Migration with surface and internal multiples

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Outline

- Motivation and introduction
- Theory
- Numerical examples
- Conclusion and future work

Motivation

Multiples can provide additional information for subsurface structures

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RTM (*Liu et al., 2011*) and LSRTM (*Zhang and Schuster, 2013; Liu et al., 2016*): Migrate controlled-order surface multiples

FWM (*Berkhout and Vershuur, 2016; Davydenko and Vershuur, 2017*): Uses an inversion based method to migrate full wavefields

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RTM and LSRTM for surface multiple;
FWM with surface and internal multiples

Reverse time migration (RTM) of surface multiple

Primary: virtual sources at the hydrophones

First-order surface multiple: the observed data

Imaging condition (*Liu et al., 2011*)

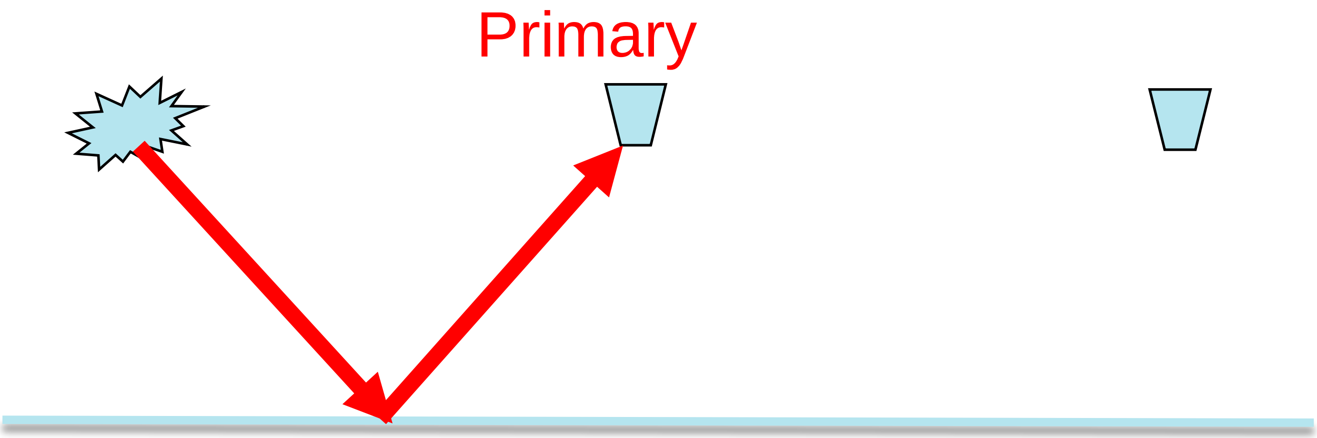

Fig 1. Forward and backward wave propagation in RTM with surface multiple

Reverse time migration (RTM) of surface multiple

Primary: virtual sources at the hydrophones

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First-order surface multiple: the observed data

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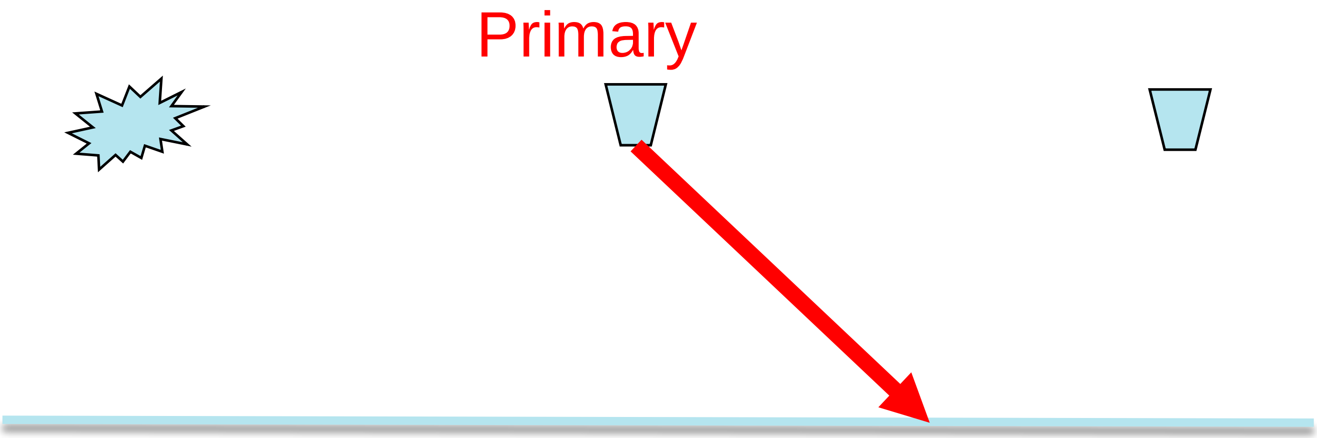

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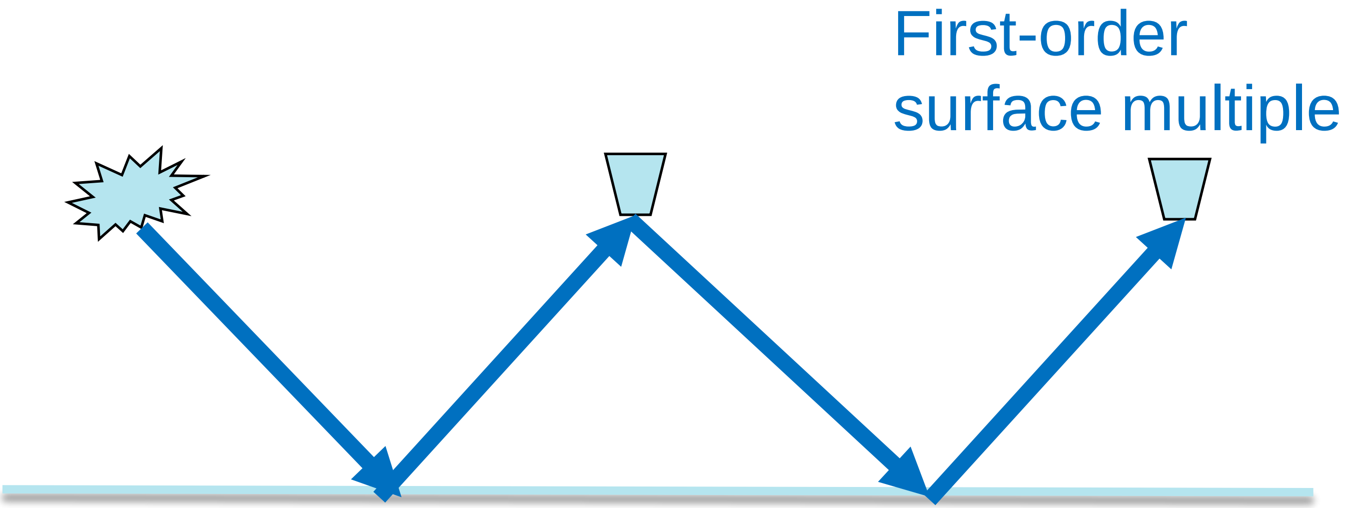

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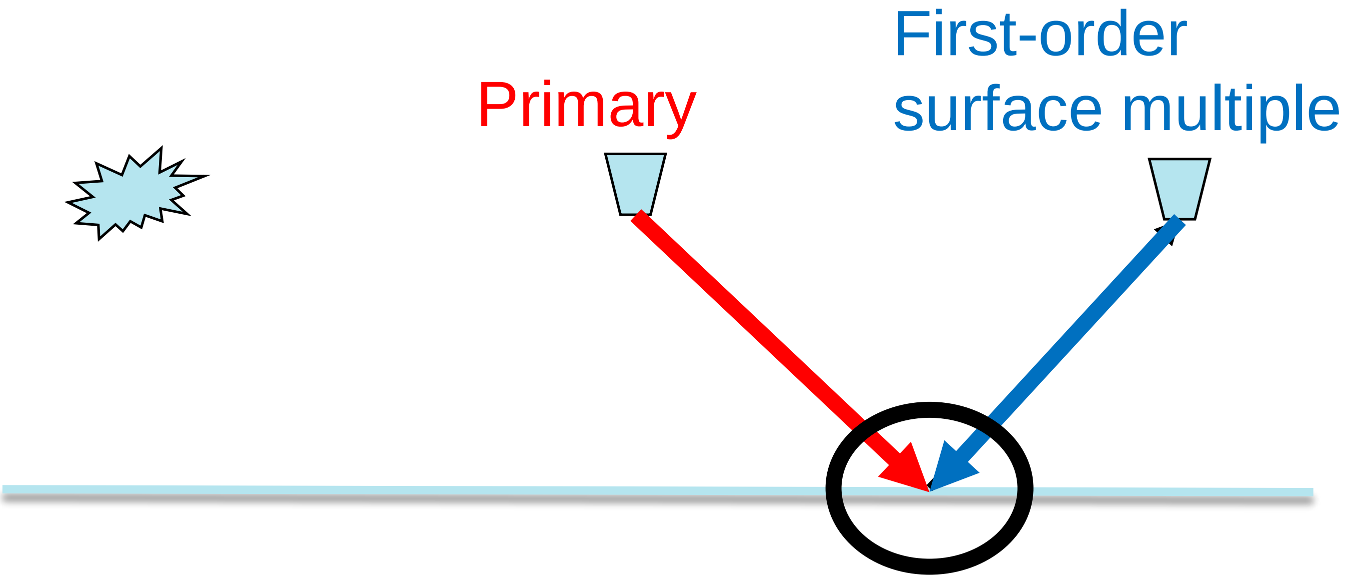


Fig 1. Forward and backward wave propagation in RTM with surface multiple

$$\mathrm{Image}(x,z) = \sum_{t=1}^{t_{max}} P_F(x,z,t) * M_B(x,z,t) \quad (1)$$

Imaging condition in RTM with surface multiple

- Artifact-free image: the downgoing (*N-1*)th-order multiple correlates with the back-propagated *N*th-order multiple of the input data

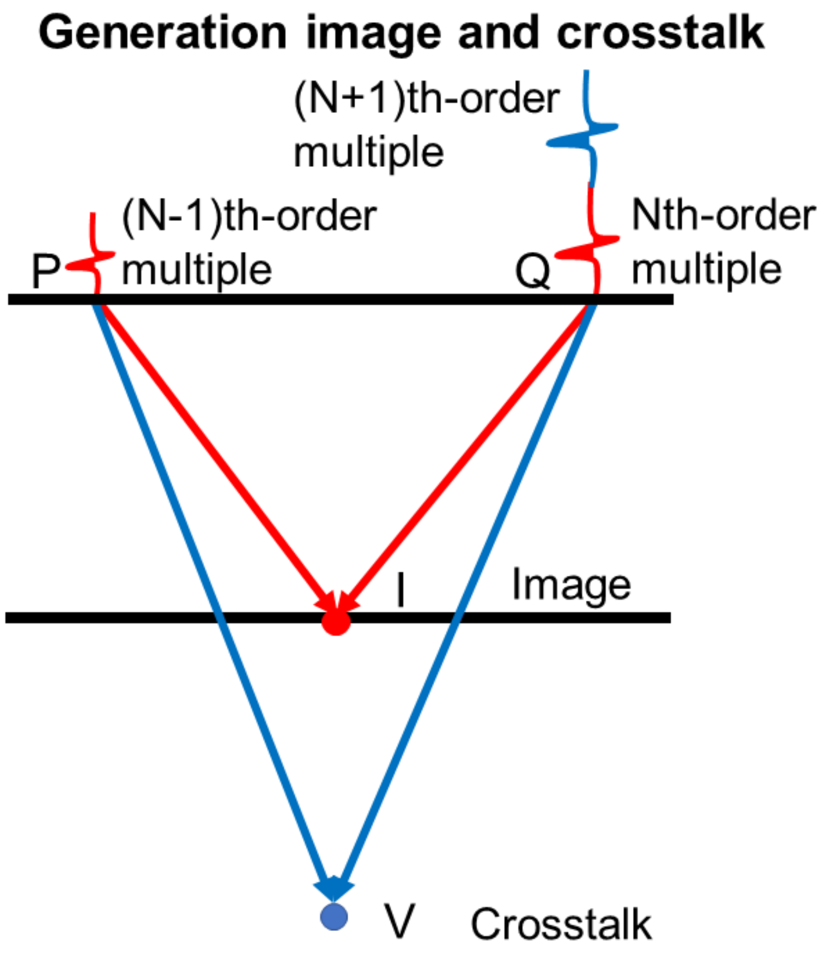
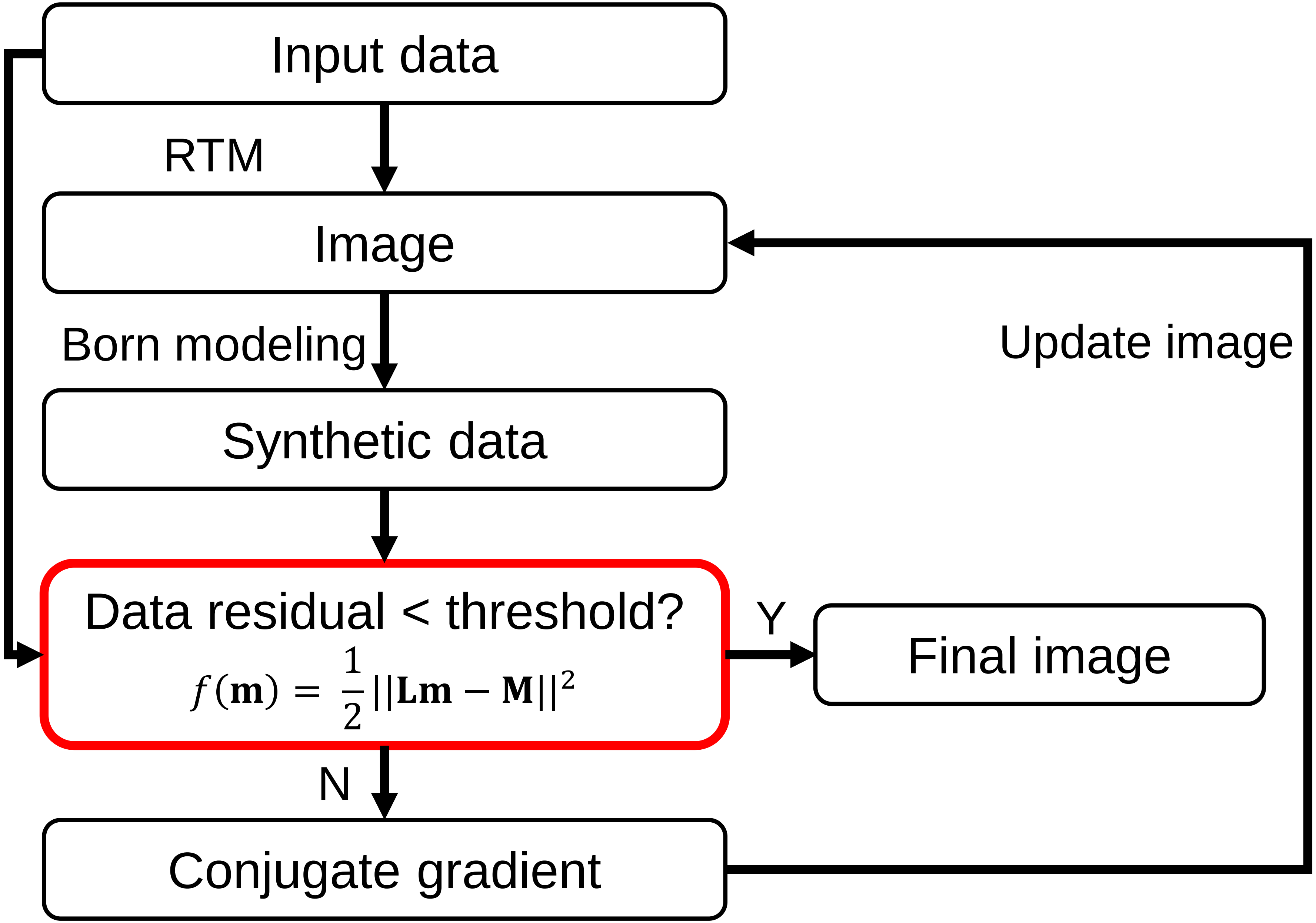
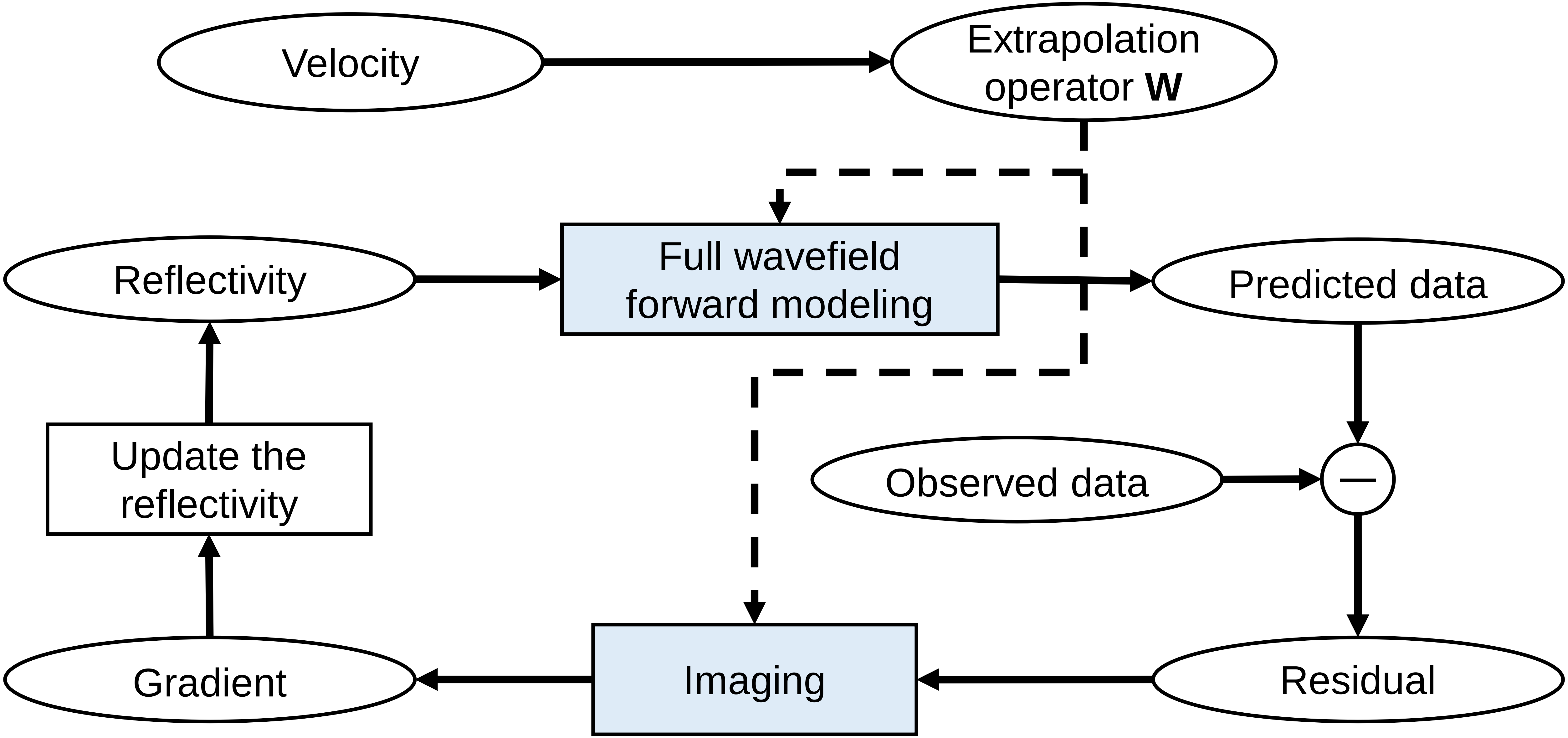


Fig 2. Generation image and crosstalk (adapted from Zhang and Schuster, 2013)

Least-squares reverse time migration (LSRTM) with surface multiple

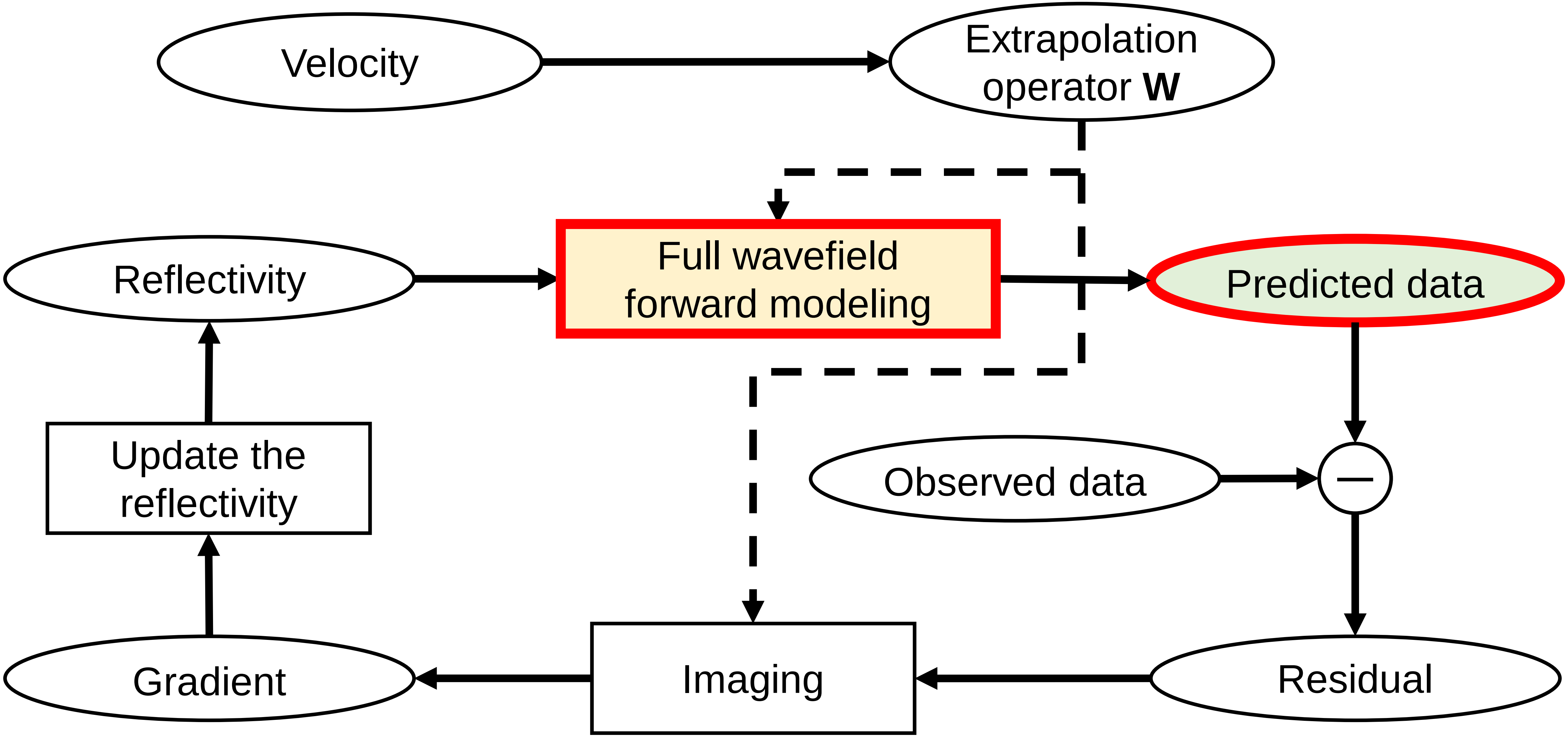


Full-wavefield migration (FWM)



Workflow adapted from Davydenko and Vershuur (2017)

Full-wavefield migration (FWM)



Workflow adapted from Davydenko and Vershuur (2017)

Forward modeling in full-wavefield migration (FWM)

- +: downgoing direction
- -: upward direction
- $\vec{P}$: wavefields approach a depth level
- $\vec{Q}$: wavefields leave a depth level
- Wavefield extrapolation operator: $\mathbf{W}$
- Transmission coefficient: $\mathbf{T} = \mathbf{I} + \delta\mathbf{T}$
- Reflection coefficient: $\mathbf{R}^{\cap}$, $\mathbf{R}^{\cup}$

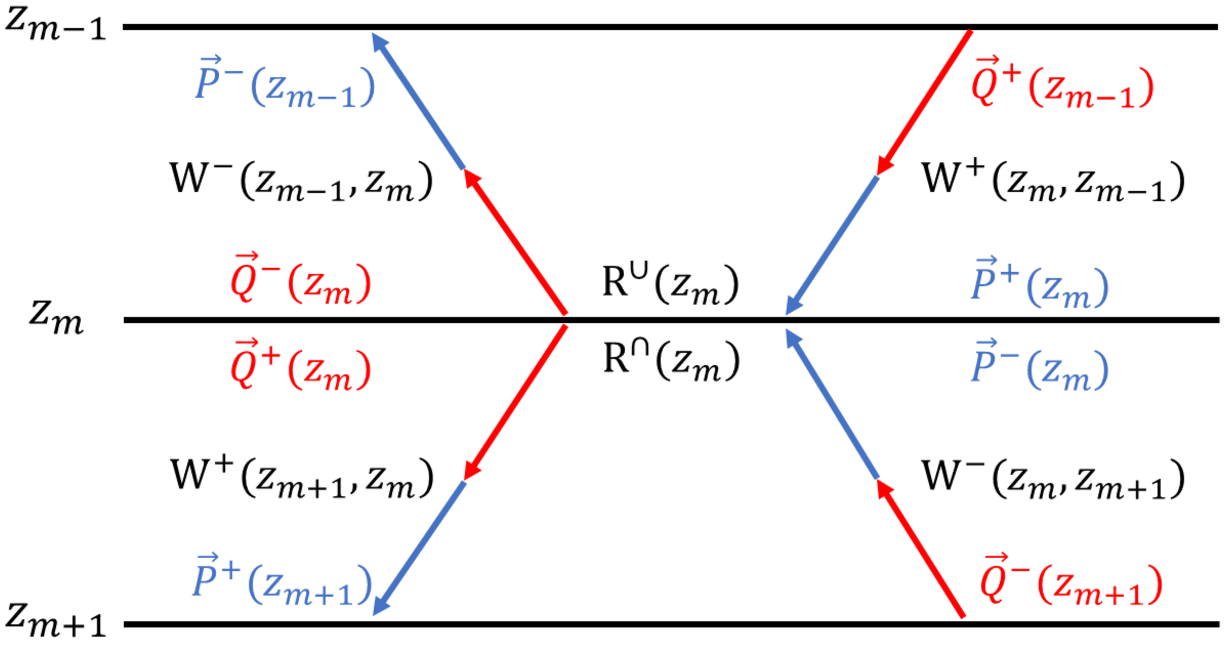


Fig 3. Forward modeling in FWM (adapted by Davydenko and Vershuur (2017))

$$\vec{Q}^+(z_m) = \vec{P}^+(z_m) + \delta\mathbf{T}^+(z_m)\vec{P}^+(z_m) + \mathbf{R}^{\cap}(z_m)\vec{P}^-(z_m) \quad (2)$$

$$\vec{Q}^-(z_m) = \vec{P}^-(z_m) + \delta\mathbf{T}^-(z_m)\vec{P}^-(z_m) + \mathbf{R}^{\cup}(z_m)\vec{P}^+(z_m) \quad (3)$$

$$\vec{P}^+(z_{m+1}) = \mathbf{W}(z_{m+1}, z_m)\vec{Q}^+(z_m) \quad (4)$$

$$\vec{P}^-(z_{m-1}) = \mathbf{W}(z_{m-1}, z_m)\vec{Q}^-(z_m) \quad (5)$$

Forward modeling in full-wavefield migration (FWM)

- Acoustic media: $\delta\mathbf{T}^{+}= \mathbf{R}^{\cup}$, $\delta\mathbf{T}^{-}= \mathbf{R}^{\cap}$

$$\vec{Q}^{+}(z_m) = \vec{P}^{+}(z_m) + \mathbf{R}^{\cup}(z_m)\vec{P}^{+}(z_m) + \mathbf{R}^{\cap}(z_m)\vec{P}^{-}(z_m) \qquad (6)$$

$$\vec{Q}^{-}(z_m) = \vec{P}^{-}(z_m) + \mathbf{R}^{\cap}(z_m)\vec{P}^{-}(z_m) + \mathbf{R}^{\cup}(z_m)\vec{P}^{+}(z_m) \qquad (7)$$

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Scattering term (secondary virtual source) $\delta\vec{S}$

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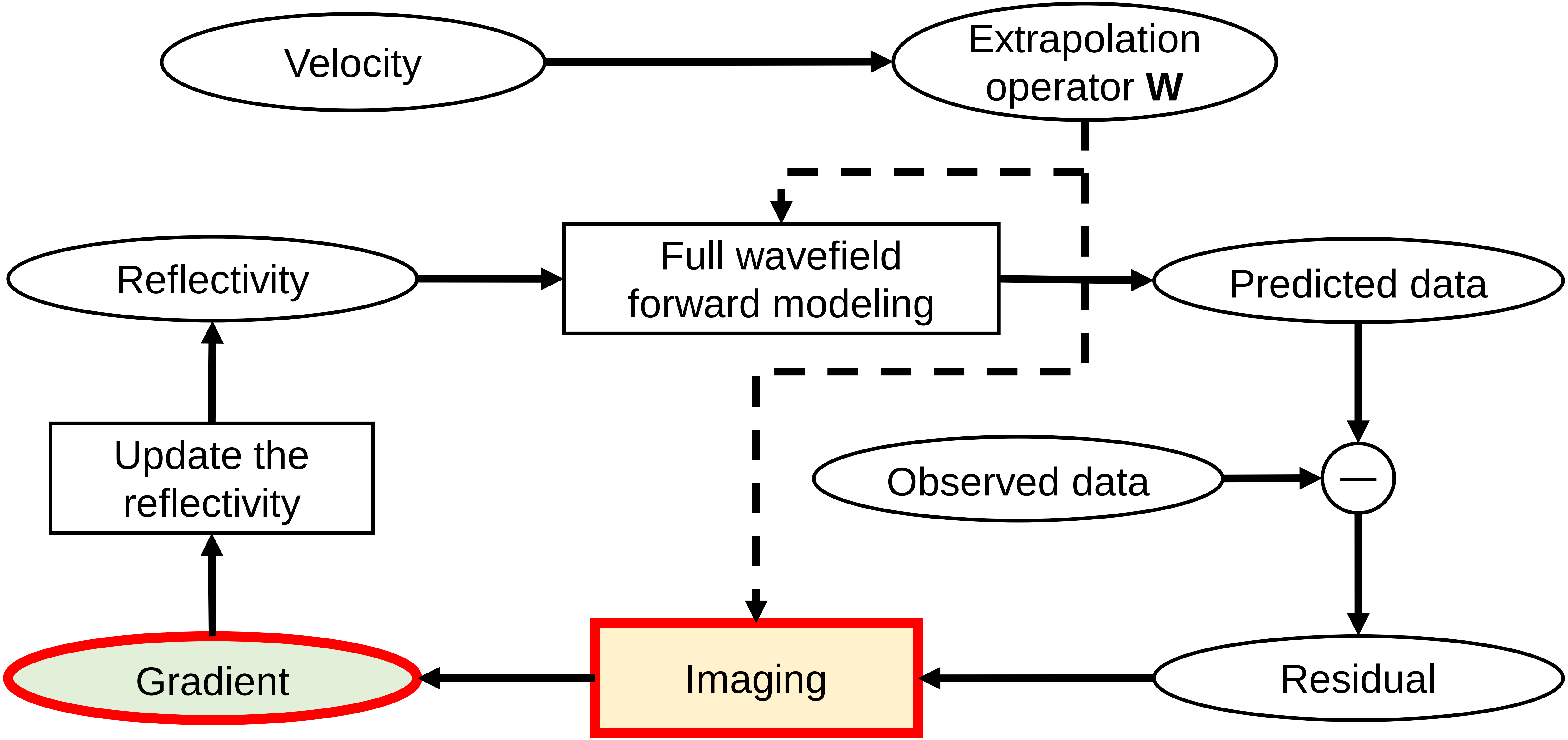
Scattering term (secondary virtual source) $\delta\vec{S}$

- Downward and upward propagation wavefields

$$\vec{P}^{+}(z_m) = \sum_{n<m} \mathbf{W}(z_m, z_n)[\vec{S}^{+}(z_n) + \delta\vec{S}(z_n)] \tag{8}$$

$$\vec{P}^{-}(z_m) = \sum_{n>m} \mathbf{W}(z_m, z_n)\delta\vec{S}(z_n) \tag{9}$$

Full-wavefield migration (FWM)



Workflow adapted from Davydenko and Vershuur (2017)

Imaging in full-wavefield migration (FWM)

- Objective function for FWM (Davydenko and Vershuur, 2017)

$$J = \sum_{\omega} ||\Delta\mathbf{P}||_2^2 + f(\mathbf{R}) = \sum_{\omega} ||\mathbf{P}_{obs} - \mathbf{P}_{mod}||_2^2 + f(\mathbf{R}) \quad (10)$$

- The gradient of objective function

$$\mathbf{C}^{\cup}(z_m) = [\Delta\mathbf{P}^{-}(z_m)][\mathbf{P}^{+}(z_m)]^H \quad (11)$$

- Update reflectivity matrix

$$\Delta\mathbf{R}^{\cup}(z_m) = \left(\sum_{\omega} \mathbf{C}^{\cup}(z_m)\right) + f'(\mathbf{R}^{\cup}(z_m)) \quad (12)$$

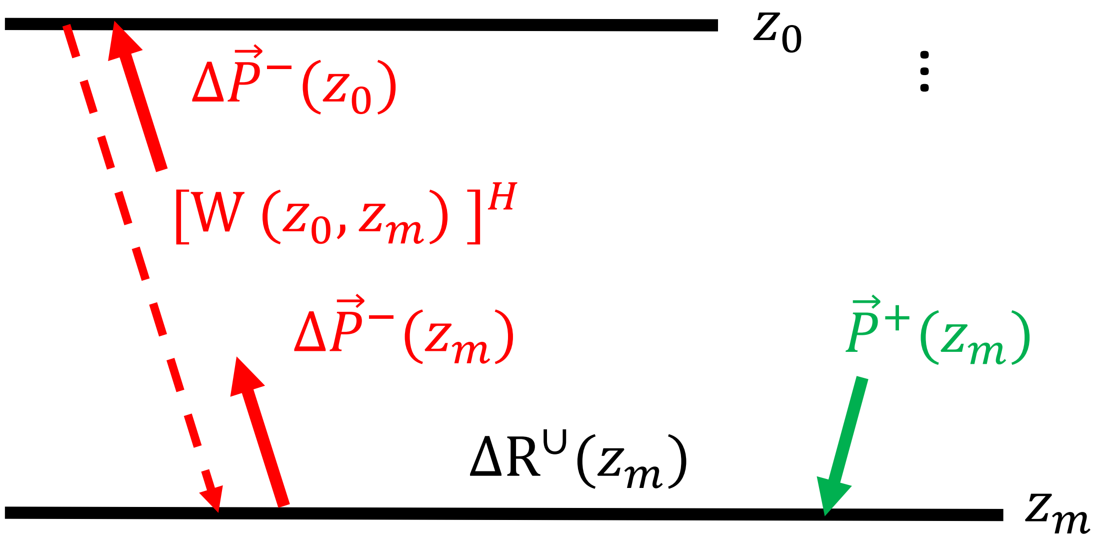
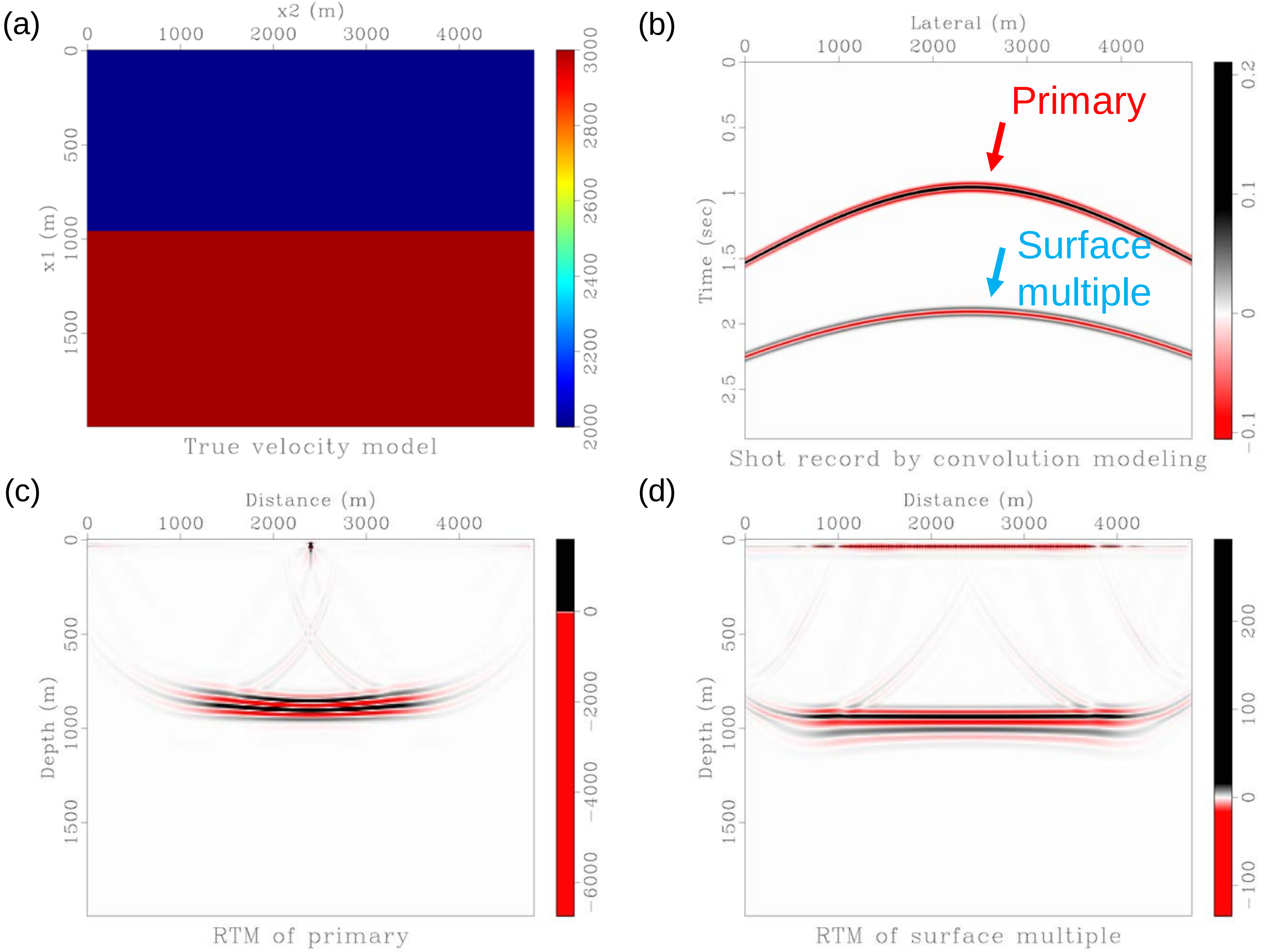


Fig 4. Reflectivity updates of both sides can be projected by cross-correlation between forward-modelled wavefield (green lines) and backward residuals (red lines).

Example 1 – RTM of the first-order surface multiple



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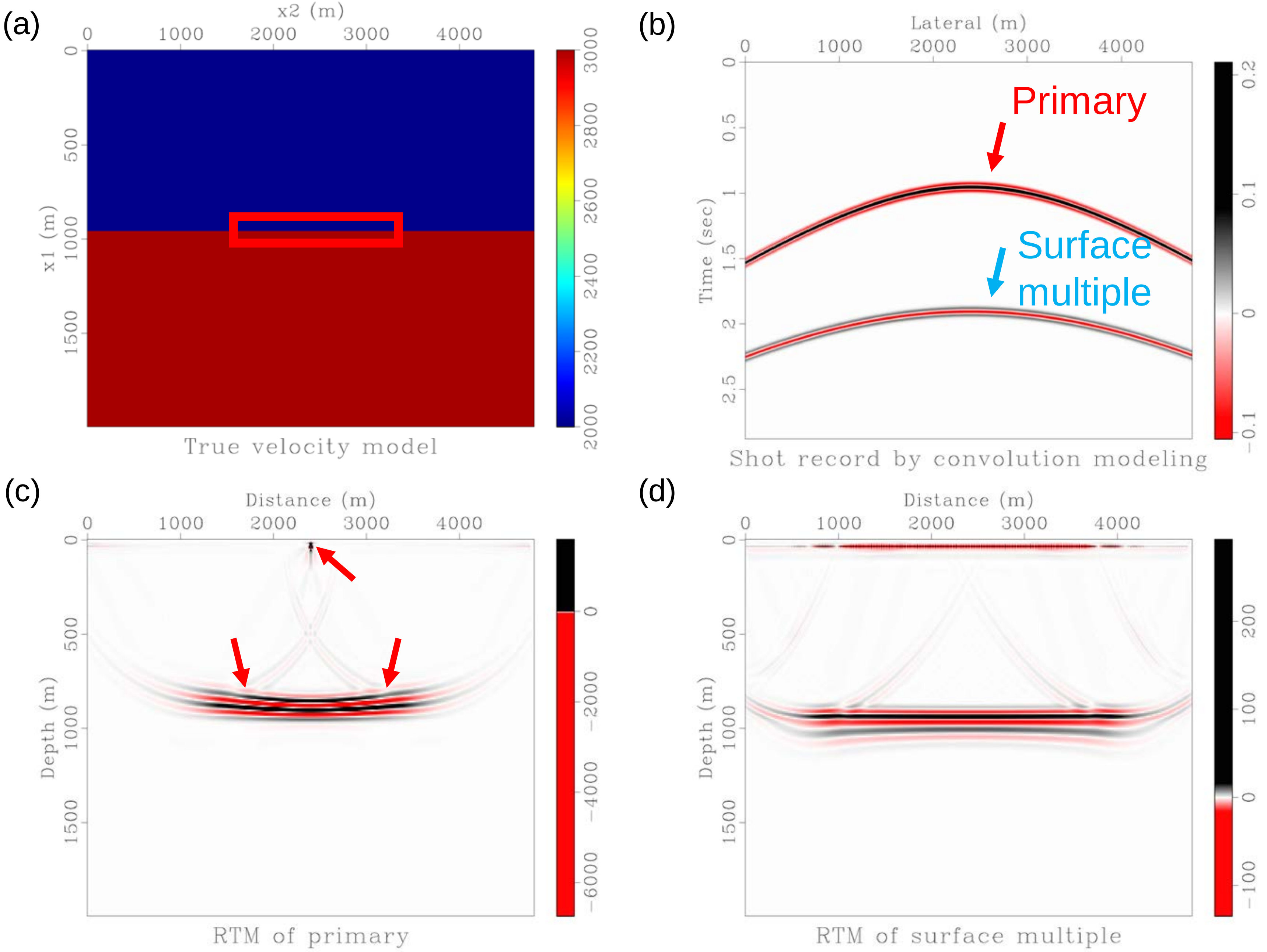

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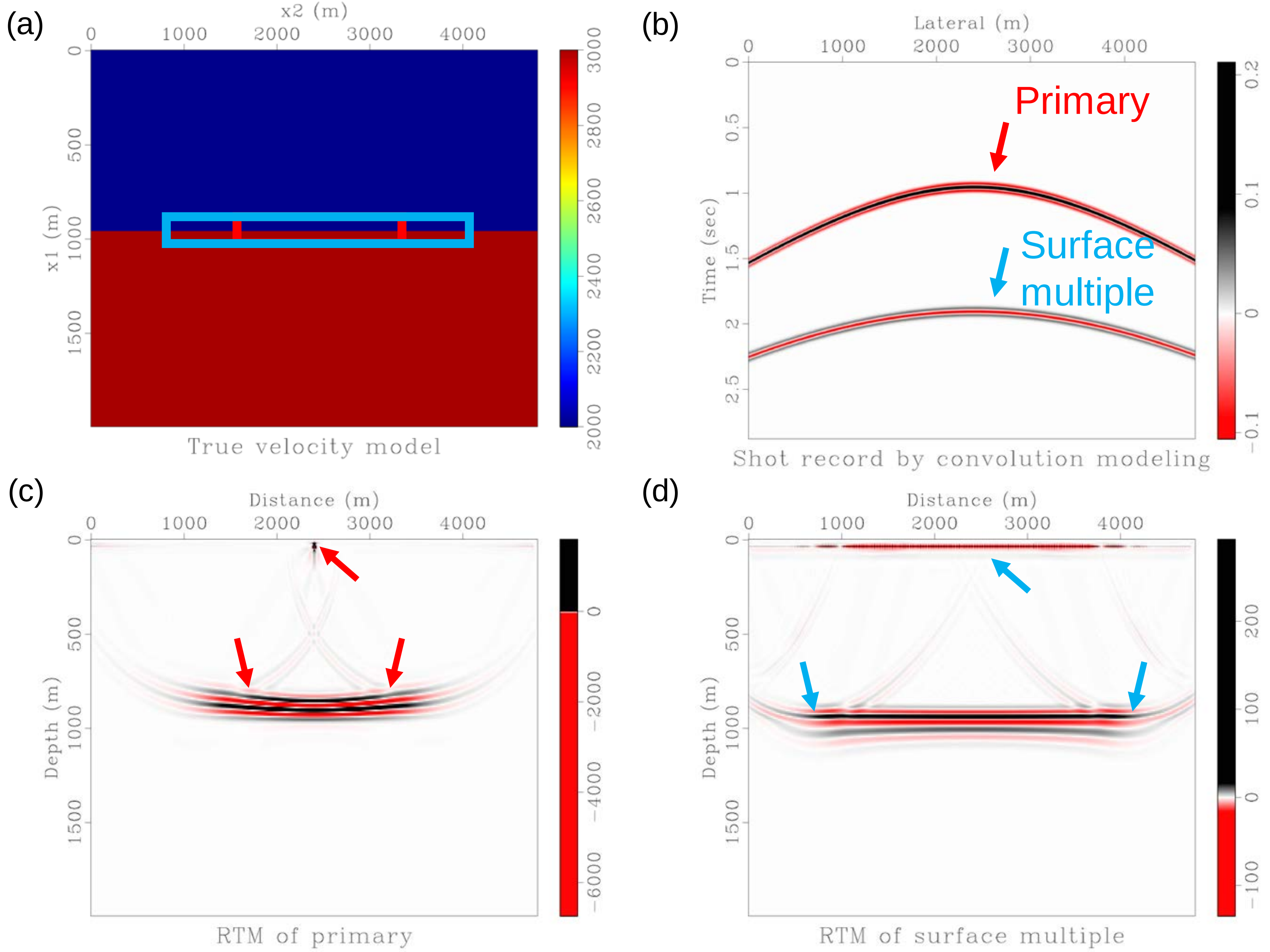
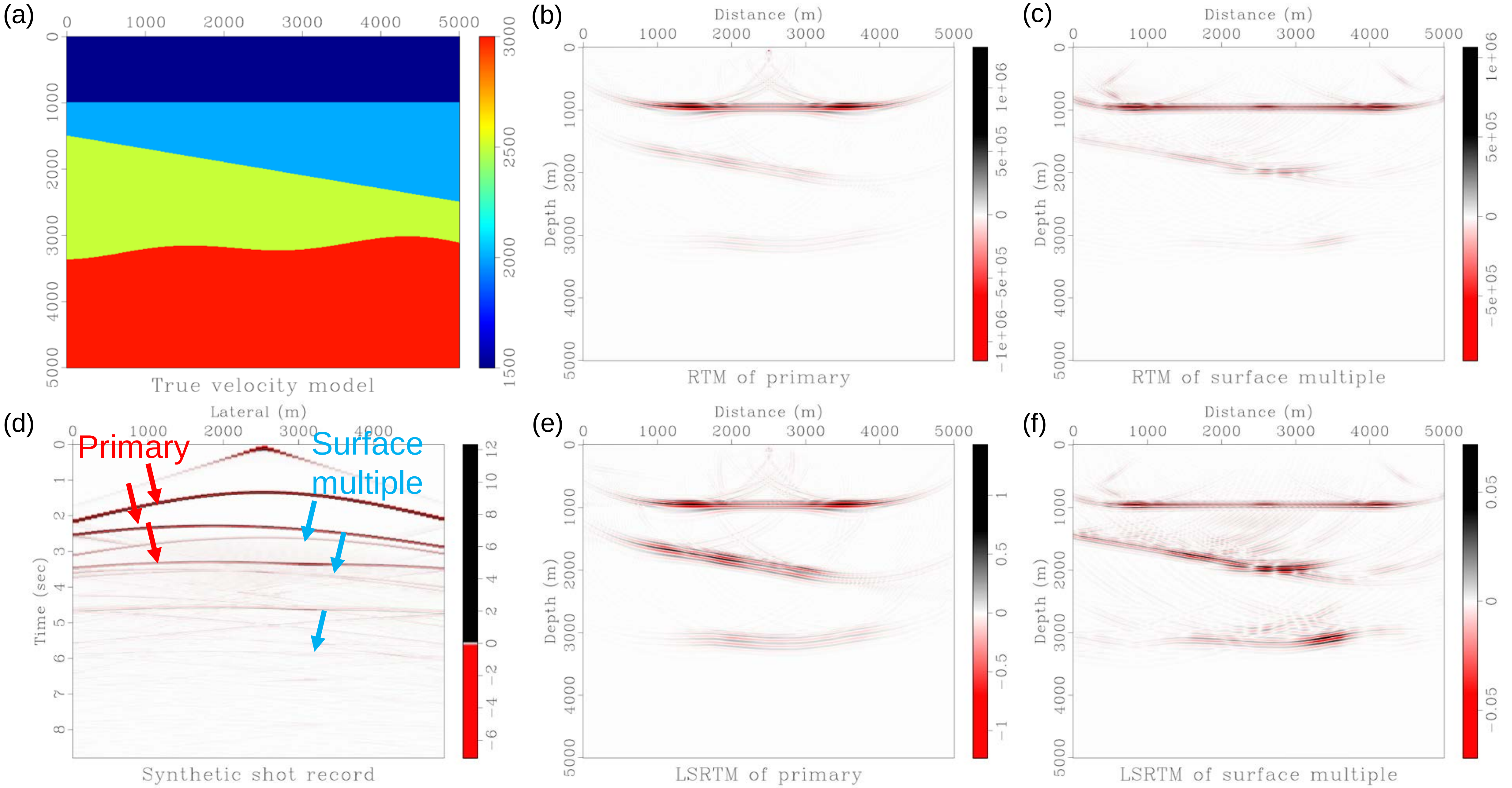


Example 2 – LSRTM of the first-order surface multiple



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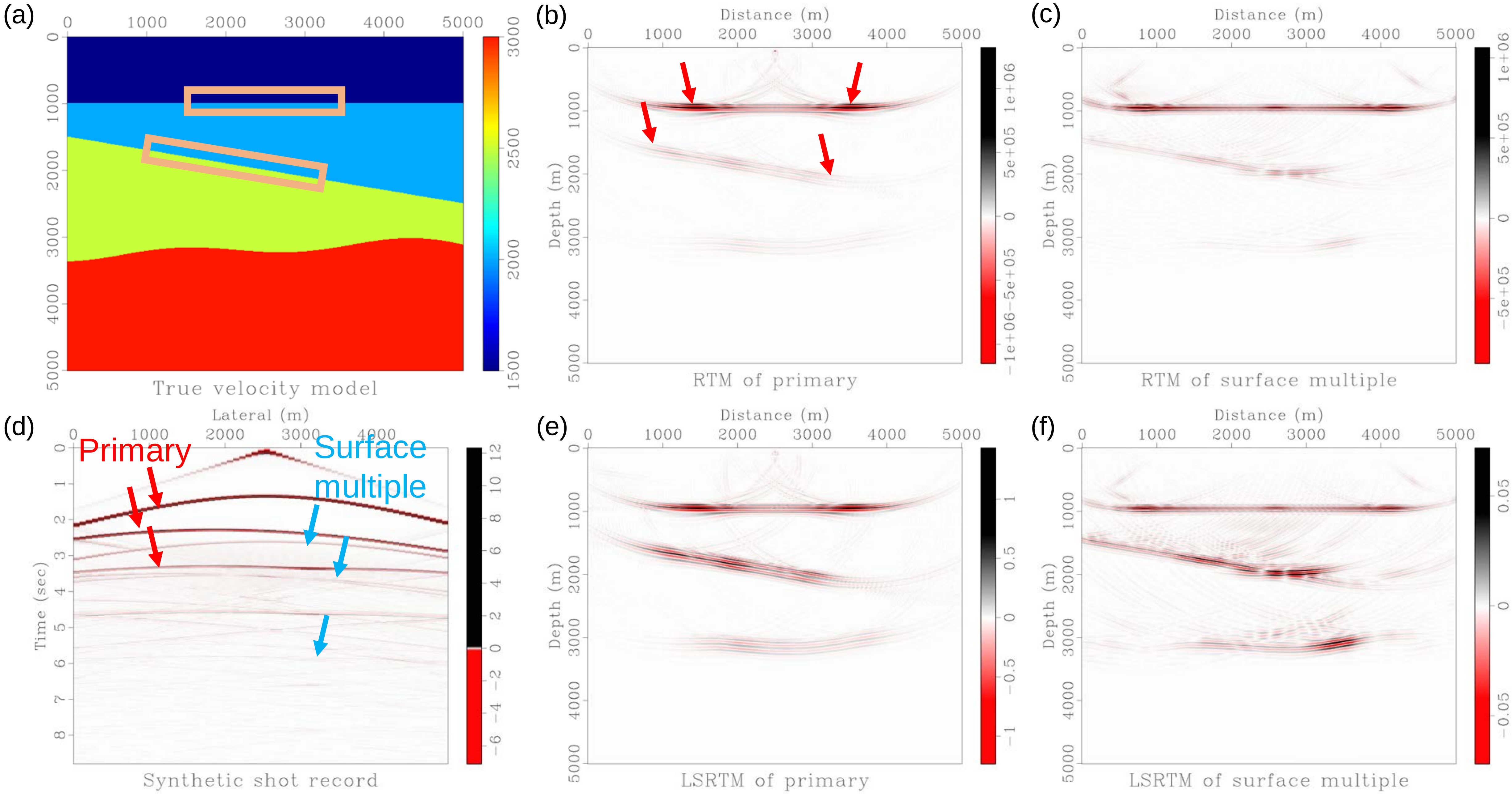

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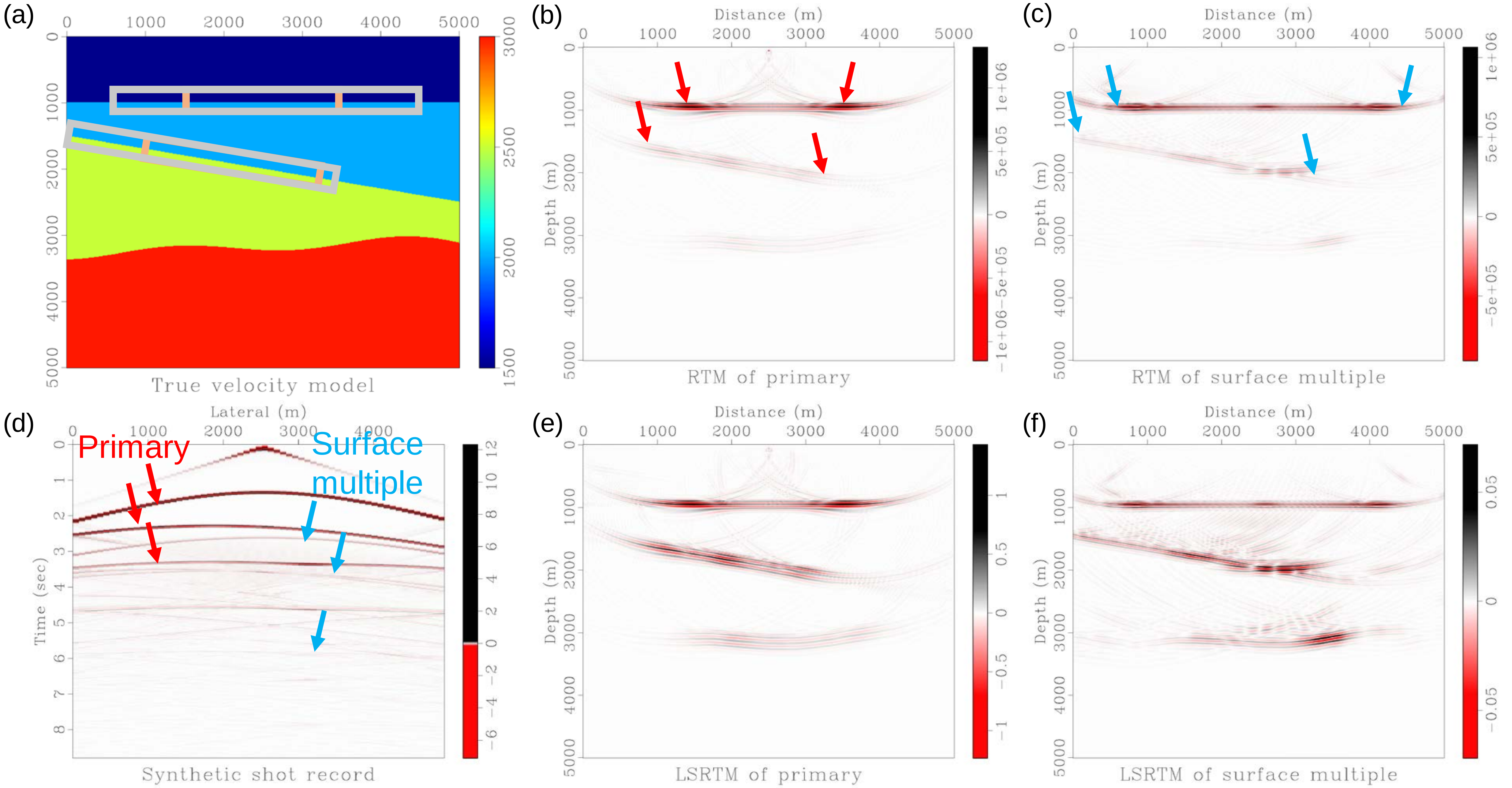

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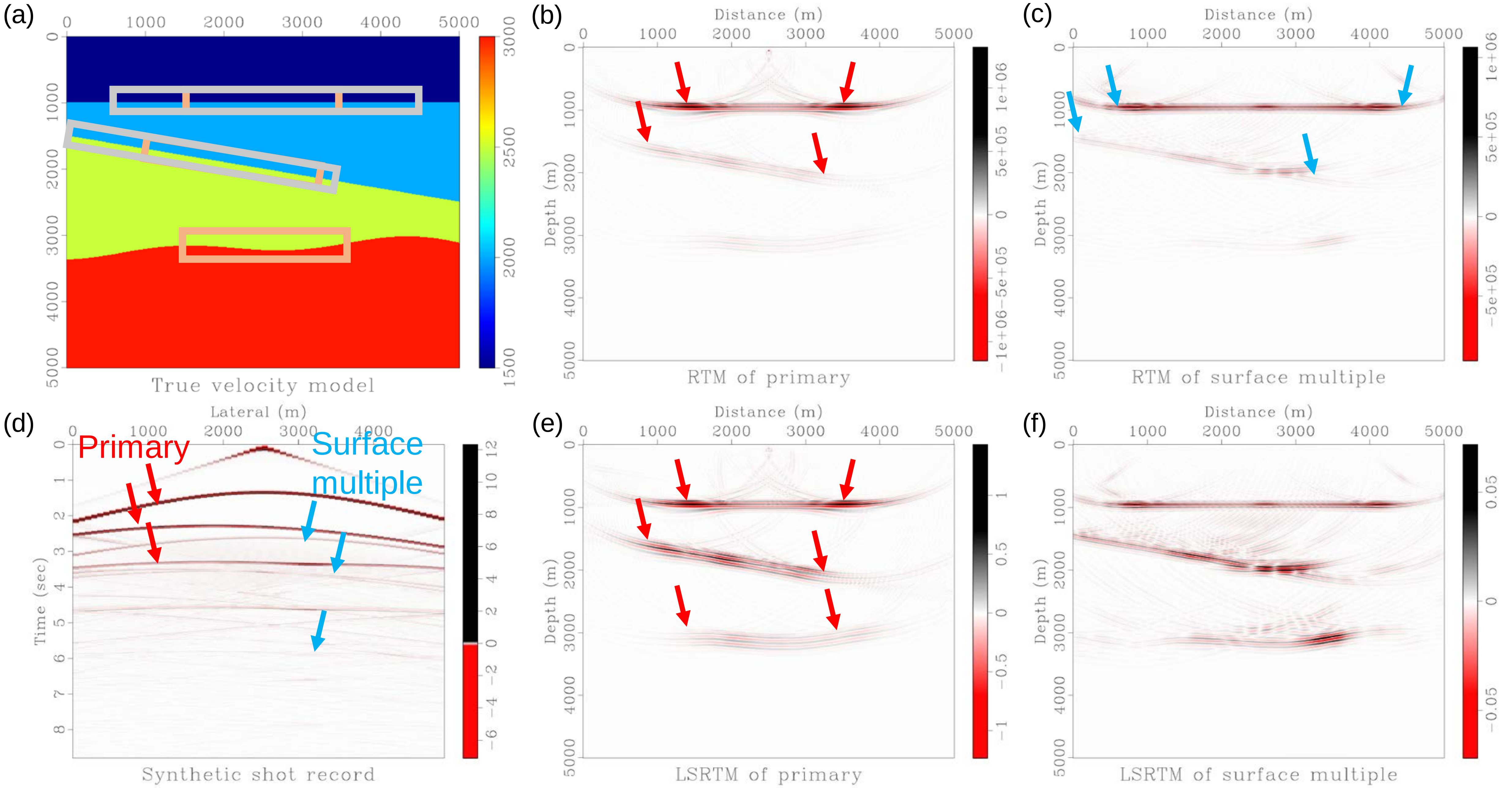

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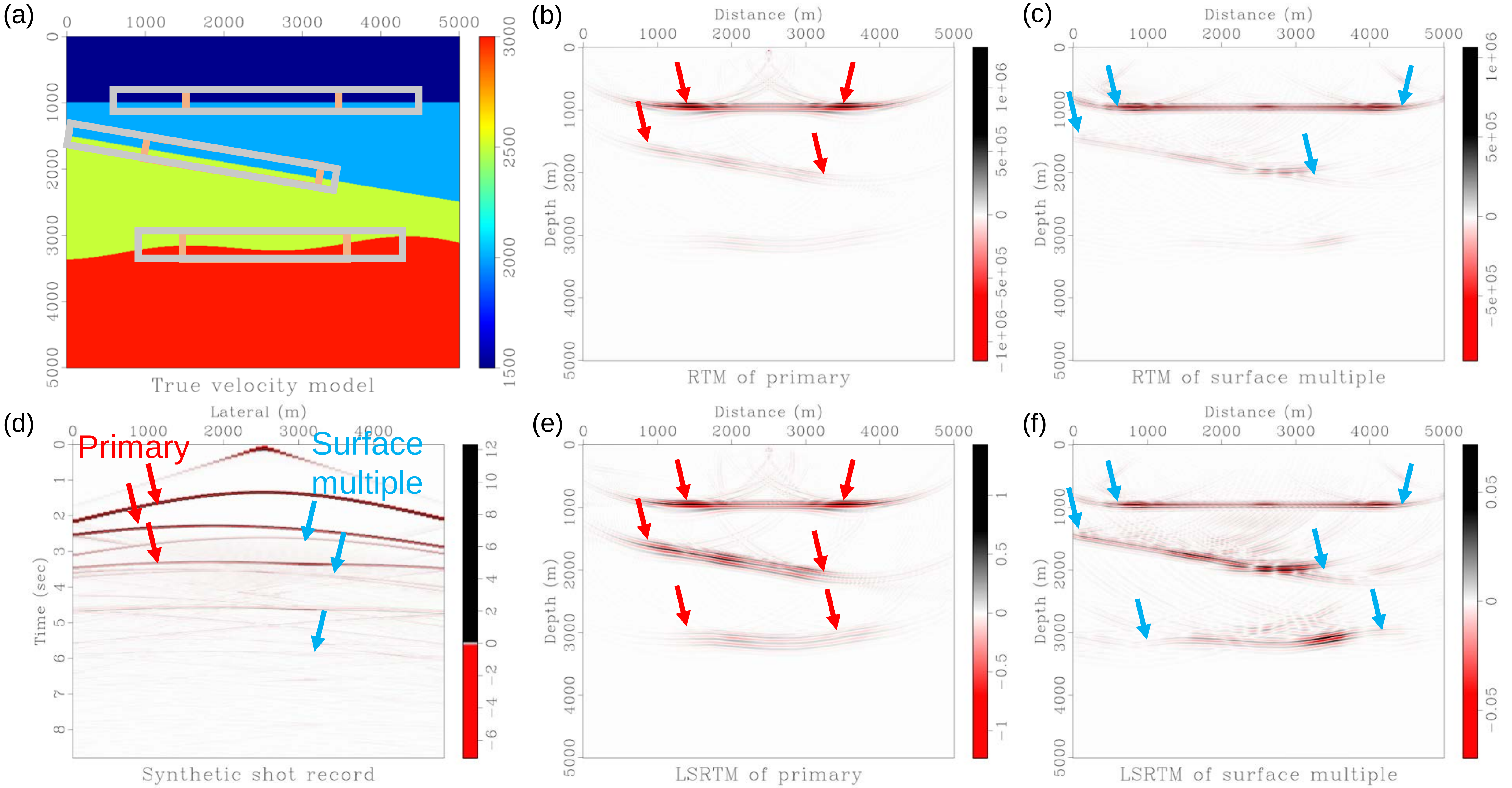
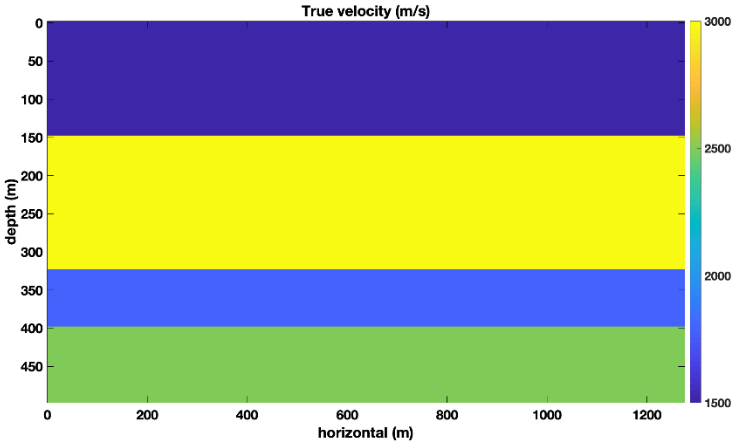
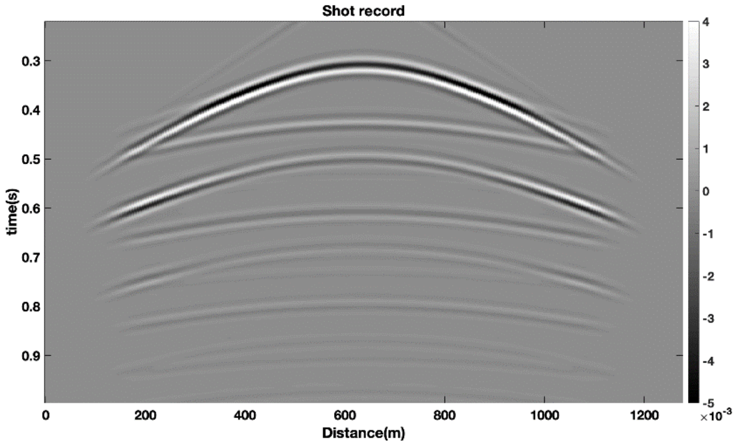


Example 3 – Compare FWM with primary wavefield migration (PWM)

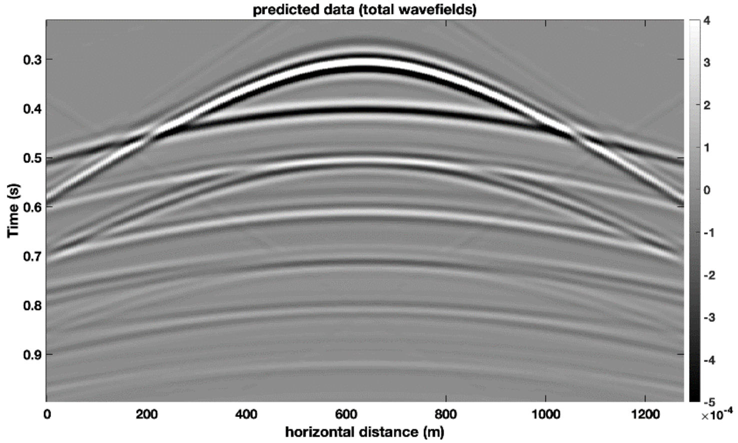
(a) True velocity model



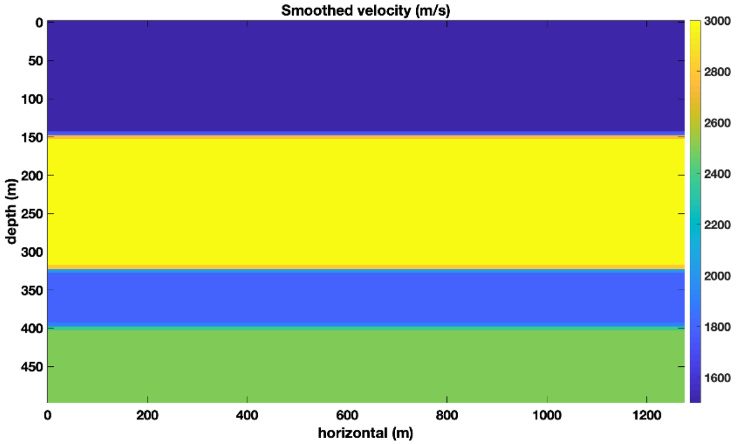
(b) Observed data



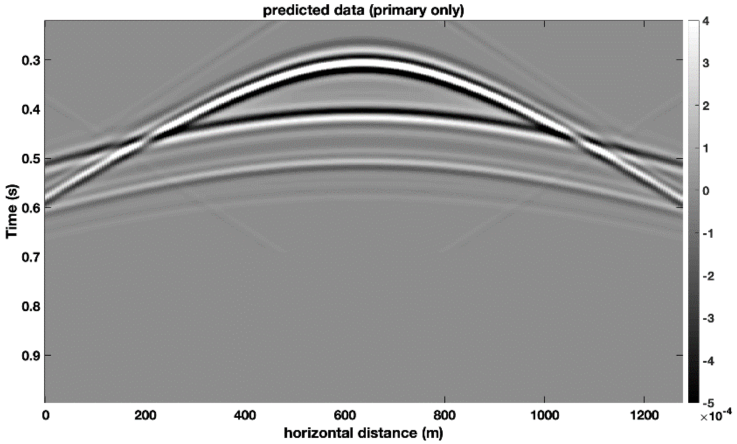
(c) Forward modeling in FWM



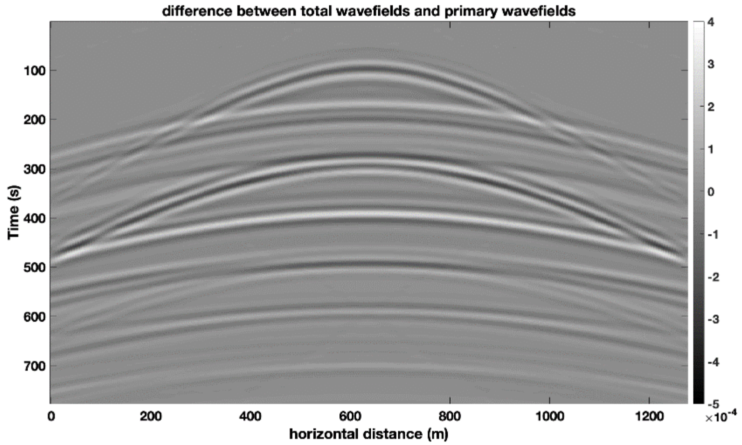
(d) Smoothed velocity model



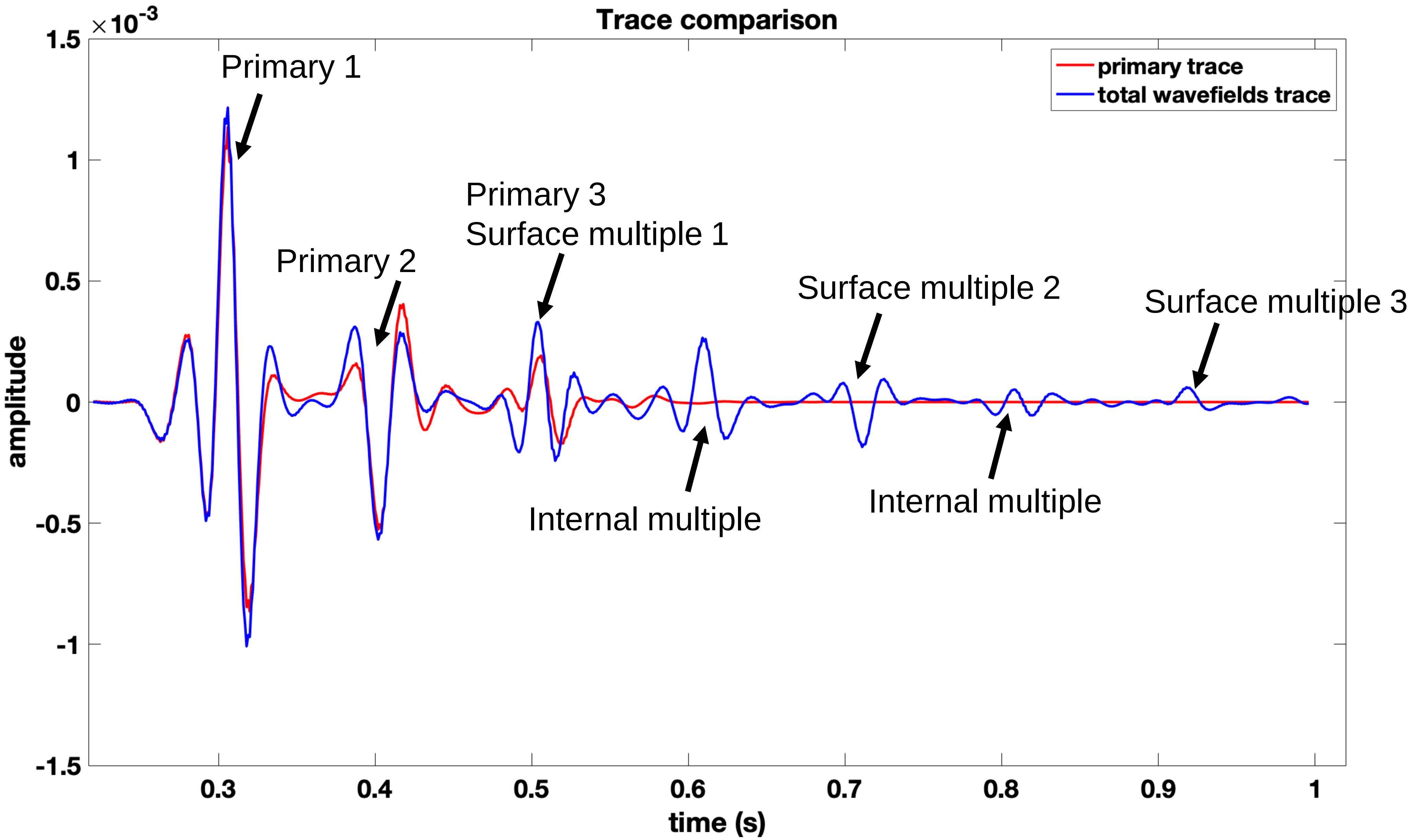
(e) Forward modeling in PWM



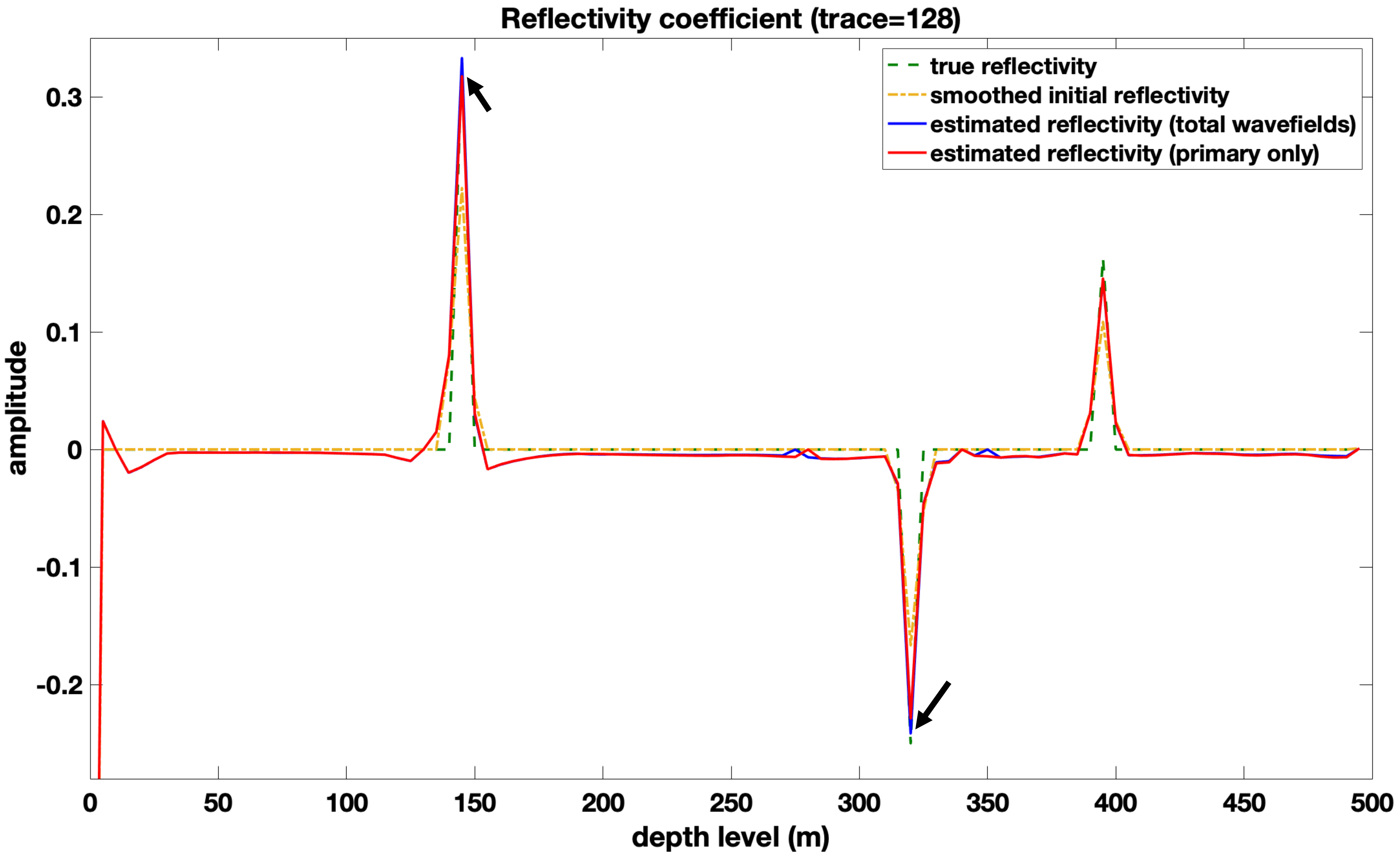
(f) Difference between (c) and (e)



Example 3 – Trace comparison



Example 3 – Reflectivity coefficient comparison



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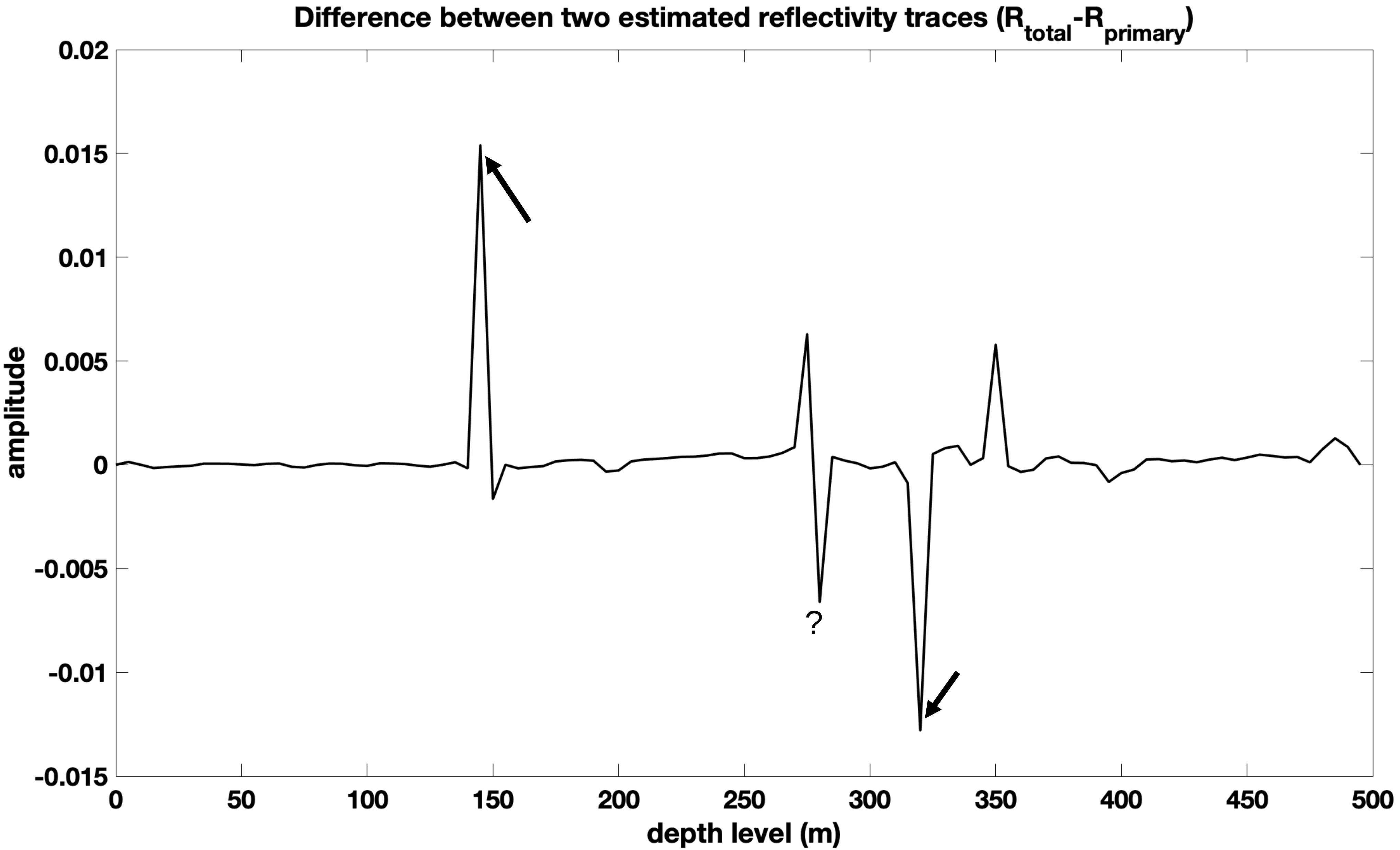

Conclusion

- RTM and LSRTM with the first-order surface multiple can enhance the illumination and signal-to-noise ratio in the image compared with primary wave
- Accurate separation for primary and multiple energy
- FWM can predict and use surface and internal multiples, recover reflectivity coefficient amplitude
- Background velocity should be close to the true velocity model

Future work

- Use surface-related multiple elimination (SRME) to separate and obtain good estimates of primary and multiples
- Work on the iterative approach and generate f-x extrapolation operator to deal with lateral velocity variation
- Update velocity model

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Questions?

Thank you!