Reverse-time true amplitude migration

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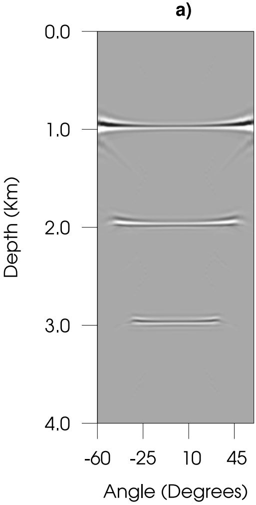
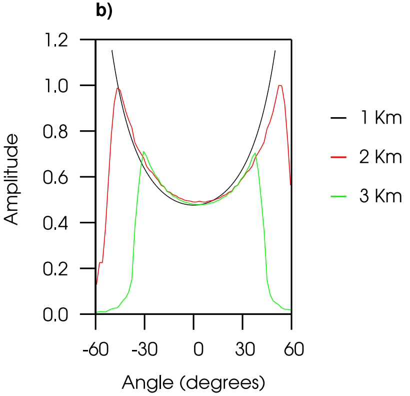
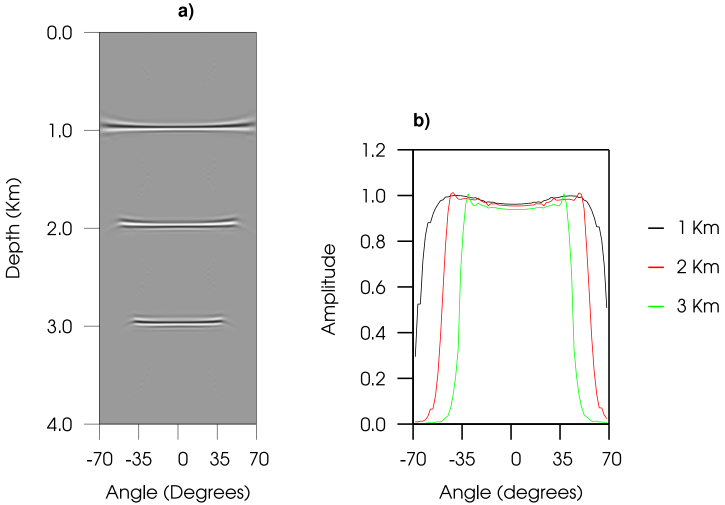
Incorrect AVO behavior





Correct reflection coefficients



[Arntsen et al., 2013] [Zhang et al., 2014]

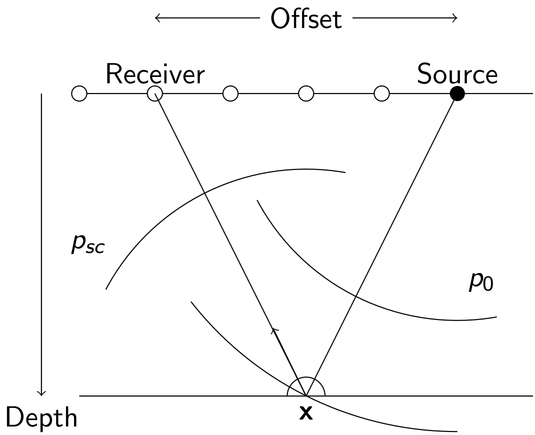
Overview

1. Introduction
2. True Amplitude Imaging condition
3. Numerical examples
4. Conclusions

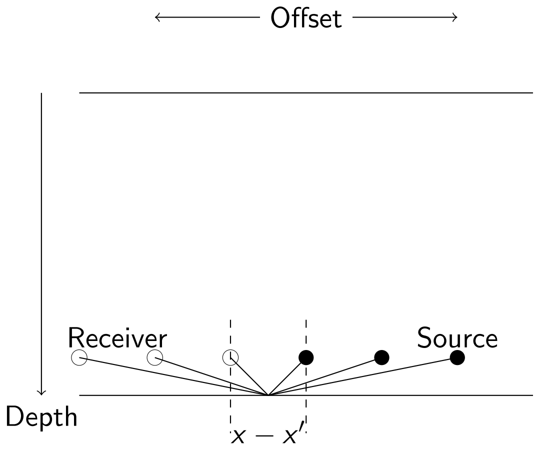
Introduction

1. AVO analysis important for exploration and reservoir characterization
2. Output gathers from migration should ideally be equal to angle-dependent reflection coefficient
3. The most commonly used imaging condition in Reverse-time migration gives gathers with incorrect angle-dependence
4. Simple modification of Claerbouts (1971) imaging condition gives correct angle dependence
5. Theoretically sound

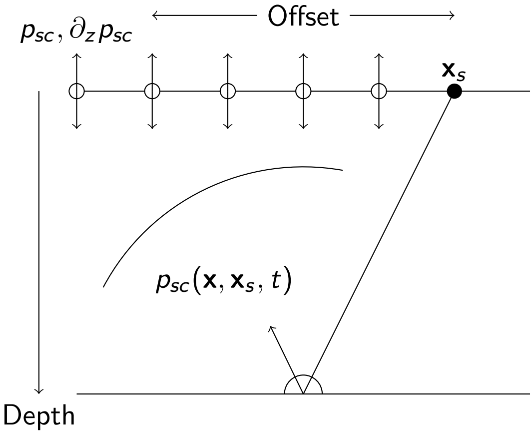
Imaging condition



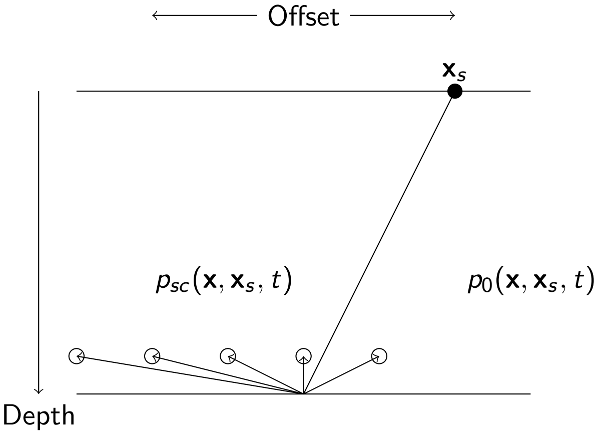
Imaging condition



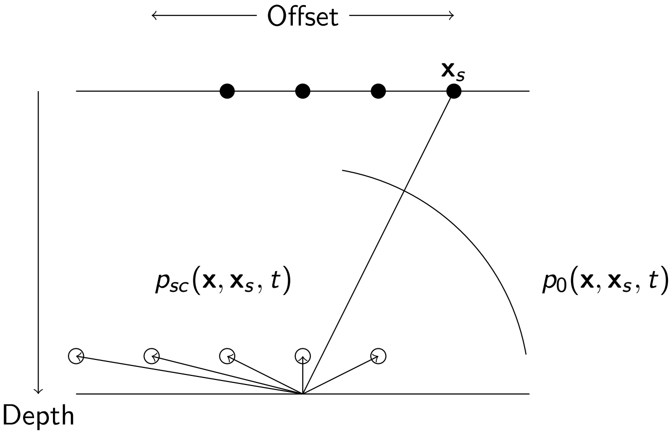
Imaging condition



Imaging condition



Imaging condition



Imaging condition

Using an approach described by f.ex [Vasconcelos et al., 2010] one finds: New imaging condition for multicomponent streamer data:

$$
\begin{aligned}
r(\mathbf{x},\mathbf{x}') = &\sum_{\mathbf{x}_s} \int dt\, \partial_z p_0(\mathbf{x},\mathbf{x}_s,t) p_{sc}(\mathbf{x}',\mathbf{x}_s,t) \\
&- \sum_{\mathbf{x}_s} \int dt\, p_0(\mathbf{x},\mathbf{x}_s,t) \partial_z p_{sc}(\mathbf{x}',\mathbf{x}_s,t)
\end{aligned} \tag{1}
$$

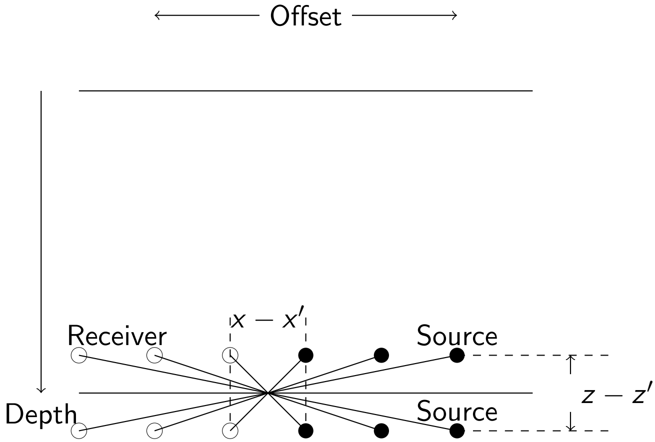
New imaging condition for conventional streamer data:

$$
r(\mathbf{x},\mathbf{x}') = \sum_{\mathbf{x}_s} \int dt\, \partial_z p_0(\mathbf{x},\mathbf{x}_s,t) p_{sc}(\mathbf{x}',\mathbf{x}_s,t) \tag{2}
$$

[Ordoñez et al., 2014] Old imaging condition: (Rickett and Sava, 2002)

$$
r_c(\mathbf{x},\mathbf{x}') = \sum_{\mathbf{x}_s} \int dt\, p_0(\mathbf{x},\mathbf{x}_s,t) p_{sc}(\mathbf{x}',\mathbf{x}_s,t) \tag{3}
$$

Imaging condition

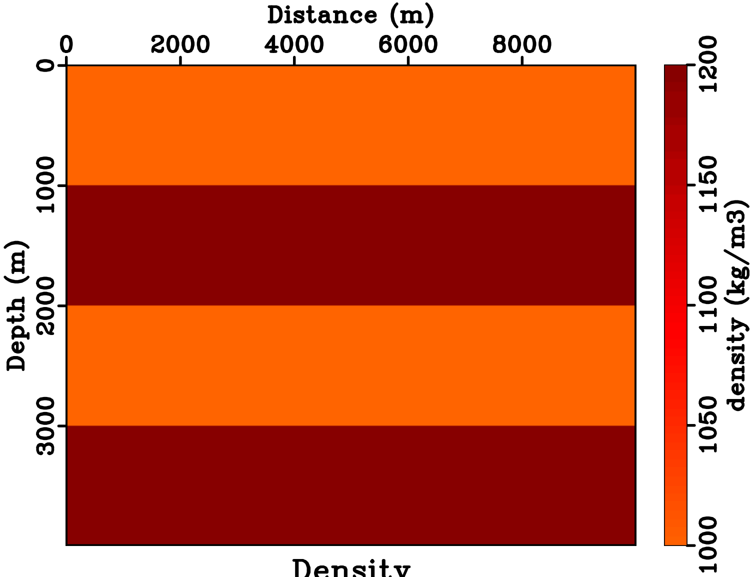


Imaging condition

Plane wave reflection coefficient:

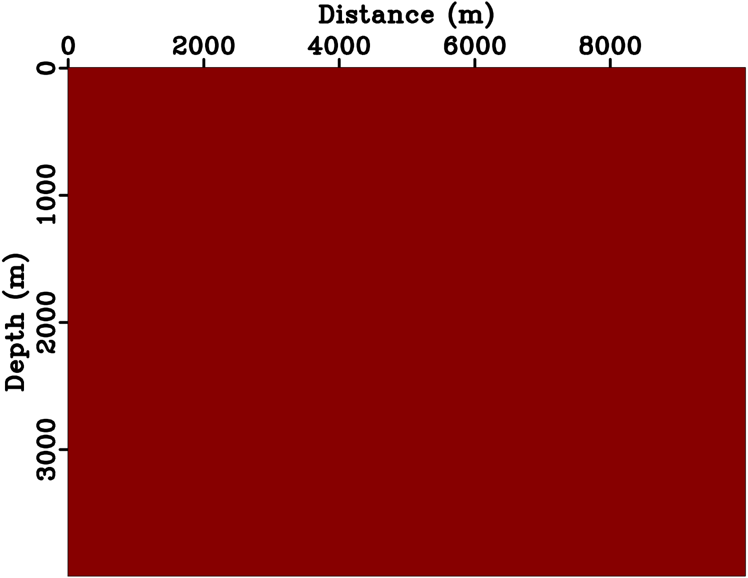
$$r(\mathbf{x}, \mathbf{k}_h, z) = \int d\mathbf{h} \, \exp(i\mathbf{k}_h \cdot \mathbf{h}) r(\mathbf{x}, \mathbf{h} = \mathbf{x} - \mathbf{x}') \tag{4}$$

Numerical example



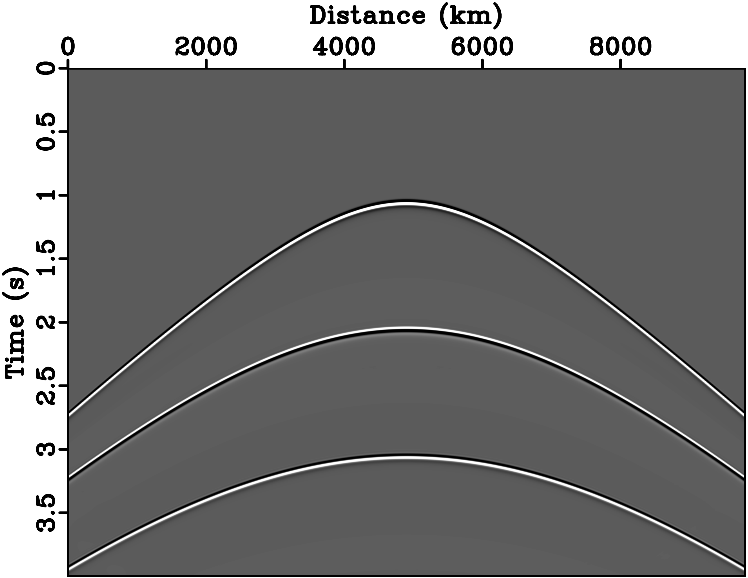
Density

Numerical example



Velocity

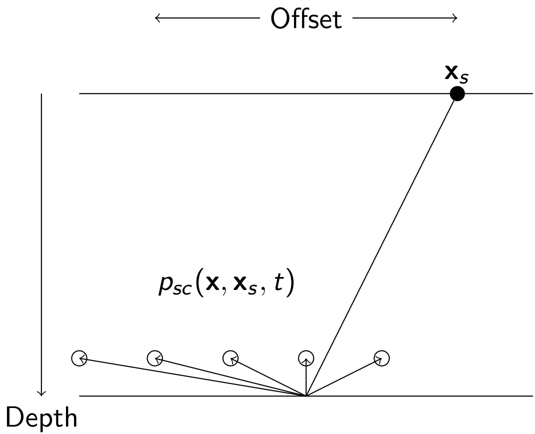
Numerical example



Data

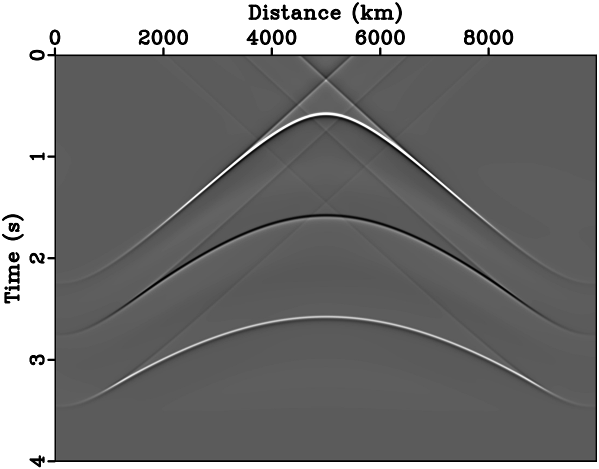
Imaging condition

Data at depth:



Numerical example

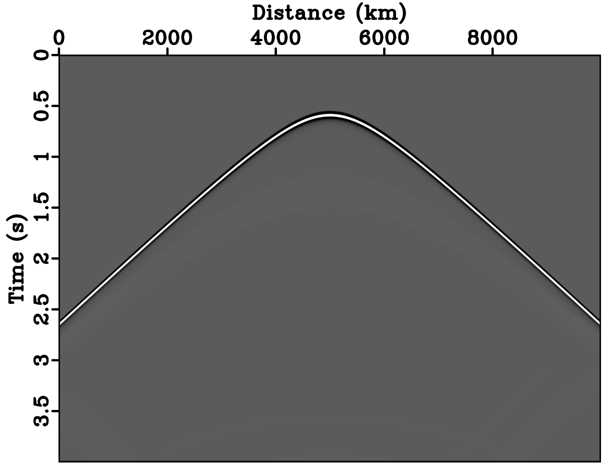
$p_{sc}(\mathbf{x}, \mathbf{x}_s, t)$ at depth of 1000 m.



Data at depth 1000m

Numerical example

$\hat{p}_0(\mathbf{x}, \mathbf{x}_s, t)$ at depth of 1000 m



Data at depth 1000m

Imaging condition

New imaging condition:

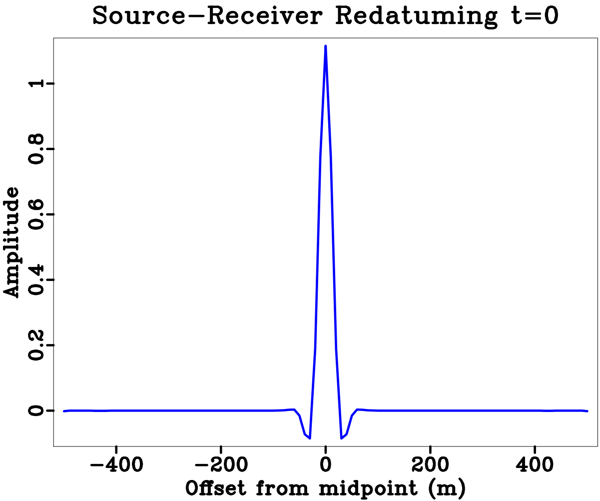
$$r(\mathbf{x}, \mathbf{x}', t = 0) = \sum_{\mathbf{x}_s} \int dt \, \partial_z p_0(\mathbf{x}, \mathbf{x}_s, t) p_{sc}(\mathbf{x}', \mathbf{x}_s, t) \tag{5}$$

Old imaging condition:

$$r_c(\mathbf{x}, \mathbf{x}', t = 0) = \sum_{\mathbf{x}_s} \int dt \, p_0(\mathbf{x}, \mathbf{x}_s, t) p_{sc}(\mathbf{x}', \mathbf{x}_s, t) \tag{6}$$

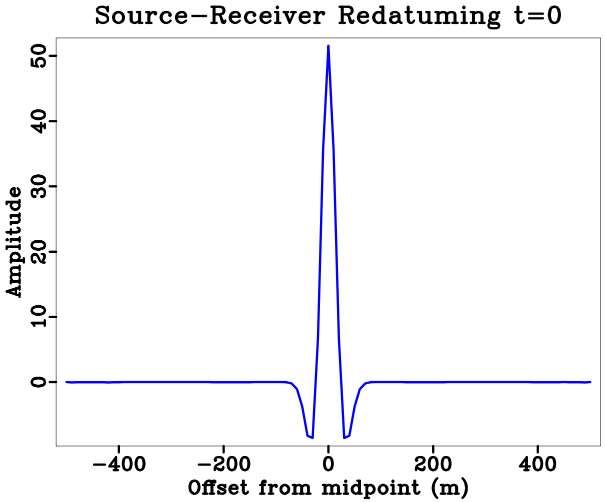
Numerical example

Reflectivity $p_{sc}(\mathbf{x} - \mathbf{x}', t = 0)$ at depth of 1000 m using new imaging condition



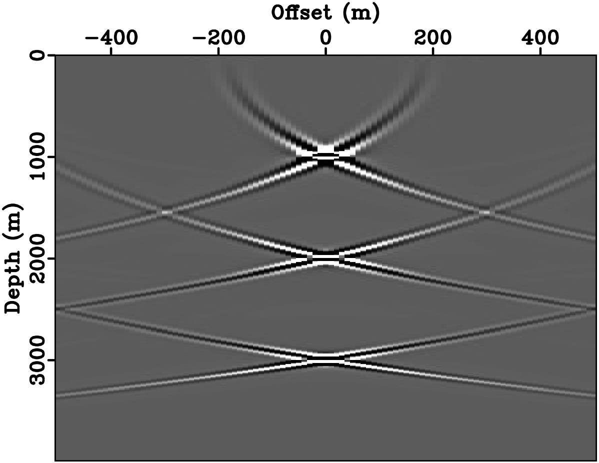
Numerical example

Reflectivity $p_{sc}(\mathbf{x} - \mathbf{x}', t = 0)$ at depth of 1000 m using old imaging condition



Numerical example

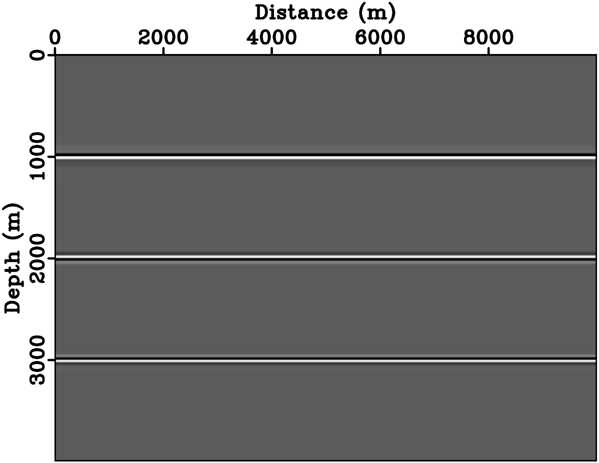
Reflectivity $p_{sc}(\mathbf{x} - \mathbf{x}', t = 0)$ at all depths using new imaging condition



Offset CIP gather

Numerical example

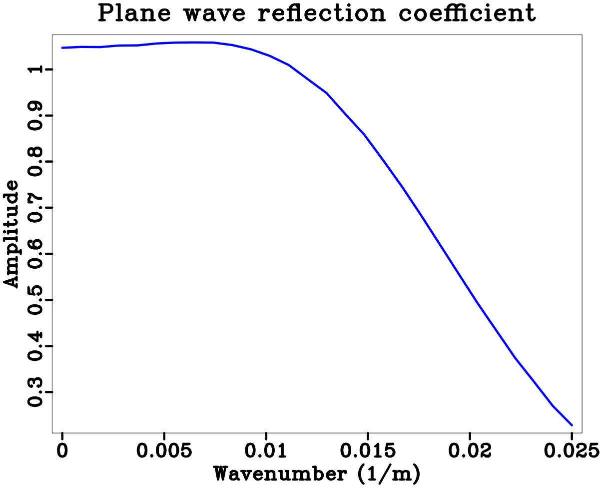
Full section $p_{sc}(\mathbf{x} - \mathbf{x}' = 0, t)$ at all depths using new imaging condition



Zero offset section

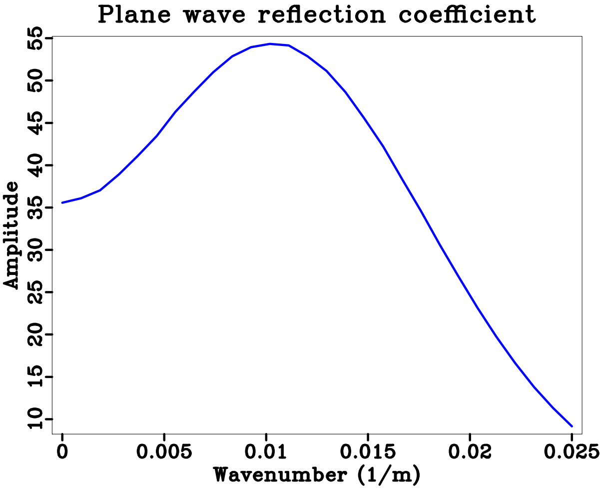
Numerical example

Plane wave reflection coefficient $p_{sc}(\mathbf{x} - \mathbf{x}', t)$ at depth of 1000 m using new imaging condition



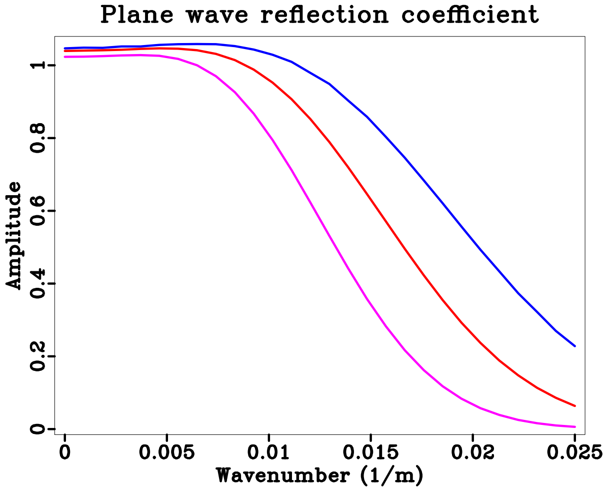
Numerical example

Plane wave reflection coefficient $p_{sc}(\mathbf{x} - \mathbf{x}', t)$ at depth of 1000 m using old imaging condition



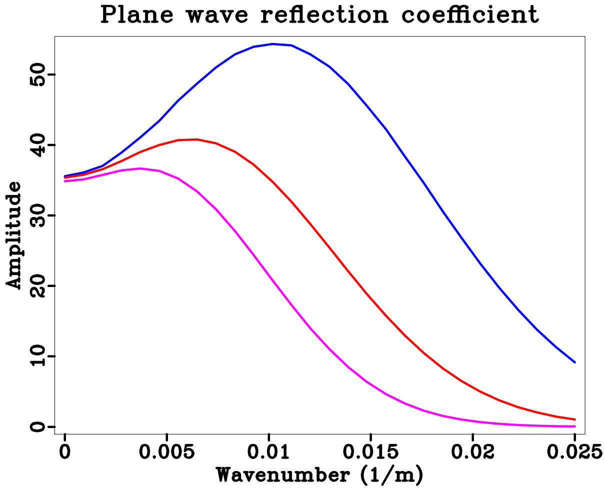
Numerical example

Reflection coefficient at three different depths using new imaging condition



Numerical example

Reflection coefficient at three different depths using old imaging condition



Summary/Conclusion

- New imaging condition gives correct Amplitude-Versus-Angle behavior
- Easy to implement for reverse-time migration
- Simple modification of existing imaging condition

Acknowledgements

ROSE consortium for financial support

References

- Arntsen, B., A. Kritski, B. Ursin, and L. Amundsen, 2013, Shot-profile true amplitude crosscorrelation imaging condition: Geophysics, **78**, S221–S231.
- Ordoñez, A., W. Söllner, T. Klüver, and L. J. Gelius, 2014, Migration of primaries and multiples using an imaging condition for amplitude-normalized separated wavefields: Geophysics, **79**, S217–S230.
- Vasconcelos, I., P. Sava, and H. Douma, 2010, Nonlinear extended images via image-domain interferometry: Geophysics, **75**, SA105–SA115.
- Zhang, Y., A. Ratcliffe, G. Roberts, and L. Duan, 2014, Amplitude-preserving reverse time migration: From reflectivity to velocity and impedance inversion: Geophysics, **79**, S271–S283.

Imaging condition

$$p_{sc}(\mathbf{x},\mathbf{x}_s,t) = -\int_S dS(\mathbf{x}')\,\rho^{-1}(\mathbf{x}')\partial_z p_{sc}(\mathbf{x}',\mathbf{x}_s,t) * \hat{g}(\mathbf{x},\mathbf{x}',t) + \int_S dS(\mathbf{x}')\rho^{-1}(\mathbf{x}')\partial_z \hat{g}(\mathbf{x},\mathbf{x}',t) * p_{sc}(\mathbf{x}',\mathbf{x}_s,t) \quad (7)$$

$$p_{sc}(\mathbf{x},\mathbf{x}_s,t) \approx \int_S dS(\mathbf{x}')\rho^{-1}(\mathbf{x}')2\partial_z \hat{g}(\mathbf{x},\mathbf{x}',t) * p_{sc}(\mathbf{x}',\mathbf{x}_s,t) \quad (8)$$

- $\hat{g}(\mathbf{x},\mathbf{x}_s,t)$: Anticausal background Green's function
- ρ: Density
- $*$: Time convolution

Imaging condition

$$
\begin{aligned}
p_{sc}(\mathbf{x}, \mathbf{x}', t) * \hat{s}(t) &= \\
&- \int_S dS(\mathbf{x}_s)\rho^{-1}(\mathbf{x}_s)\,\partial_z p_{sc}(\mathbf{x}', \mathbf{x}_s, t) * \hat{p}_0(\mathbf{x}, \mathbf{x}_s, t) \\
&+ \int_S dS(\mathbf{x}_s)\partial_z \hat{p}_0(\mathbf{x}', \mathbf{x}_s, t) * p_{sc}(\mathbf{x}', \mathbf{x}_s, t) \qquad (9)
\end{aligned}
$$

$$
p_{sc}(\mathbf{x}, \mathbf{x}', t) * \hat{s}(t) \approx \int_S ds(\mathbf{x}_s)\partial_z \hat{p}_0(\mathbf{x}', \mathbf{x}_s, t) * p_{sc}(\mathbf{x}', \mathbf{x}_s, t) \qquad (10)
$$

- $\hat{p}_0(\mathbf{x}, \mathbf{x}_s, t)$: Anticausal downgoing wavefield