RTM imaging condition using impedance sensitivity kernel combined with Poynting vector

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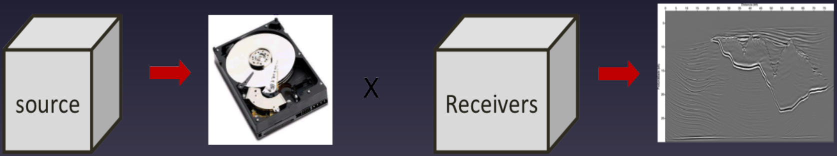
Reverse time migration (RTM)

- In RTM, the cross-correlation imaging condition, which is given by:

$$I_{cc}(\mathbf{x}) = \int P_F(\mathbf{x},t)\; P_B(\mathbf{x},t)\, dt \qquad (1)$$

is used in practice and is often preferable due to stability reasons.



Forward propagation

Backward propagation
+
cross-correlation

Final image

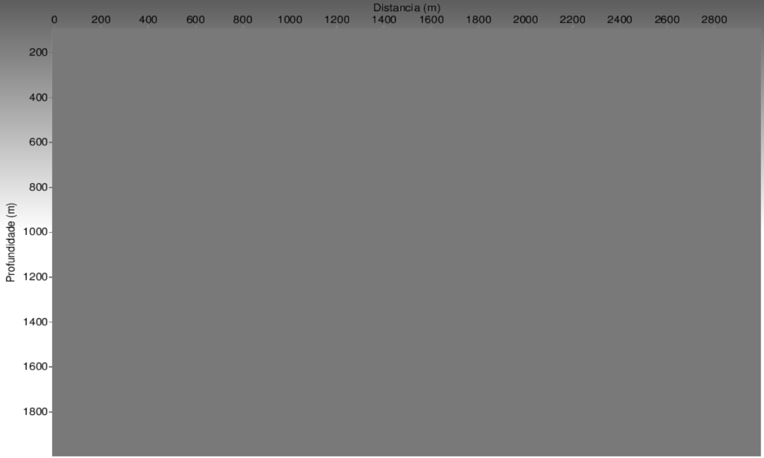


Image at time=2.0 s

Conventional Imaging Condition

Image at time=1.2 s

Conventional Imaging Condition

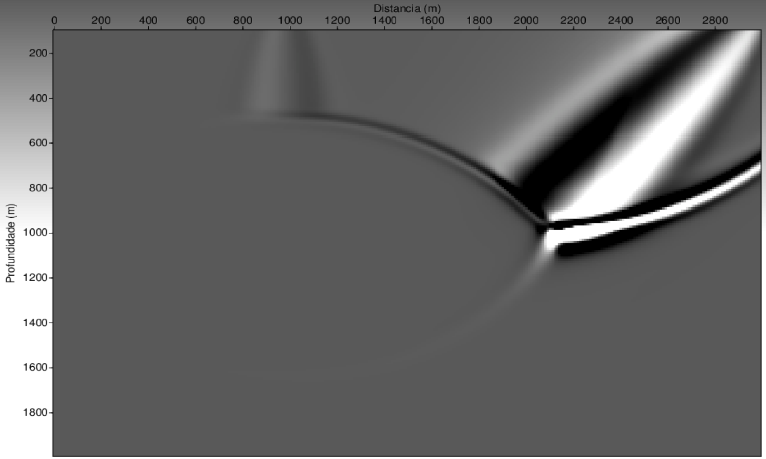


Image at time=0.8 s

Conventional Imaging Condition

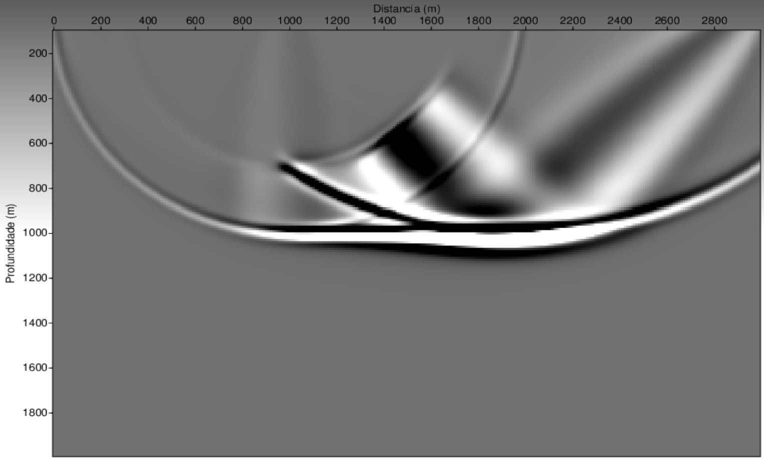


Image at time=0.4 s

Conventional Imaging Condition

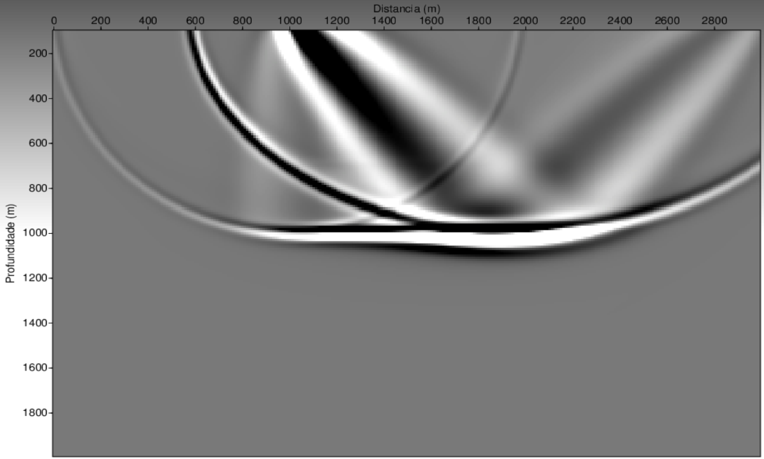
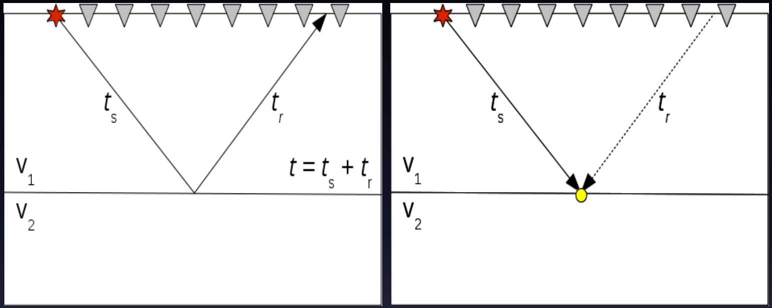


Image at time=0.0 s

Conventional Imaging Condition

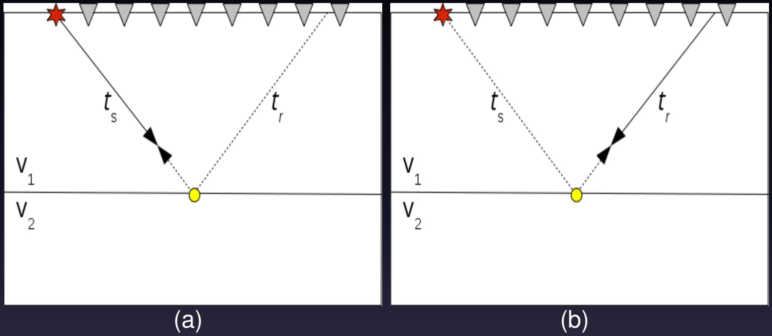


(a) (b)

(a) Propagation path of a source wavefield. The imaging relation $t = t_s + t_r$ is used to generate an imaging point.

(b) The cross-correlation imaging condition generates reflections above a hard interface in the velocity field.

Origin of the low frequency noise (backscattered waves)

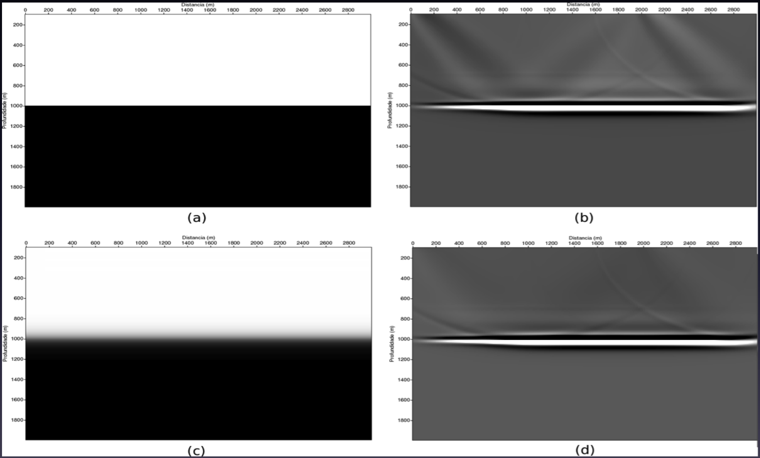


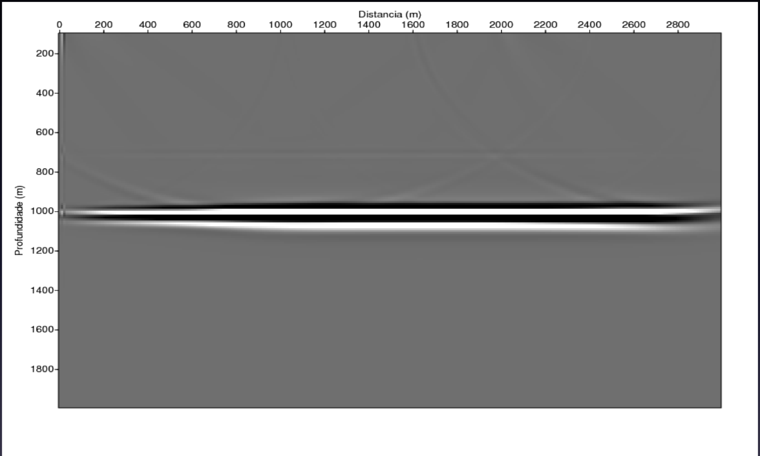
The propagation paths of a source wavefield (solid lines).

The propagation of a receiver wavefield (dashed lines).

The arrows indicate the propagation direction with time running forward.

Smoothing of the velocity field





Laplacian filtering:

$$\nabla^2 I(\mathbf{x}) = \frac{\partial^2 I(\mathbf{x})}{\partial x^2} + \frac{\partial^2 I(\mathbf{x})}{\partial z^2}$$

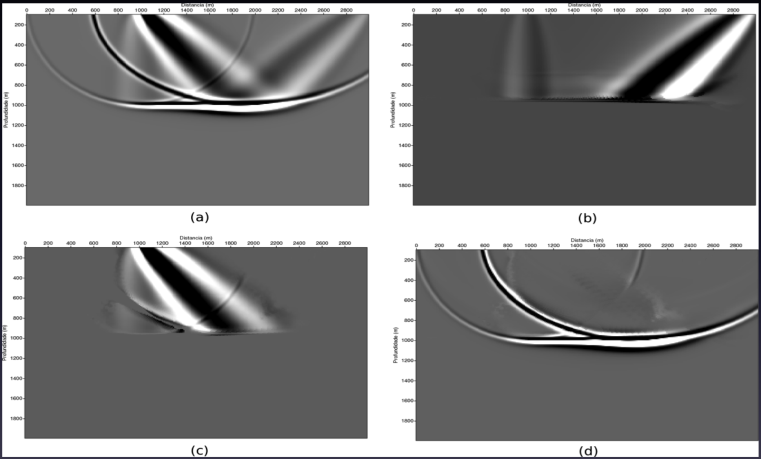
RTM - Imaging condition

- Imaging condition proposed by Bulcão et al. (2007):

$$I_c(\mathbf{x}) = \sum_{t=0}^{t_f} P_{F_d}(\mathbf{x}, t)\ P_{B_d}(\mathbf{x}, t) \tag{2}$$

- To avoid the cross-correlation of the downgoing waves with the upgoing waves, cause of the low frequency noise.

Imaging conditions



(a) Conventional; (b) $P_{F_u} * P_{B_d}$

(c) $P_{F_d} * P_{B_u}$ (d) $P_{F_d} * P_{B_d}$

Poynting Vector

- Separation can be done if the propagation direction of the wavefield is known;
- This information can be obtained by the computation of the Poynting vector.

$$\vec{S}(\mathbf{x}, t) = -\frac{\partial P(\mathbf{x}, t)}{\partial t} \nabla P(\mathbf{x}, t) \tag{3}$$

- Now, we need to compute the temporal derivative of the wavefield.

Poynting Vector Computation

- Wavefield is extrapolated in time by rapid expansion method (REM) (Pestana and Stoffa, 2010).
- Acoustic wave equation solution is given by

$$P(\mathbf{x}, t + \Delta t) = -P(\mathbf{x}, t - \Delta t) + 2\,\cos(L\Delta t)\,P(\mathbf{x}, t) \qquad (4)$$

where $L = c^2(\mathbf{x})\,\sqrt{-\nabla^2}$

- The cosine function is expanded by (Tal-Ezer et al.,1987)

$$\cos(L\Delta t) = \sum_{k=0}^{M} C_{2k}\,J_{2k}(R\,\Delta t)\,Q_{2k}\left(\frac{i\,L}{R}\right) \qquad (5)$$

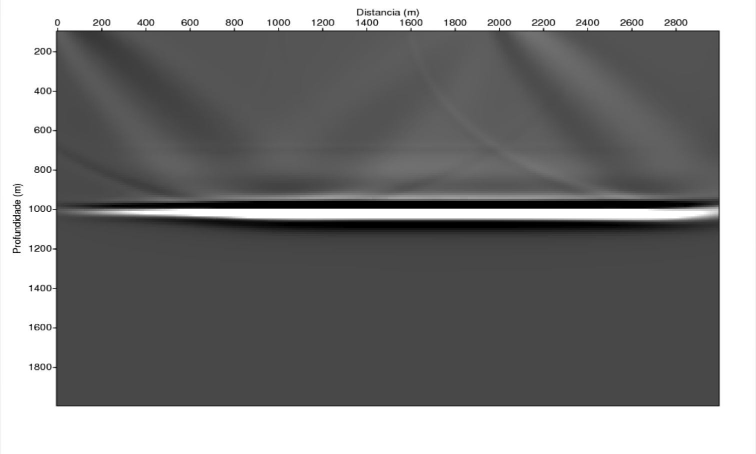
Time derivative computed by REM

- The time derivative of the wavefield can be computed by (Tessmer, 2011) :

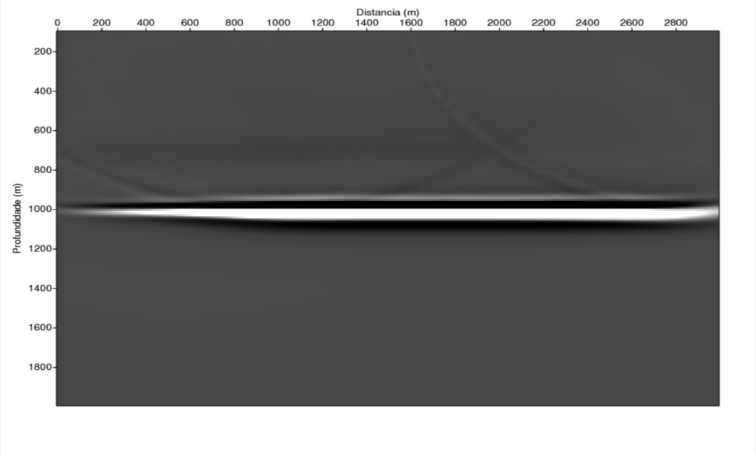
$$\begin{aligned}\dot{P}(\mathbf{x}, t+\Delta t) &- \dot{P}(\mathbf{x}, t-\Delta t) \\ &= \sum_{k=0}^{M} C_{2k} \frac{d}{d\tau} J_{2k}(\tau = R\,\Delta t)\, Q_{2k}\left(\frac{i\,L}{R}\right) P(\mathbf{x}, t)\end{aligned} \tag{6}$$

- Now, we can decompose the wavefield (source/receiver) in its downgoing and upgoing components.

Conventional imaging condition



Using Poynting vector: $I(\mathbf{x}) = P_{F_d} * P_{B_d}$



Imaging conditions for RTM

- Cross-correlation imaging condition:

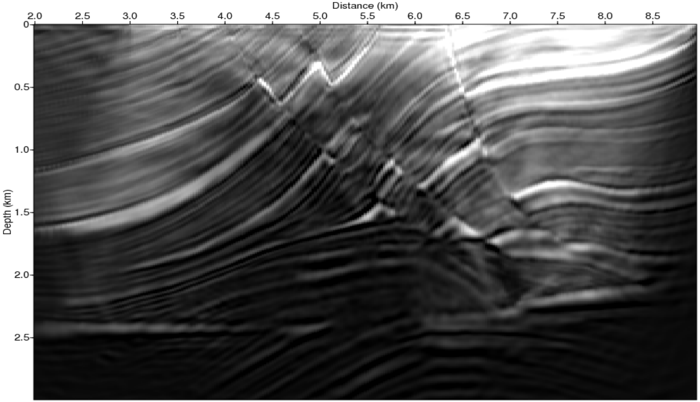
$$I_{cc}(\mathbf{x}) = \int P_F(\mathbf{x},t)\; P_B(\mathbf{x},t)\, dt$$

- Impedance sensitivity kernel imaging condition and Poynting vector.

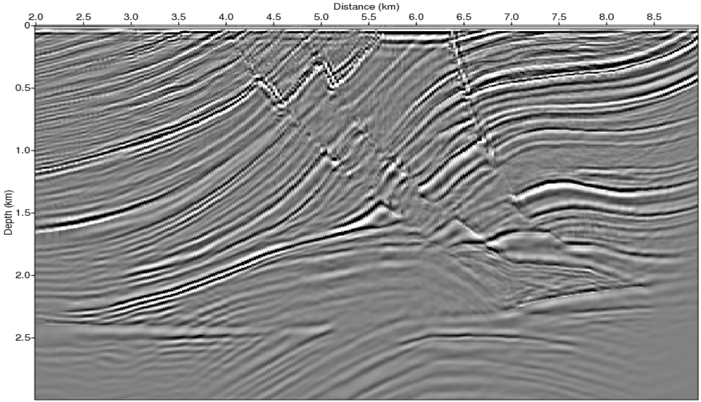
Based on the relationship of inversion and imaging (Luo et al., 2009; Zhou et al., 2009; Whitmore and Crawley, 2012):

$$\begin{aligned} I_k(\mathbf{x}) &= \frac{1}{v^2(\mathbf{x})} \int \frac{\partial}{\partial t} P_F(\mathbf{x},t)\; \frac{\partial}{\partial t} P_B(\mathbf{x},t)\; dt \\ &+ \int \nabla P_F(\mathbf{x},t) . \nabla P_B(\mathbf{x},t)\; dt \end{aligned} \qquad (7)$$

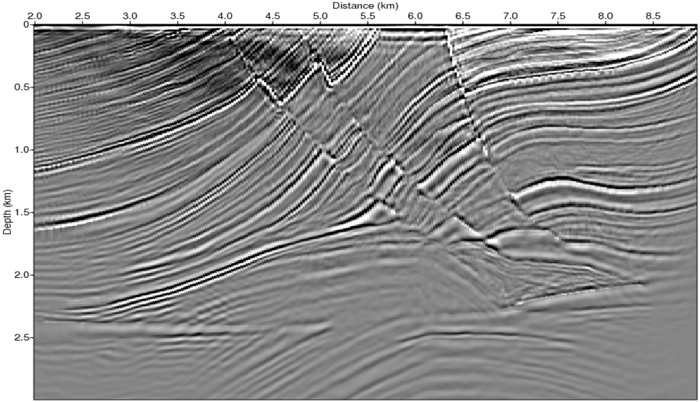
Conventional Imaging condition - Marmousi data



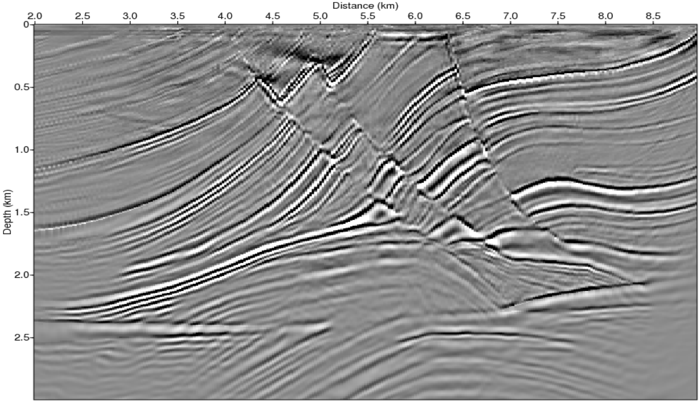
Conventional + Laplacian filtering



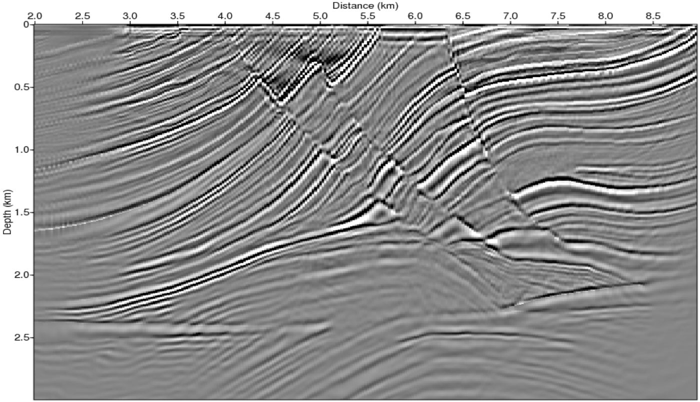
Impedance sensitivity kernel



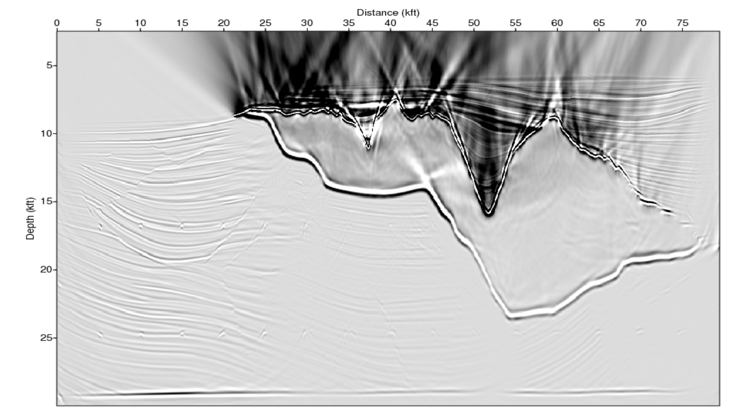
Impedance sensitivity kernel - (P_{F_d} and P_{B_d})



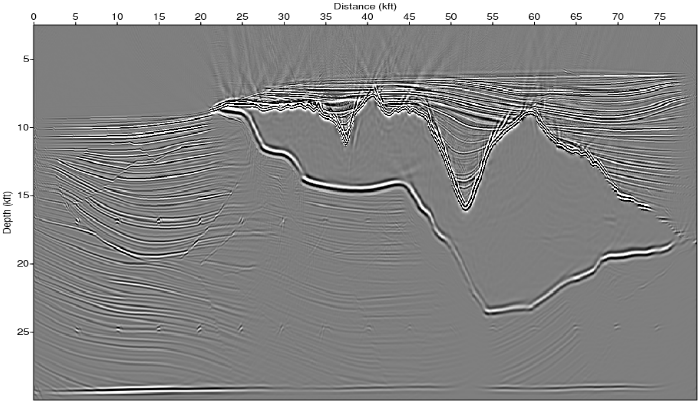
Impedance sensitivity kernel (P_{F_d})



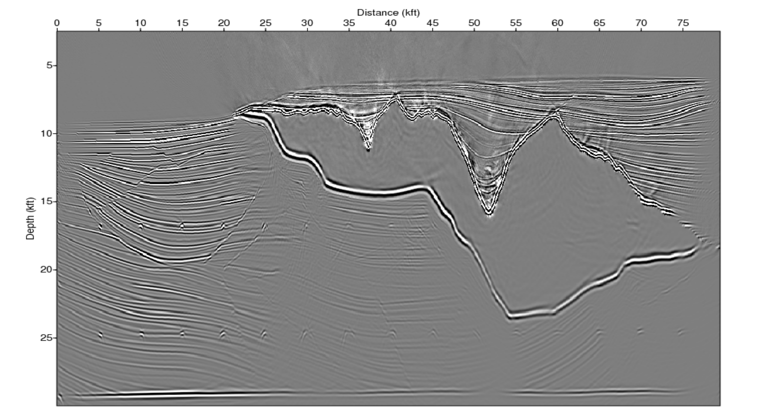
Conventional Imaging condition - Sigsbee2a



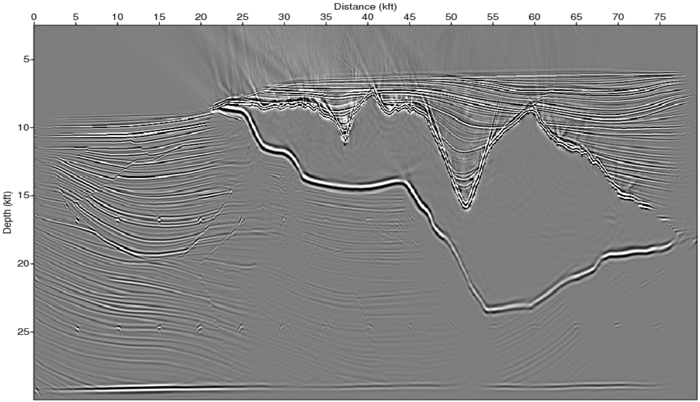
Conventional + Laplacian filtering



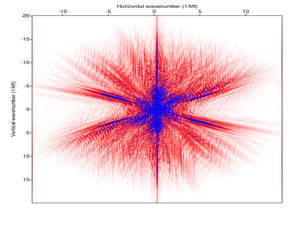
Impedance sensitivity kernel - (P_{F_d} and P_{B_d})



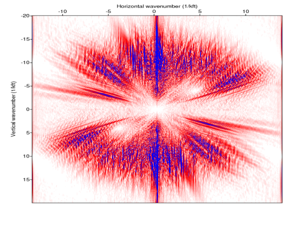
Impedance sensitivity kernel (P_{F_d})



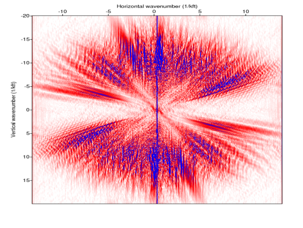
2-D Fourier spectrum - Sigsbee2a



(a)



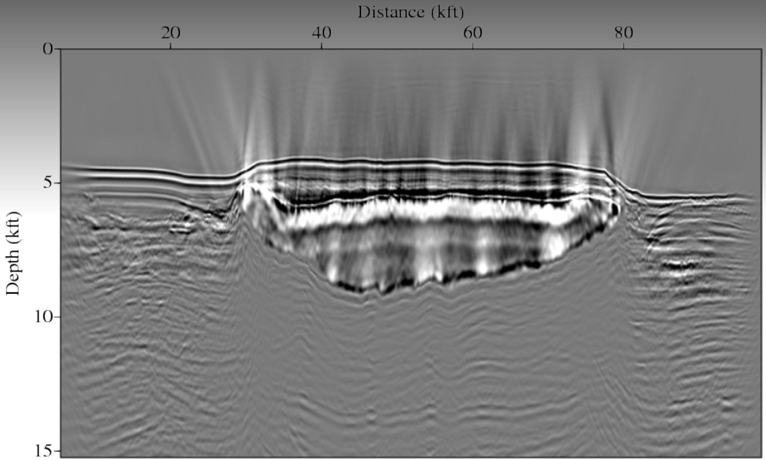
(b)



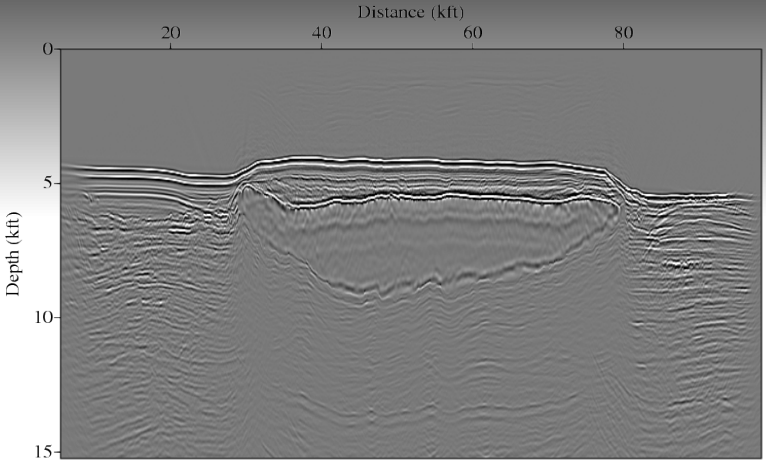
(c)

(a) Conventional imaging condition; (b) Laplacian filter; (c) Impedance sensitivity kernel (P_{F_d}).

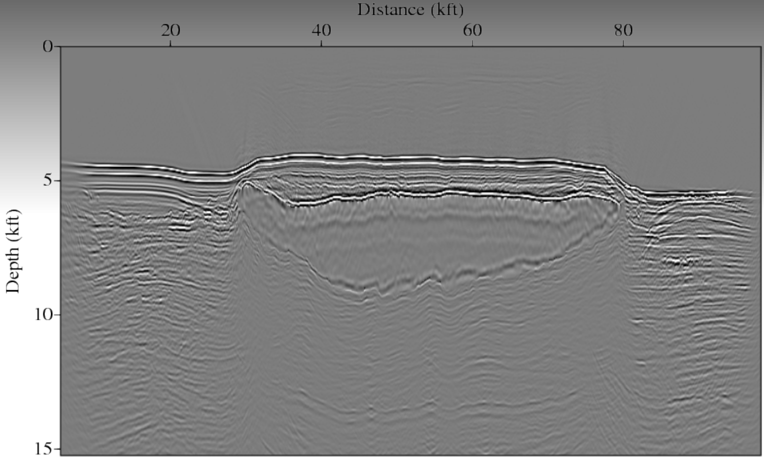
Mexico dataset RTM result: Conventional imaging condition



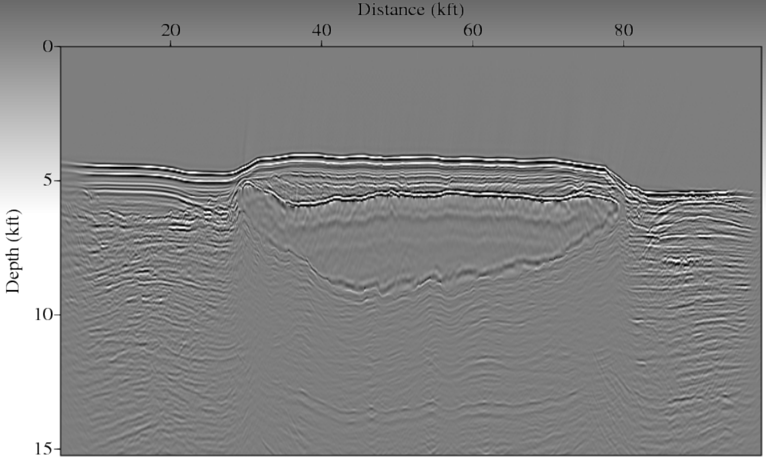
Conventional imaging condition plus Laplacian filtering

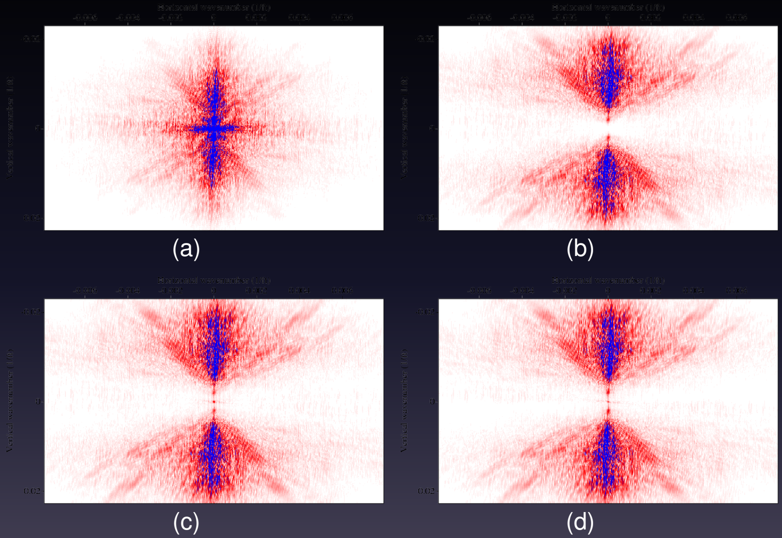


Impedance sensitivity kernel - (P_{F_d} and P_{B_d})



-Impedance sensitivity kernel (P_{F_d})





(a) Conventional imaging condition; (b) Imaging condition plus Laplacian filtering;

(c) Impedance sensitivity kernel - (P_{F_d} and P_{B_d}) (d) Impedance sensitivity kernel (P_{F_d})

Conclusions - I

- The practical Laplacian filter is easy to apply and can remove these artifacts but it can damage the signal of interest;
- We proposed to use the impedance sensitivity kernel to replace the conventional cross-correlation and attenuate the low frequency artifacts;

Conclusions - II

- We demonstrated with synthetic examples that the RTM results obtained with impedance kernel for the downgoing wavefield separated using the Poynting vector can preserve the reflections and attenuate the low frequency artifacts;

- The proposed imaging condition can be cheaply applied during the migration procedure;

Acknowledgements

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Thank you for your attention.