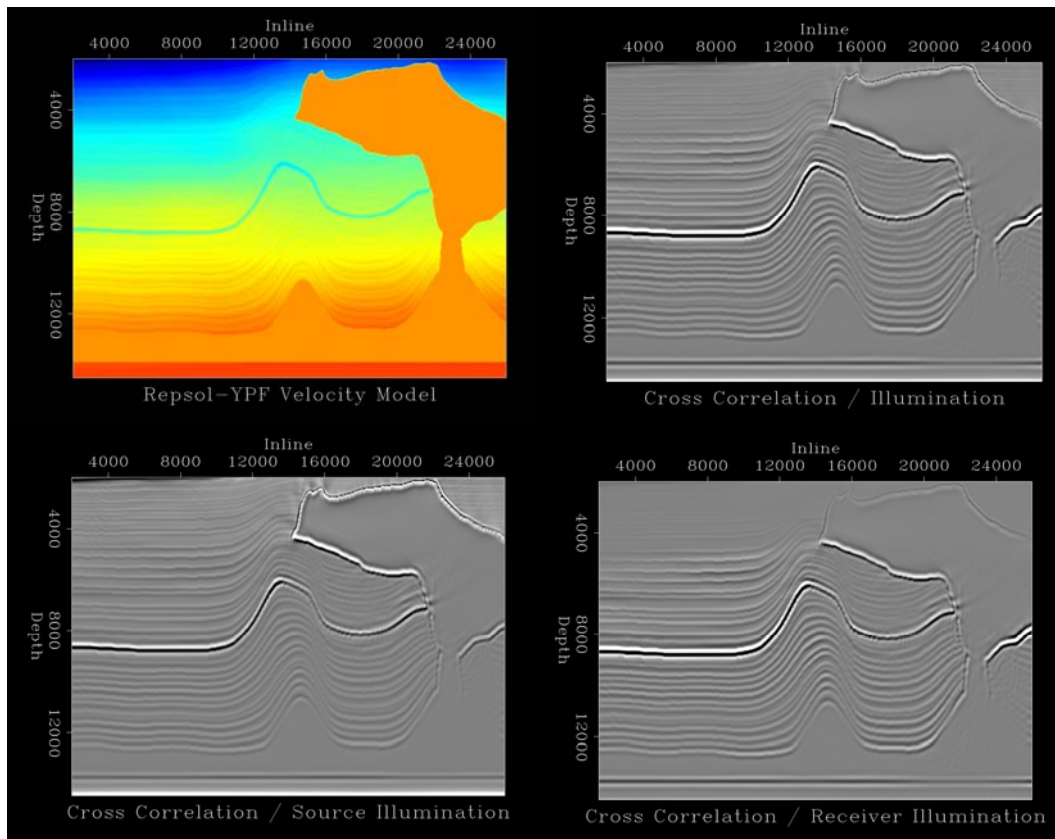
### Repsol-YPF velocity model

With a two-dimensional slice through the synthetic Repsol-YPF velocity model we illustrate the effect of the different imaging conditions for reverse time migration in challenging geological environment. The Repsol-YPF velocity model was developed within the Kaleidoscope project and it contains a high velocity salt body (Figure 4a), which leads to strong illumination effects. With the cross-correlation only the reflectivity of the deeper reflectors is underestimated. Similar to the case of layered media, the combination of source illumination and receiver illumination yields the true reflectivity (Figure 4b). The migrated image shows no illumination effects from the salt body. All reflectors are almost constant along the profile and the strong reflector at about 8,500 m depth is preserved.

Normalizing the cross-correlation by the source illumination alone (Figure 4c) puts too much weight on the shallow layers and the strong reflector at about 8500 m depth is too weak. Additionally, the reflectivity is smaller close to the salt body, which is caused by residual illumination effects. Normalizing the cross-correlation by the receiver illumination (Figure 4d) shows the opposite effects. Only the combination of these two illumination compensations yields the correct reflectivity.

### 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 source illumination and the receiver illumination. The sum of the two images takes into account geometrical spreading and it yields the correct reflectivity. The imaging condition requires little additional computation, because the illuminations can be computed directly from the source wave-field and the receiver wave-field, respectively.



**Figure 4:** (a) Two-dimensional slice through the Repsol-YPF velocity model, (b) migrated image with the combined imaging conditions (equation 4), (c) migrated image with the compensation of the source illumination alone (equation 2), (d) migrated image with the compensation of the receiver illumination alone (equation 3).

## Acknowledgment

We thank Repsol-YPF for permission to publish this work.

## References

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