Evaluating the potential of reflection-based waveform inversion (RWI)

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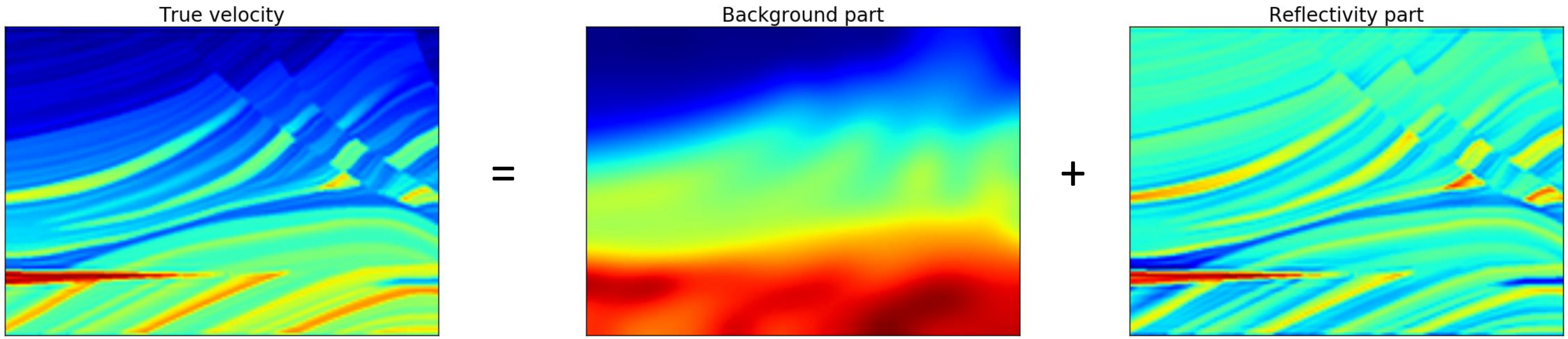
Outline

- Motivation
- Modeling by seismic demigration
- FWI workflow
- RWI workflow
- Example
- Issues with RWI
- Conclusion

Motivation

- The velocity of the earth can be separated into a background velocity model (long-wavelength) and a reflectivity model (short-wavelength).



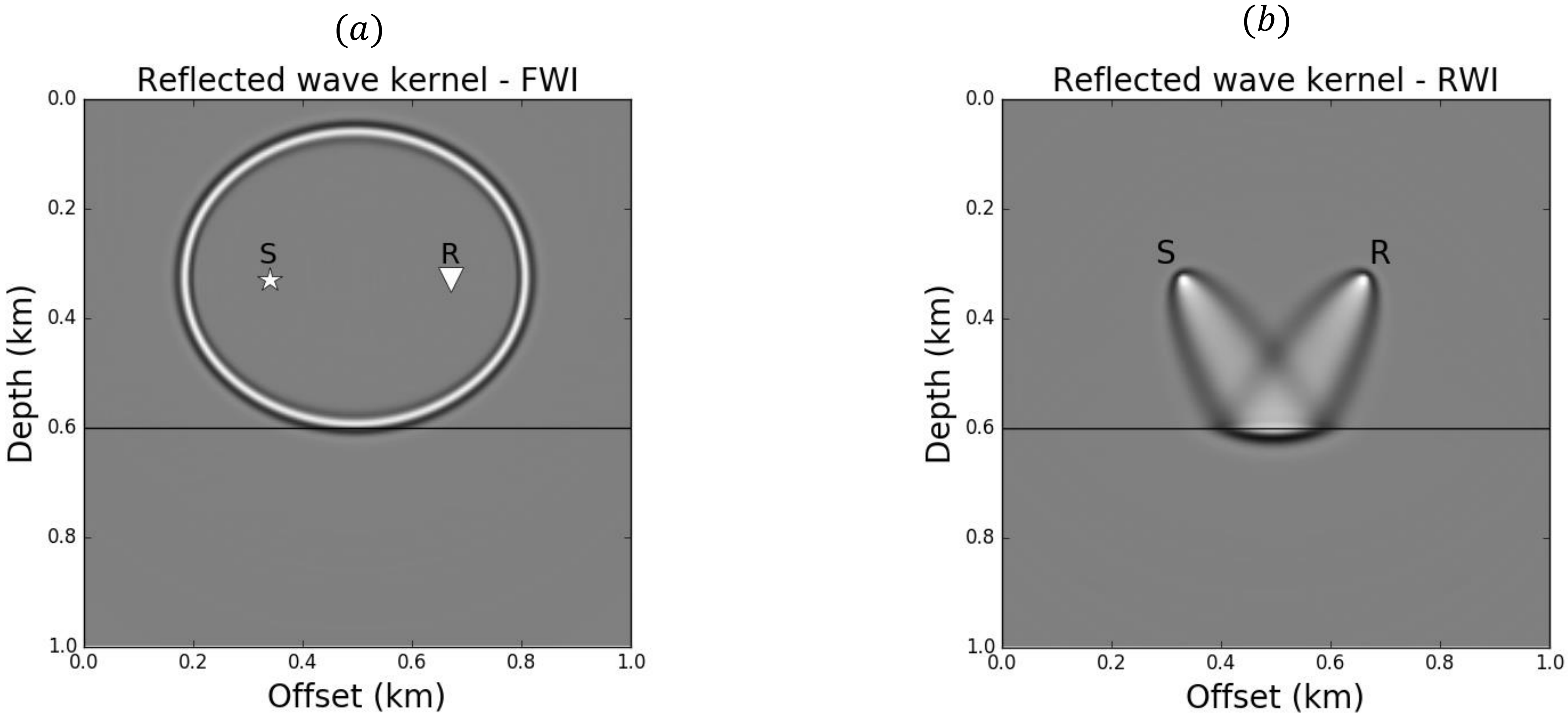
Motivation

- FWI relies on the presence of low-frequency and long-offset data to recover the long-wavelength components of the velocity model.

- FWI recovers the long-wavelength components of the velocity model for the shallow section but it fails to recover it for the deep section.

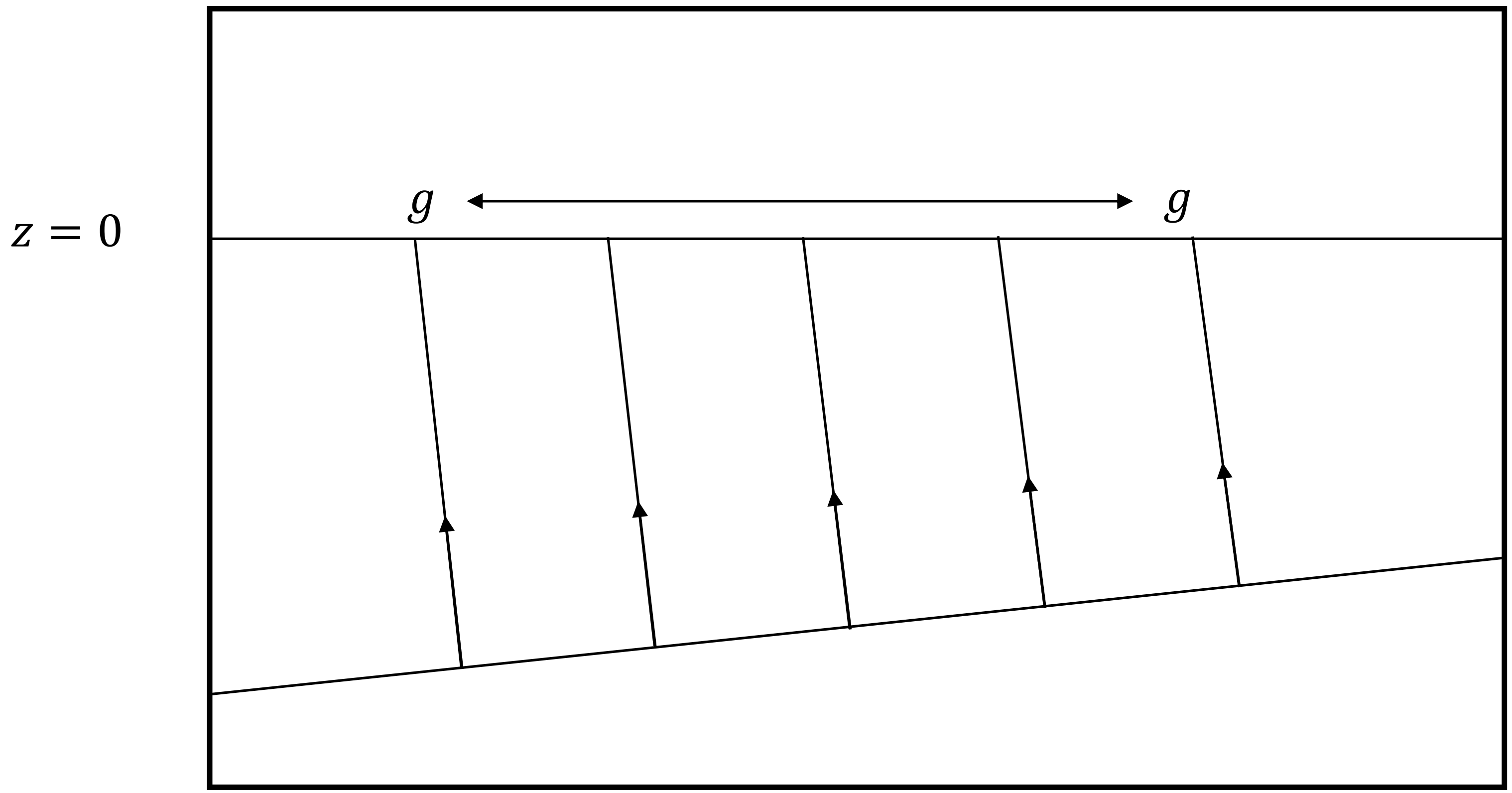
- RWI aims at recovering the long-wavelength components of the velocity model in the deep part by using the transmission wavepaths of the reflection data.

Motivation – Reflected waves contribution to model update



Seismic demigration – The exploding reflector model

Exploding reflector model

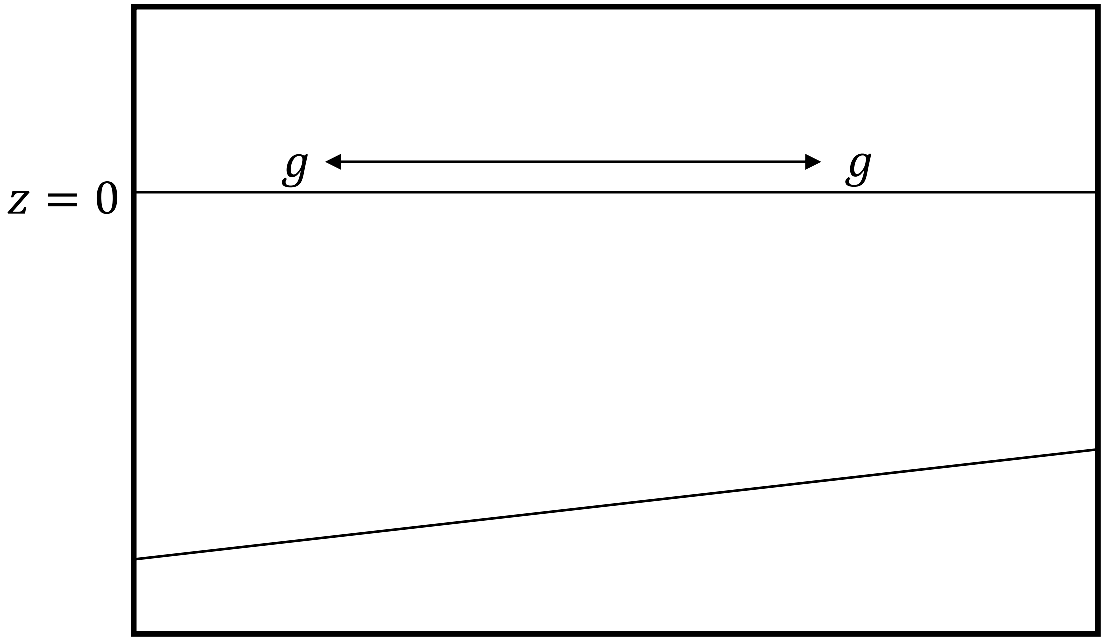


A dipping reflector

Seismic demigration

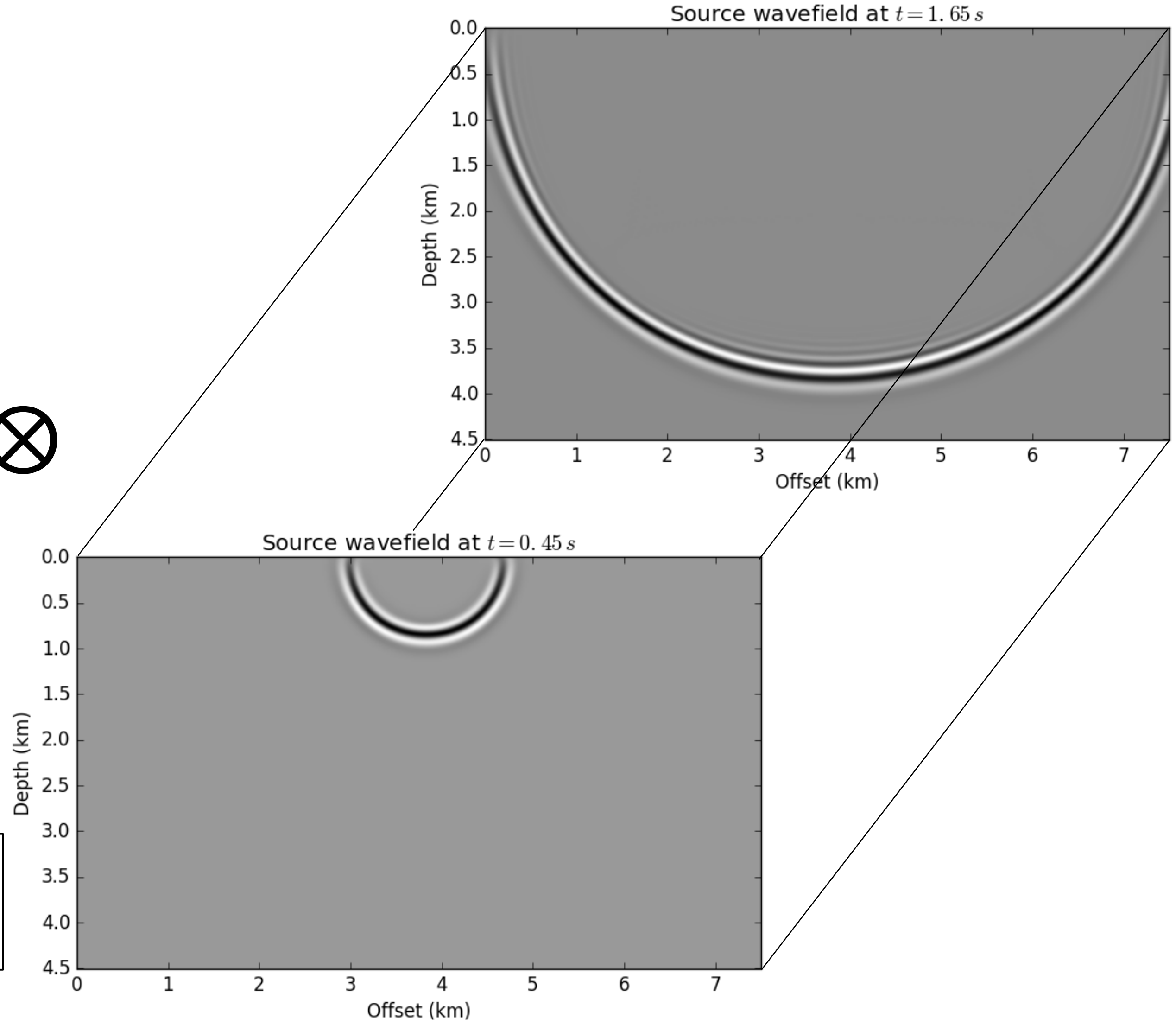
$I(\vec{x})$

Migrated Image in Depth



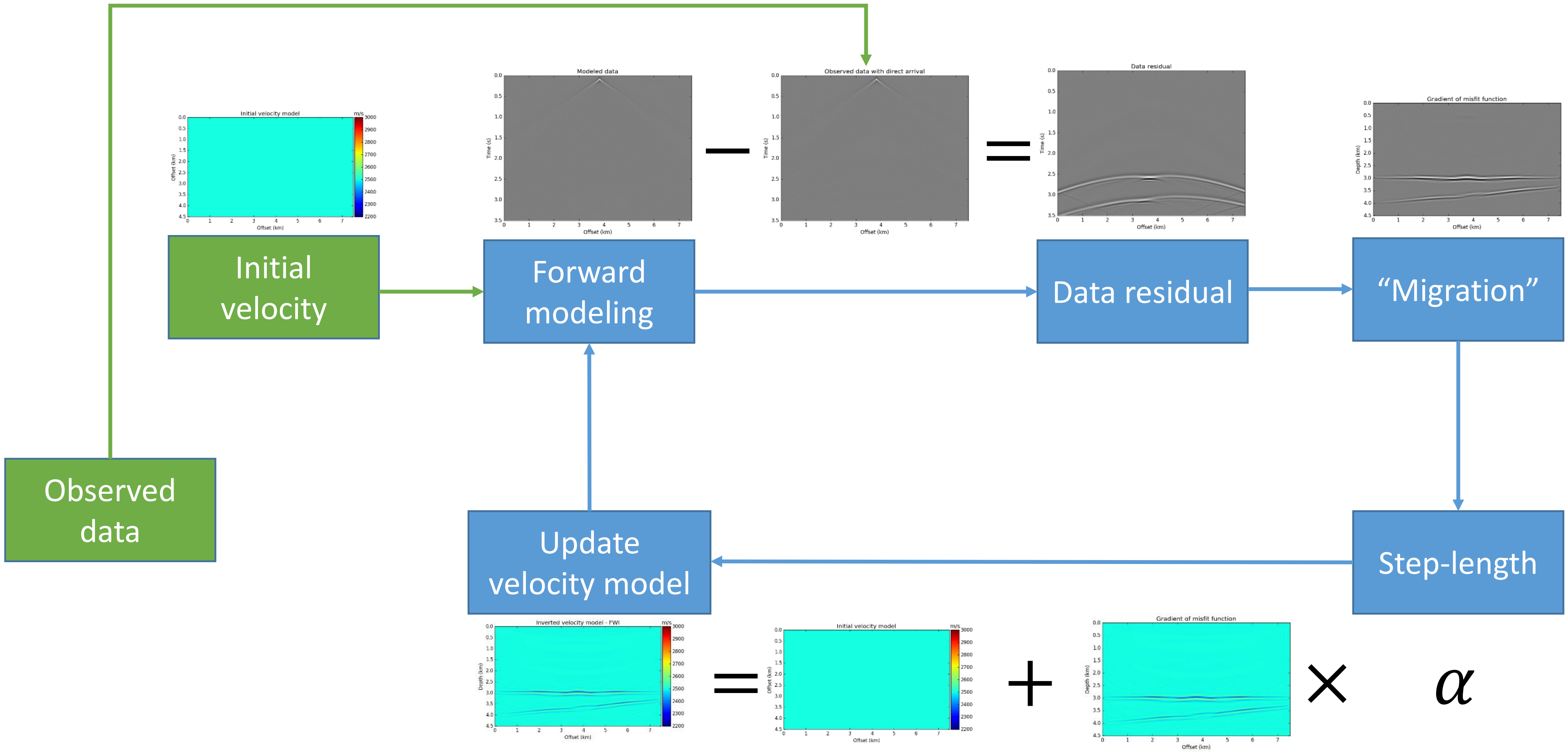
$\otimes$

Source wavefield $U_s(\vec{x}, t; \vec{x}_s)$

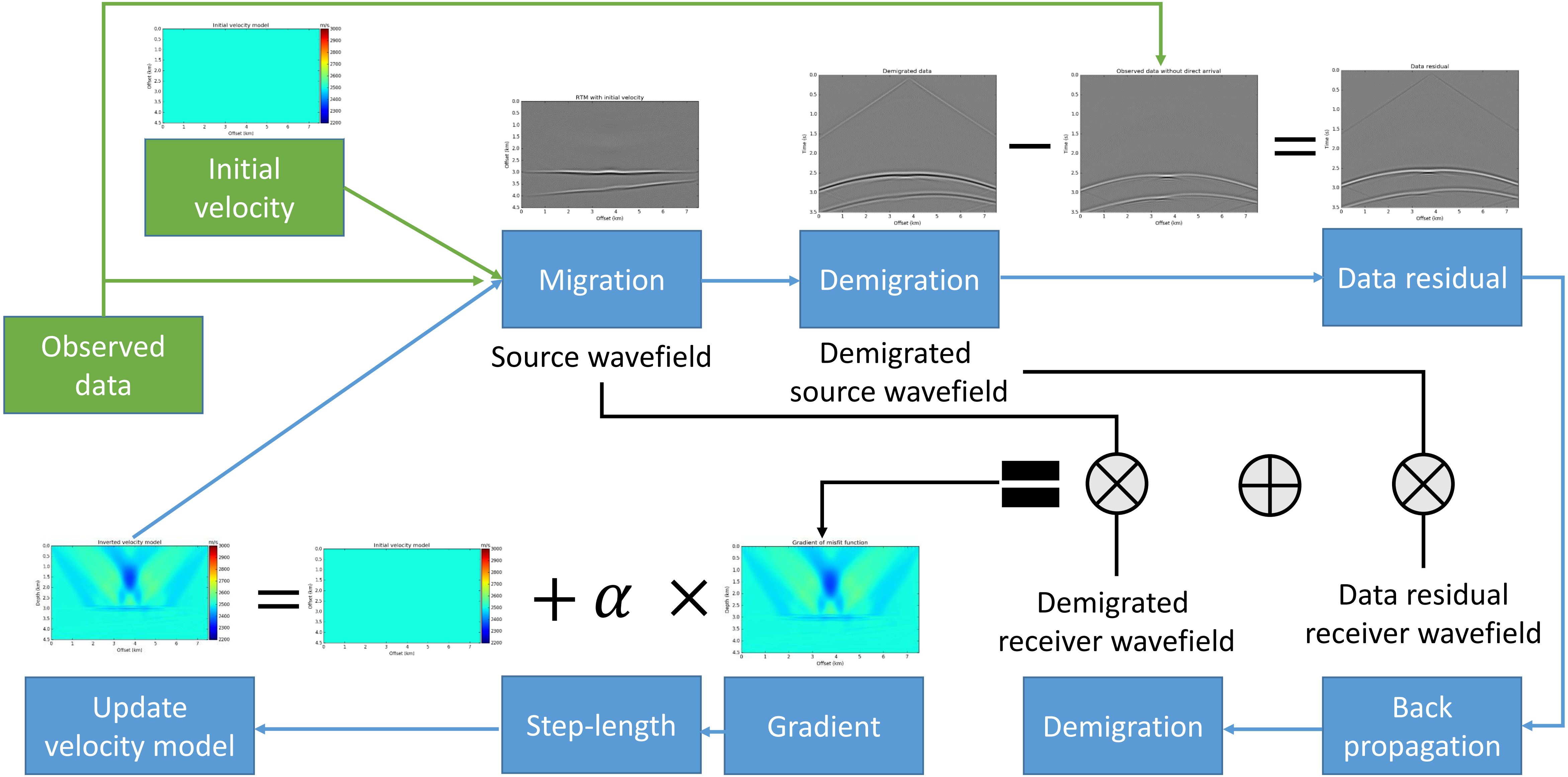


$$\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)\delta U_s(\vec{x}, t; \vec{x}_s) = I(\vec{x}) \cdot U_s(\vec{x}, t; \vec{x}_s)$$

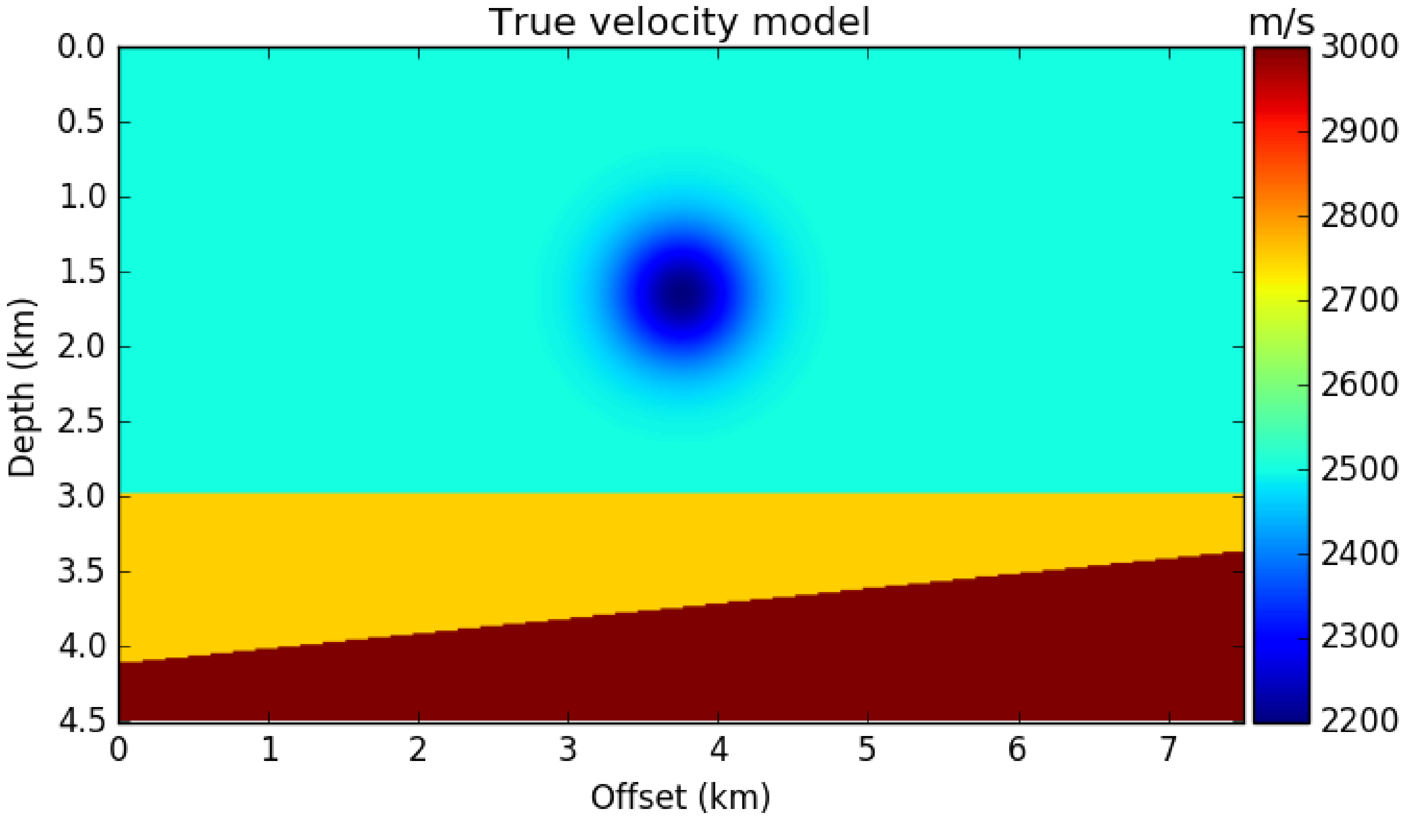
FWI workflow



RWI workflow

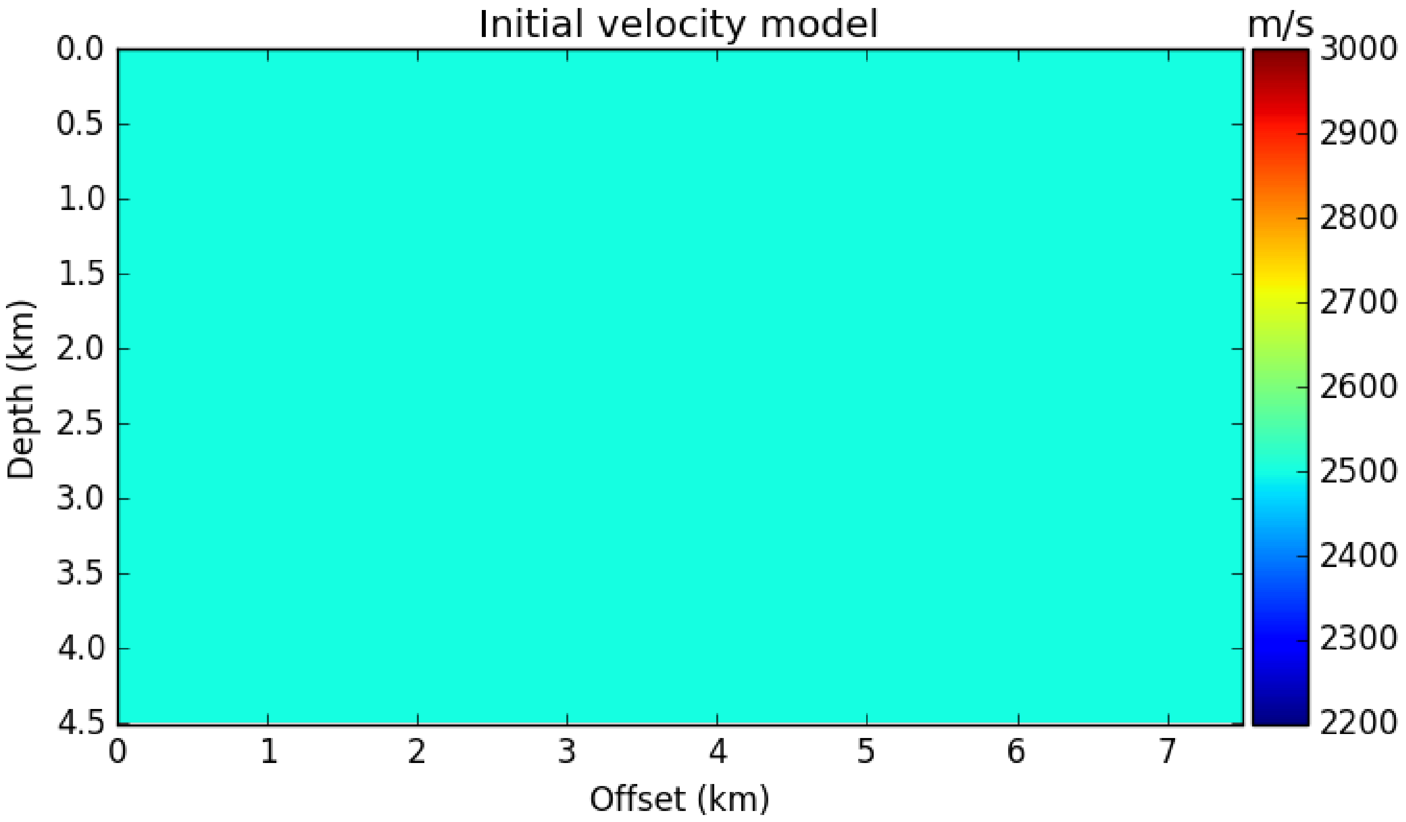


Example: true velocity model

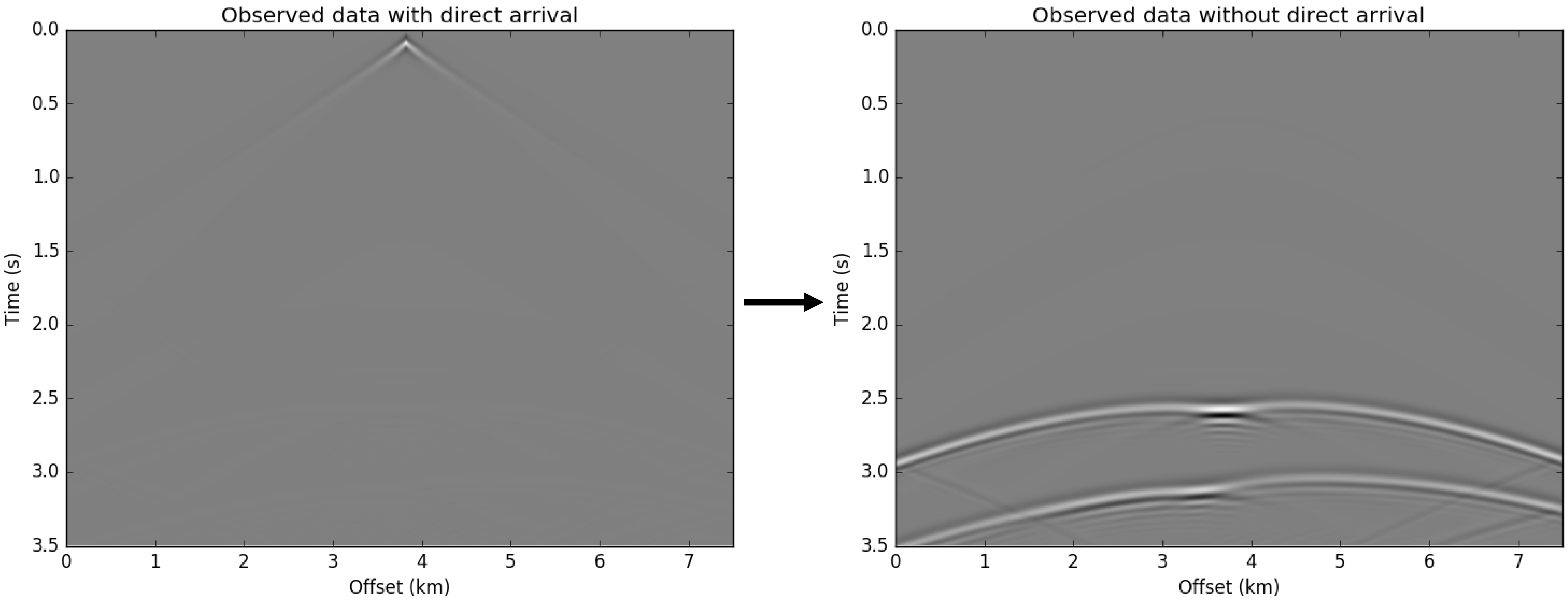


- <u>Background velocity</u>: 2500 m/s
- <u>Center of lens velocity</u>: 2200 m/s
- <u>Source wavelet</u>: Ricker with 10 Hz dominant frequency

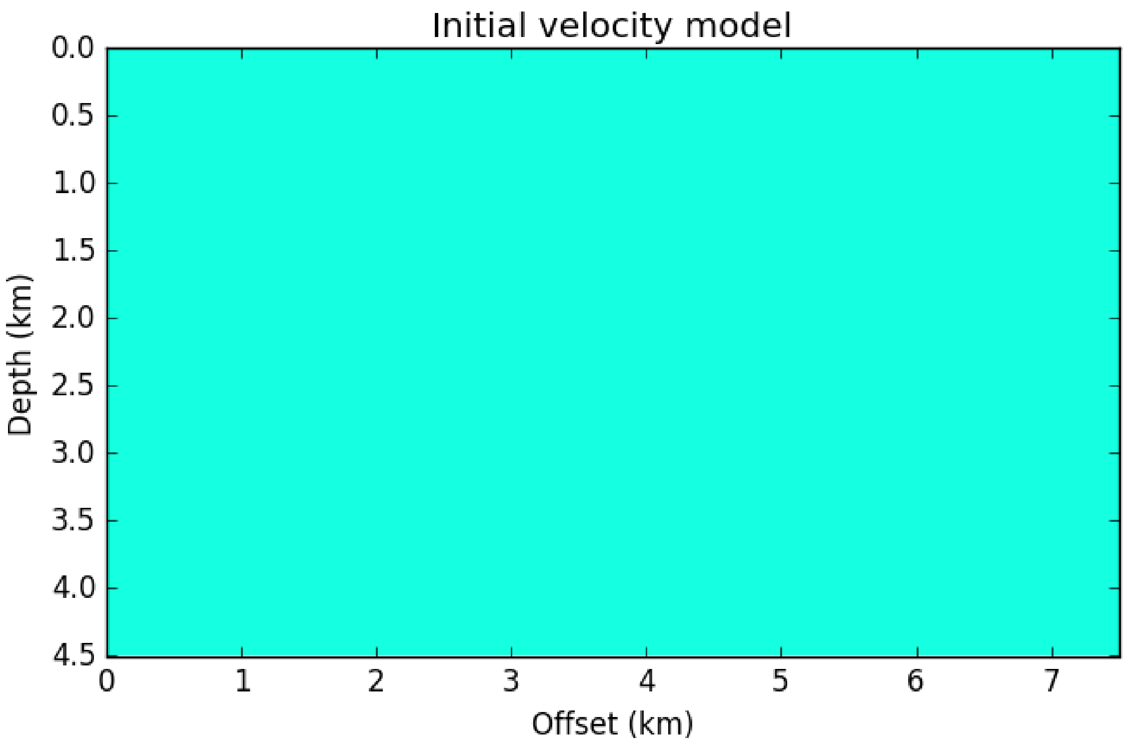
Example: initial velocity model

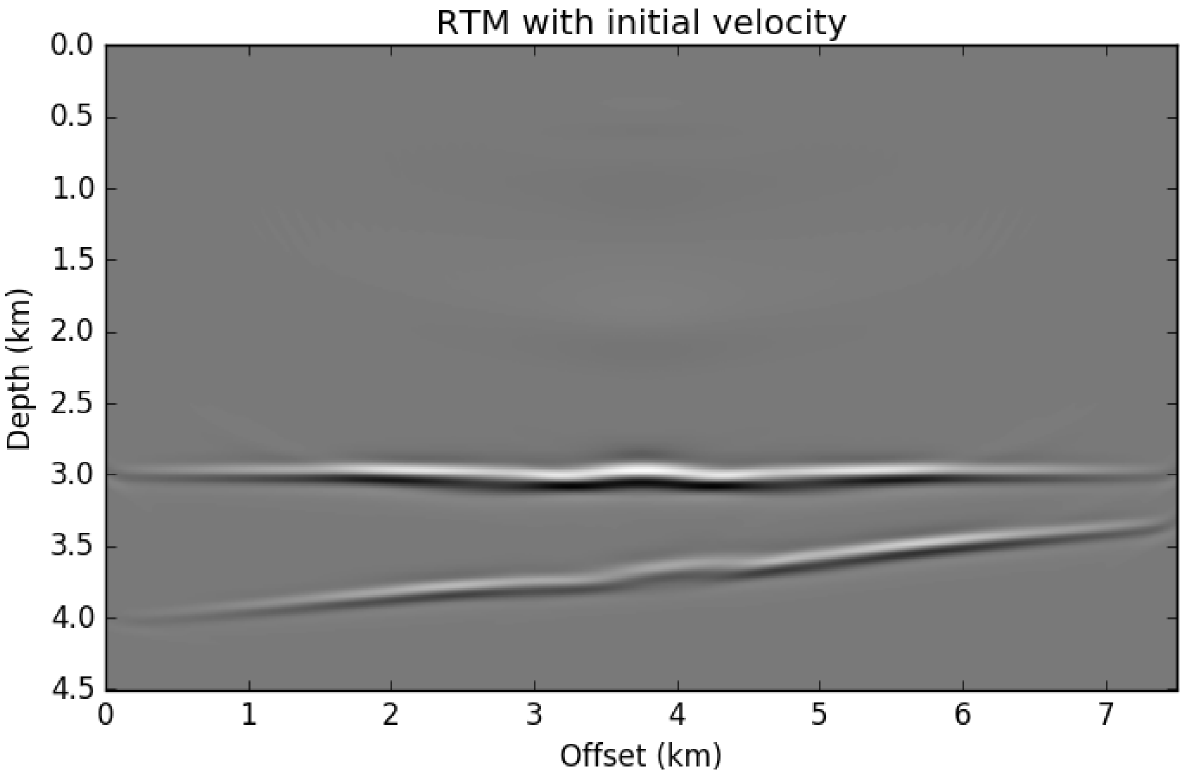


Example: observed data

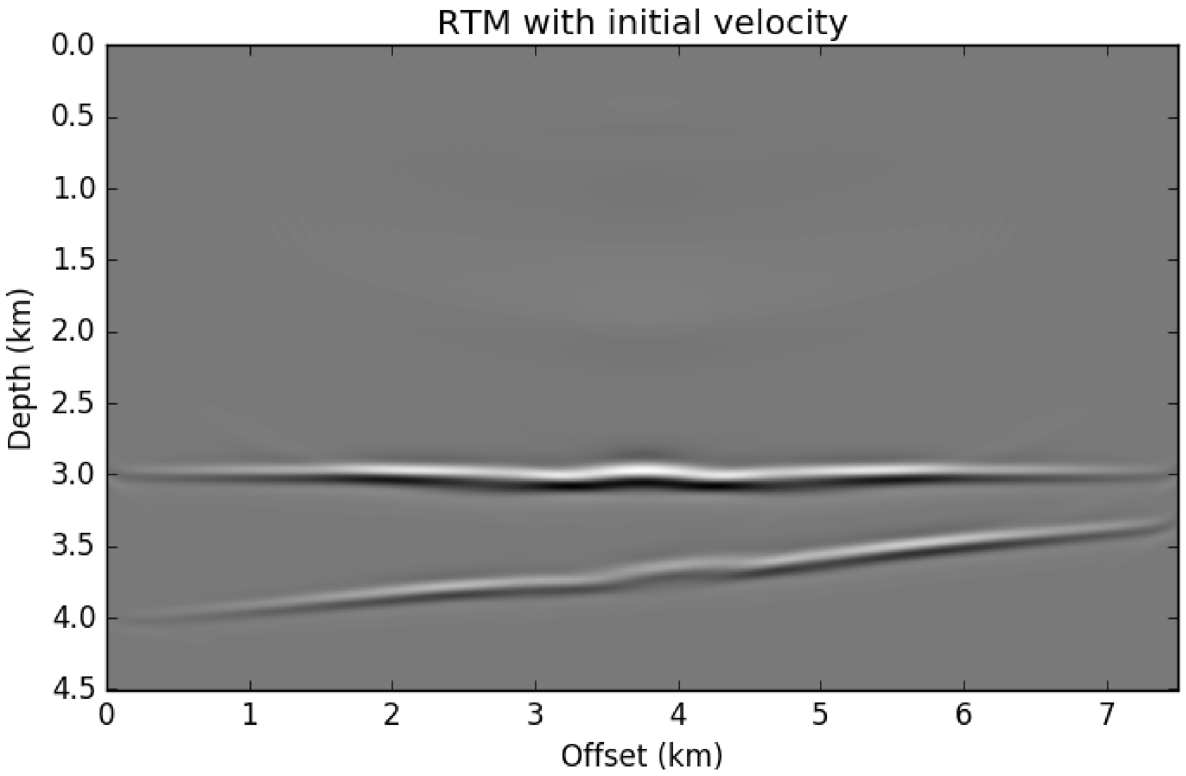


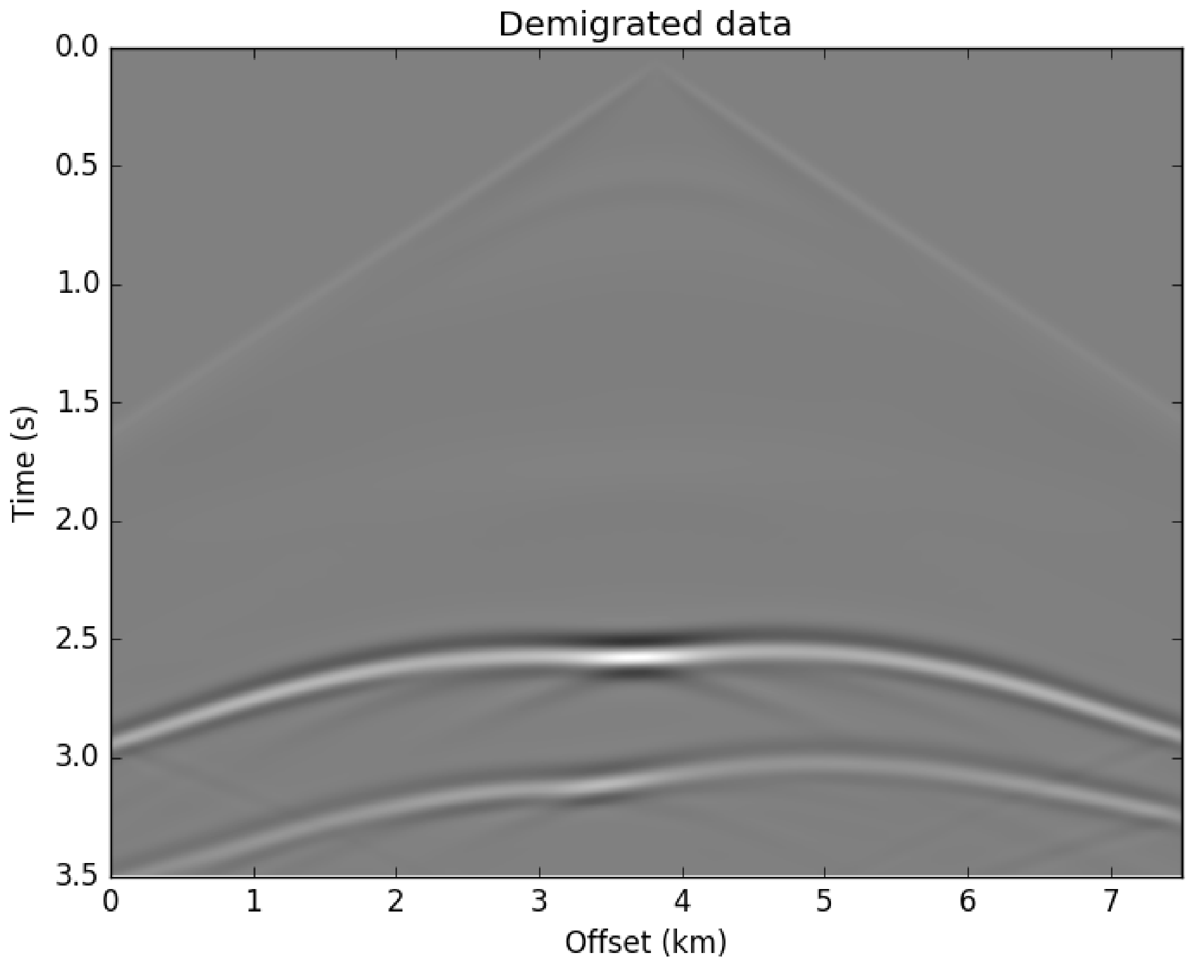
Example: migration





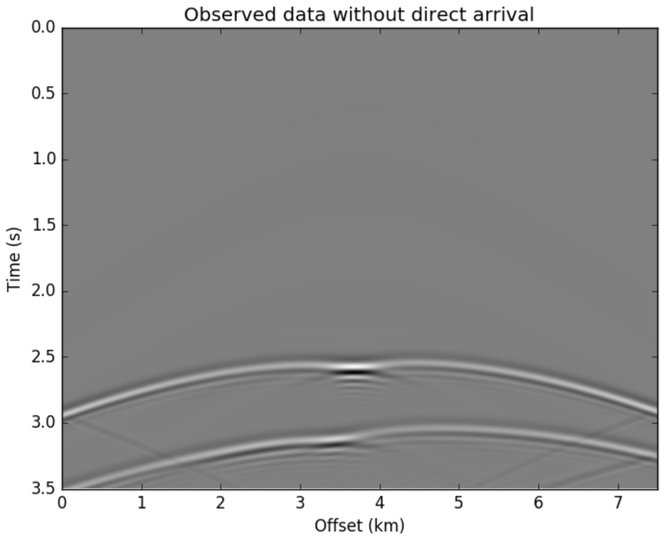
Example: demigration 1





Example: residual, back-propagation, and demigration 2

Observed data



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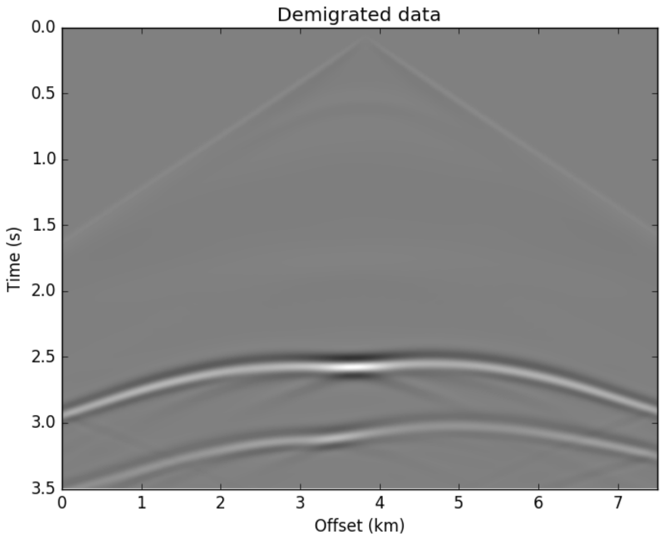
Demigrated data



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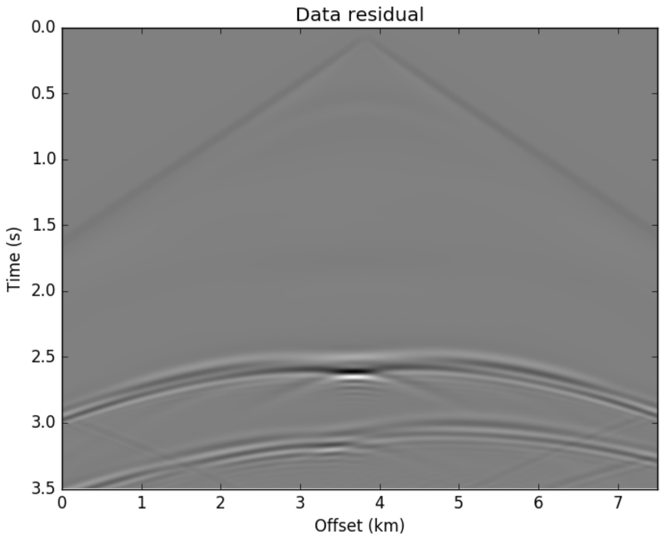
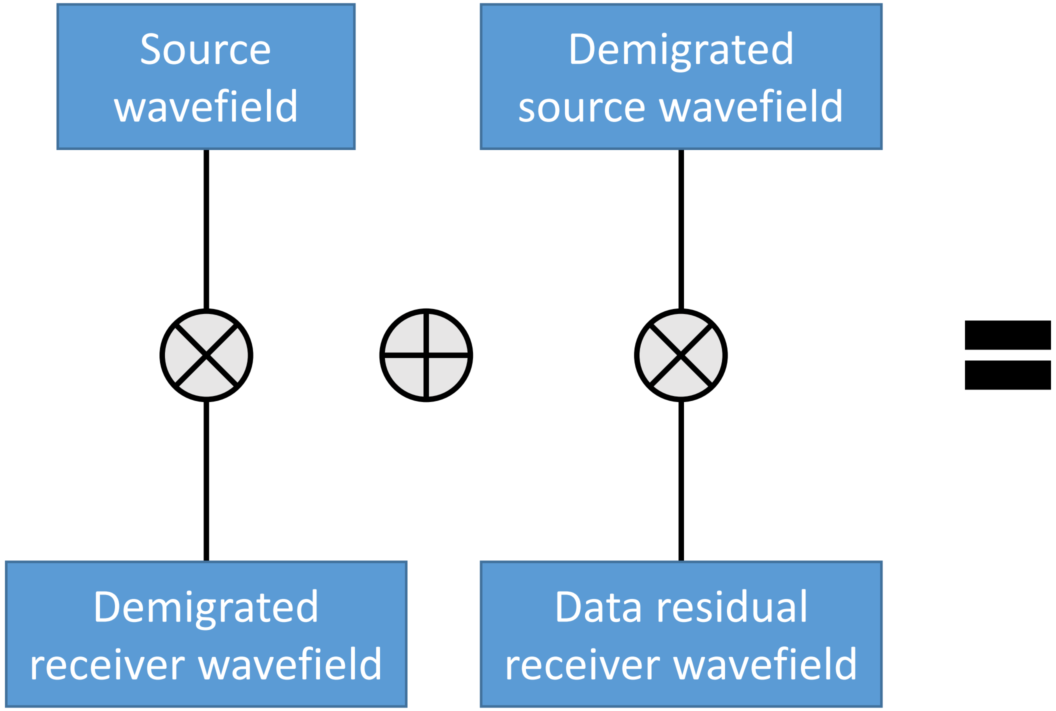
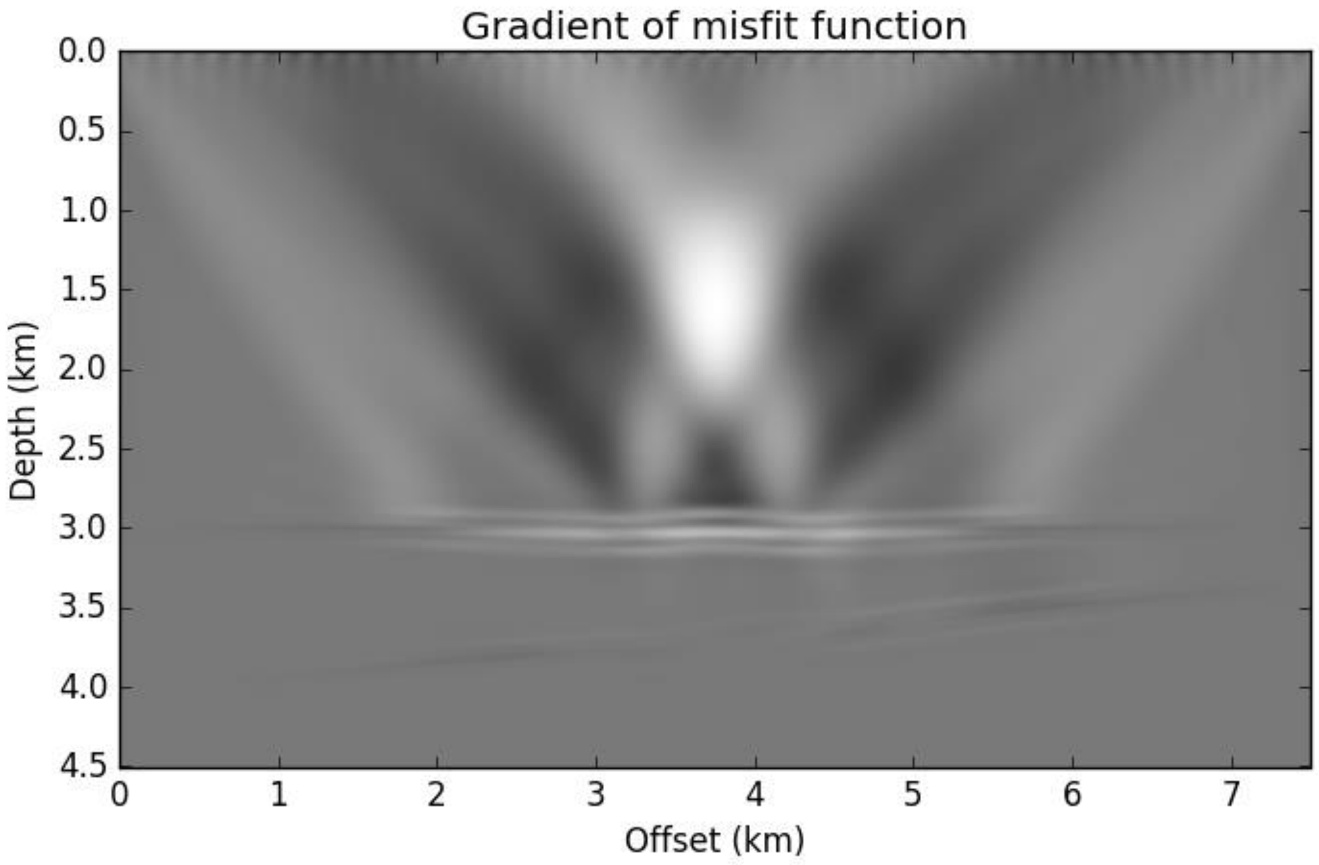
Data residual



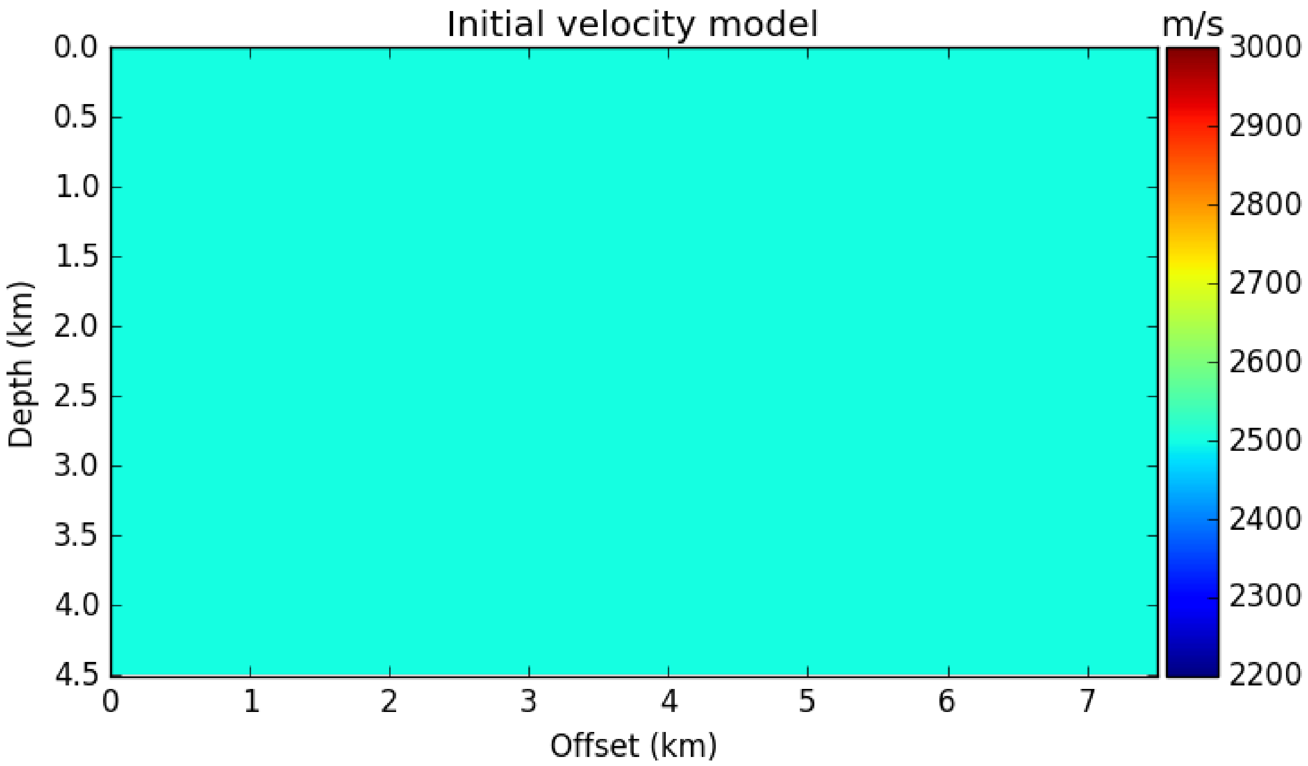
$$d_{obs} - d_{cal} = \delta d$$

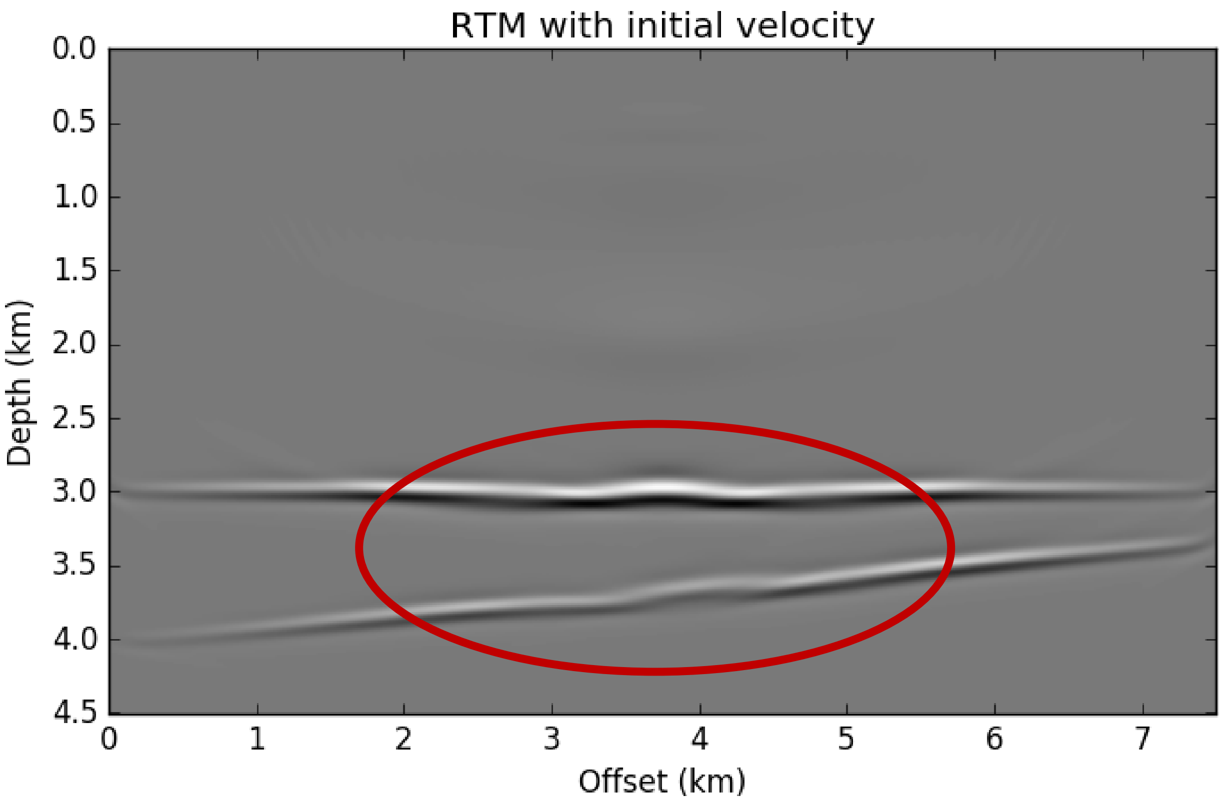
Example: gradient



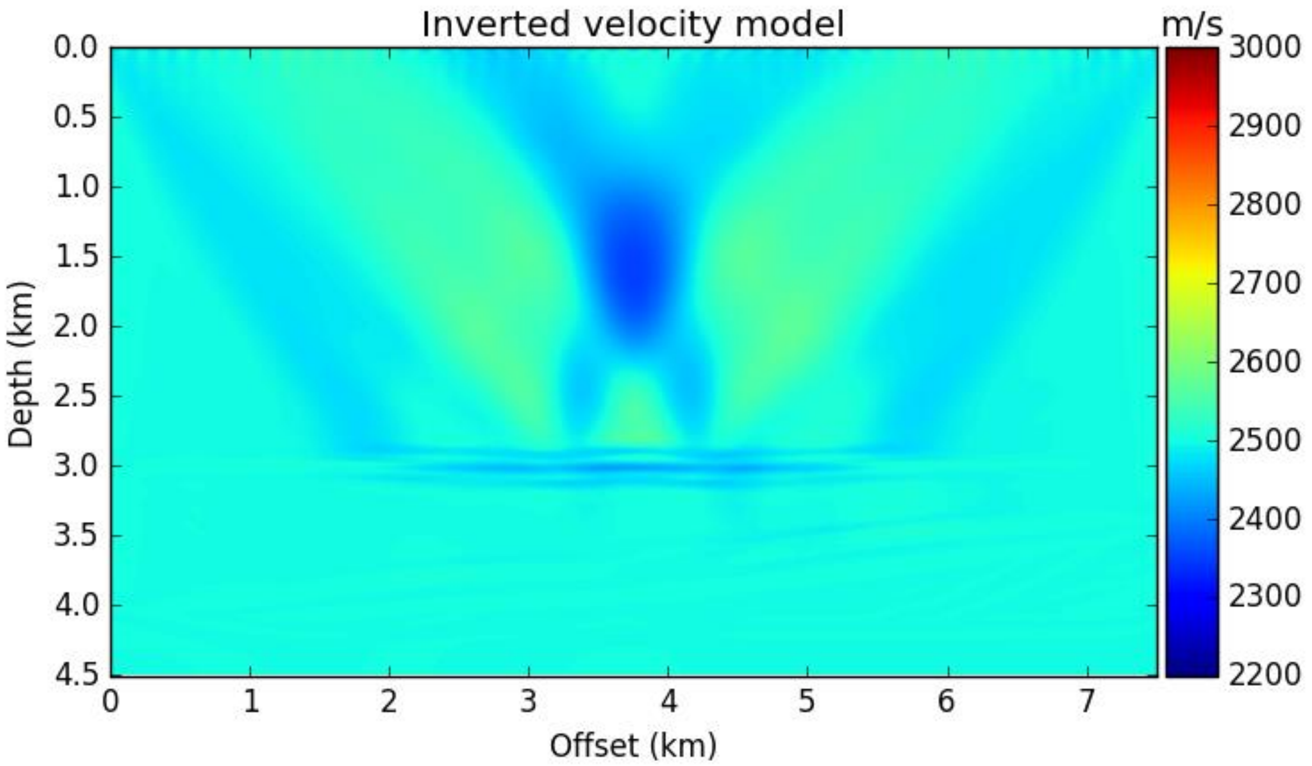


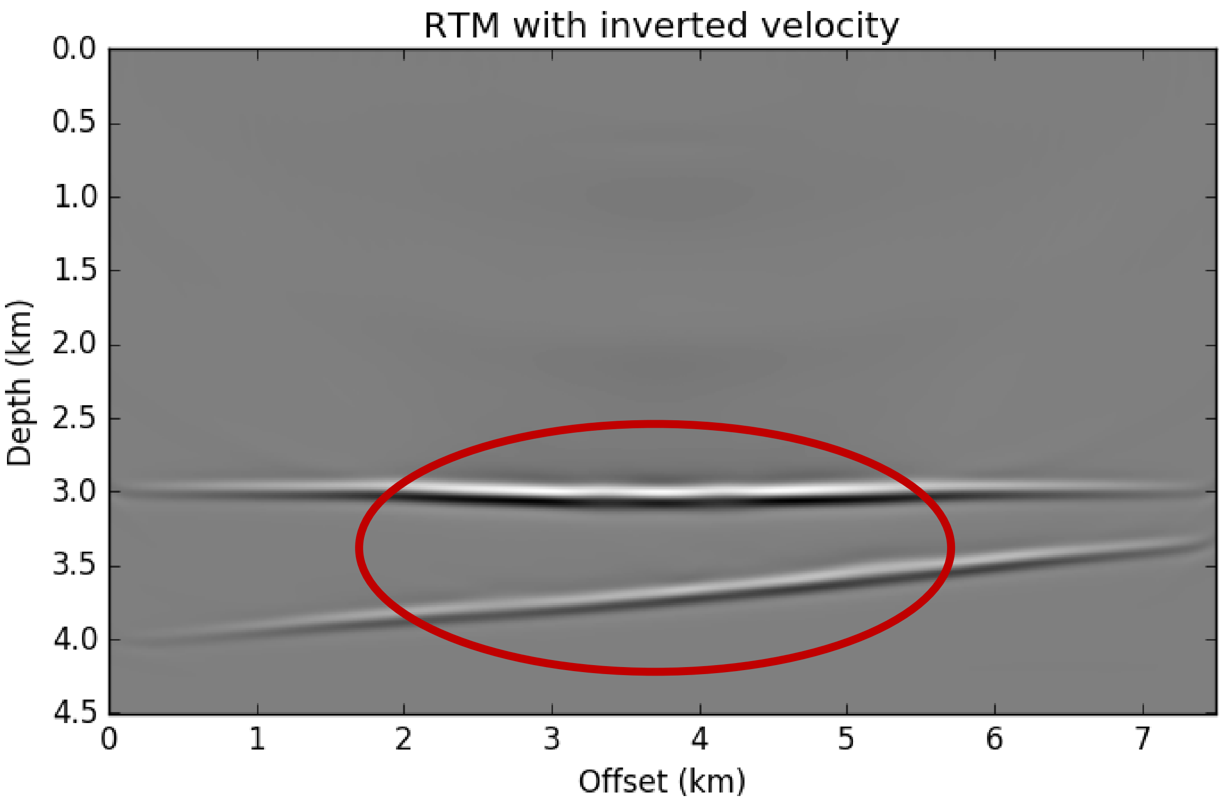
Example: results – initial velocity



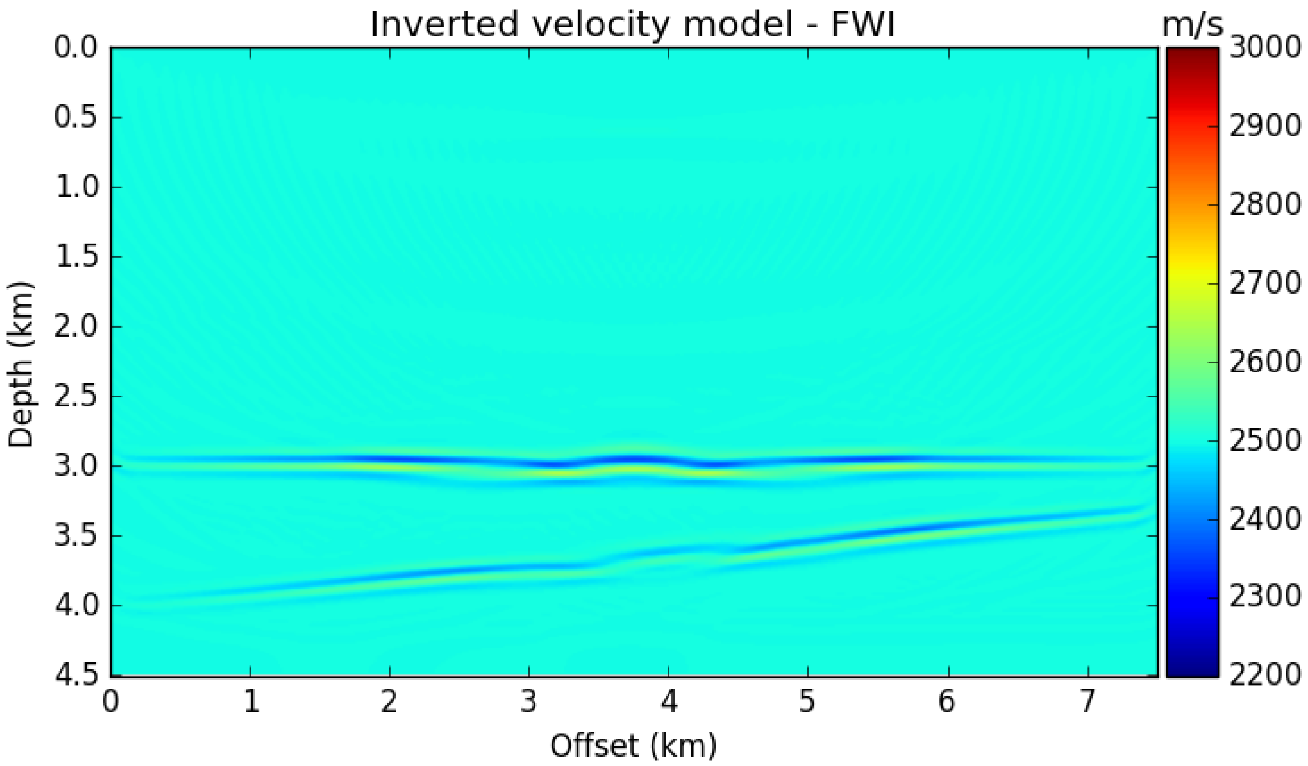


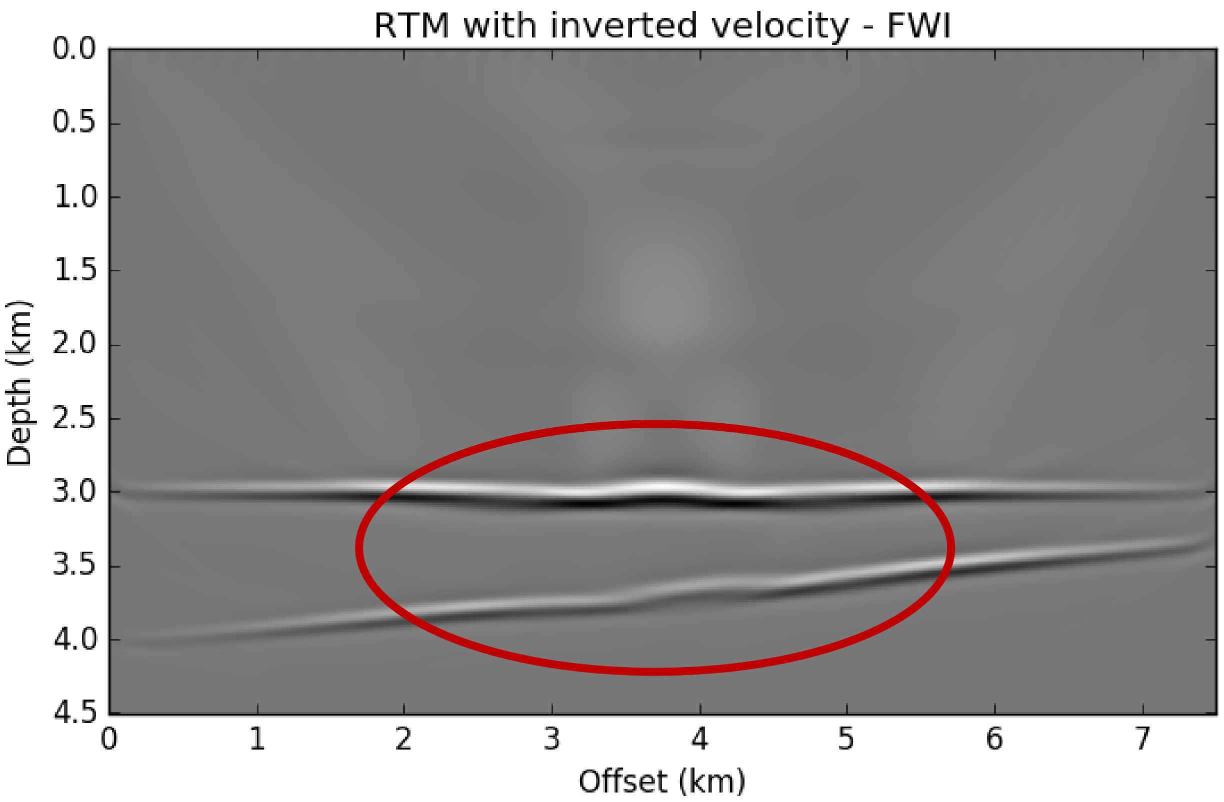
Example: results – RWI





Example: results - FWI





Issues with RWI

- Neglects other waves (e.g. direct waves).
- RTM artifacts, if not handled properly, will contaminate the demigrated data.
- Computationally expensive.

Conclusion

- RWI provides a better environment to retrieve the long-wavelength components in the deep part of the velocity model.
- RWI could provide a good initial velocity model for FWI.
- Future work:
  - Implementing a multi-parameter RWI.
  - Implementing a joint RWI that include direct waves.

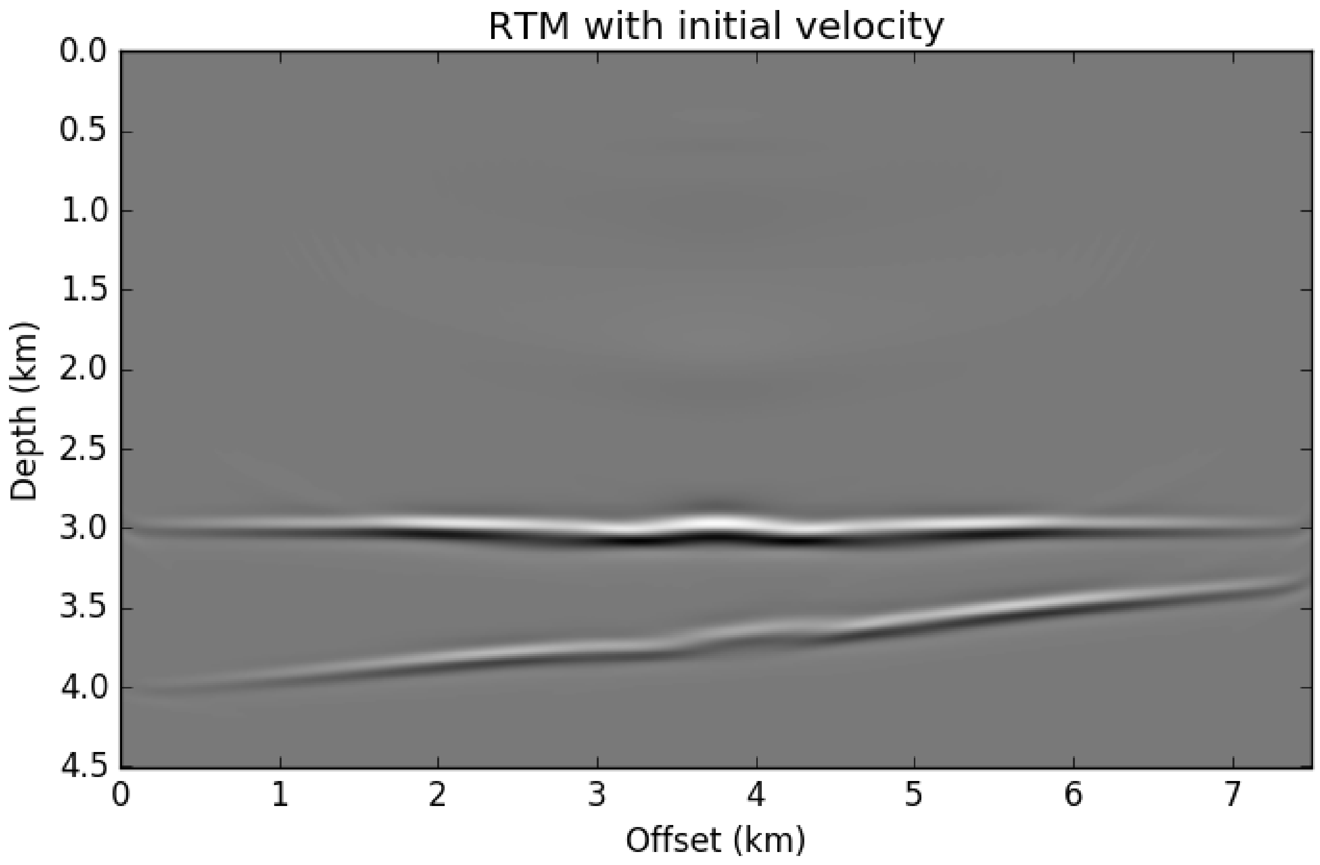
Acknowledgements

- CREWES sponsors.
- NSERC (grant 461179-13)
- Scott Keating
- CREWES faculty, staff, and students

Questions?

Appendix: Equations

Migration

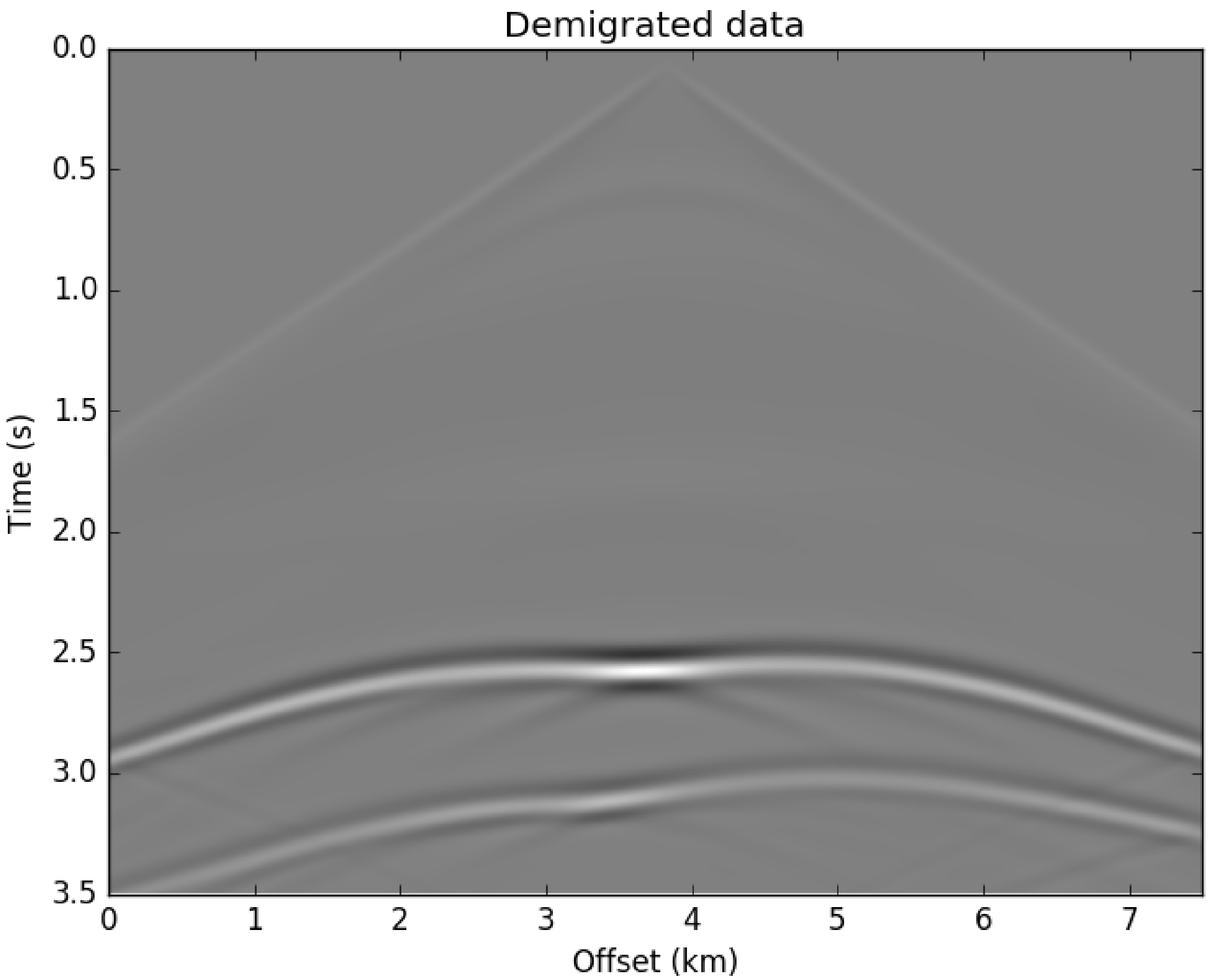


$$\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right) U_s(\vec{x}, t; \vec{x}_s) = f(t)\delta(\vec{x} - \vec{x}_s)$$

$$\left\{\begin{array}{c}\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right) U_r(\vec{x}, t; \vec{x}_s) = 0 \\ U_r(\vec{x}_r, t; \vec{x}_s) = d_{obs}(\vec{x}_r, t; \vec{x}_s)\end{array}\right\}$$

$$I(\vec{x}) = \sum_{x_s} \int_0^T U_s(\vec{x}, t; \vec{x}_s) \cdot U_r(\vec{x}, T - t; \vec{x}_s) dt$$

Demigration 1



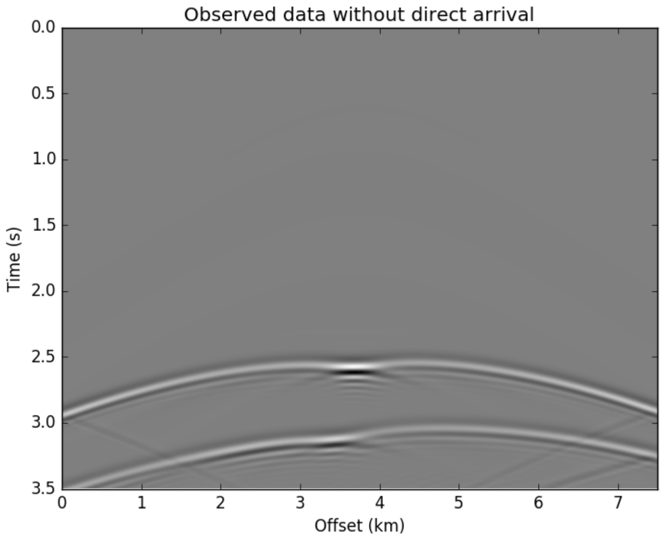
$$\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right) U_s(\vec{x}, t; \vec{x}_s) = f(t)\delta(\vec{x} - \vec{x}_s)$$

$$\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right) \delta U_s(\vec{x}, t; \vec{x}_s) = I(\vec{x}) \cdot U_s(\vec{x}, t; \vec{x}_s)$$

$$d_{cal} = \delta U_s(\vec{x}_r, t; \vec{x}_s)$$

Residual

Observed data



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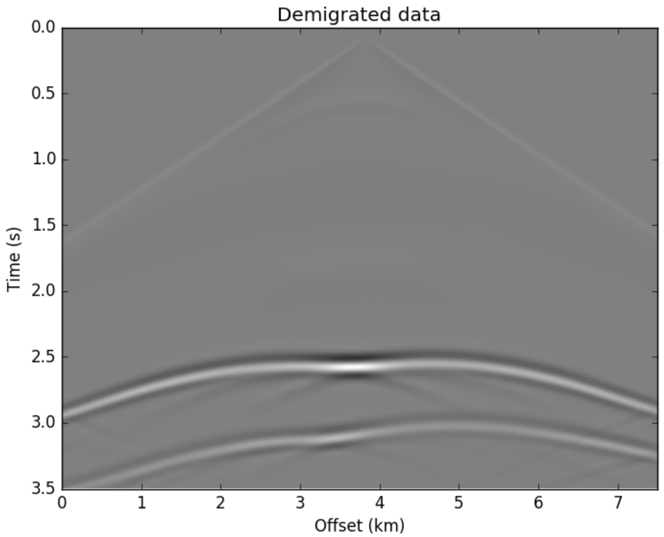
Demigrated data



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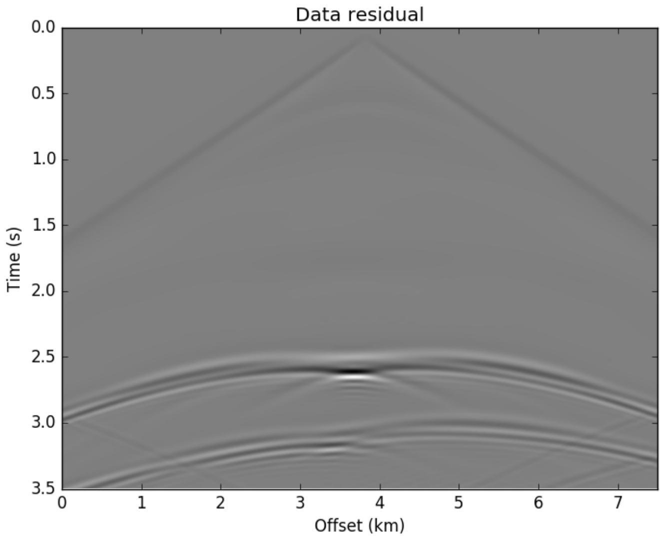
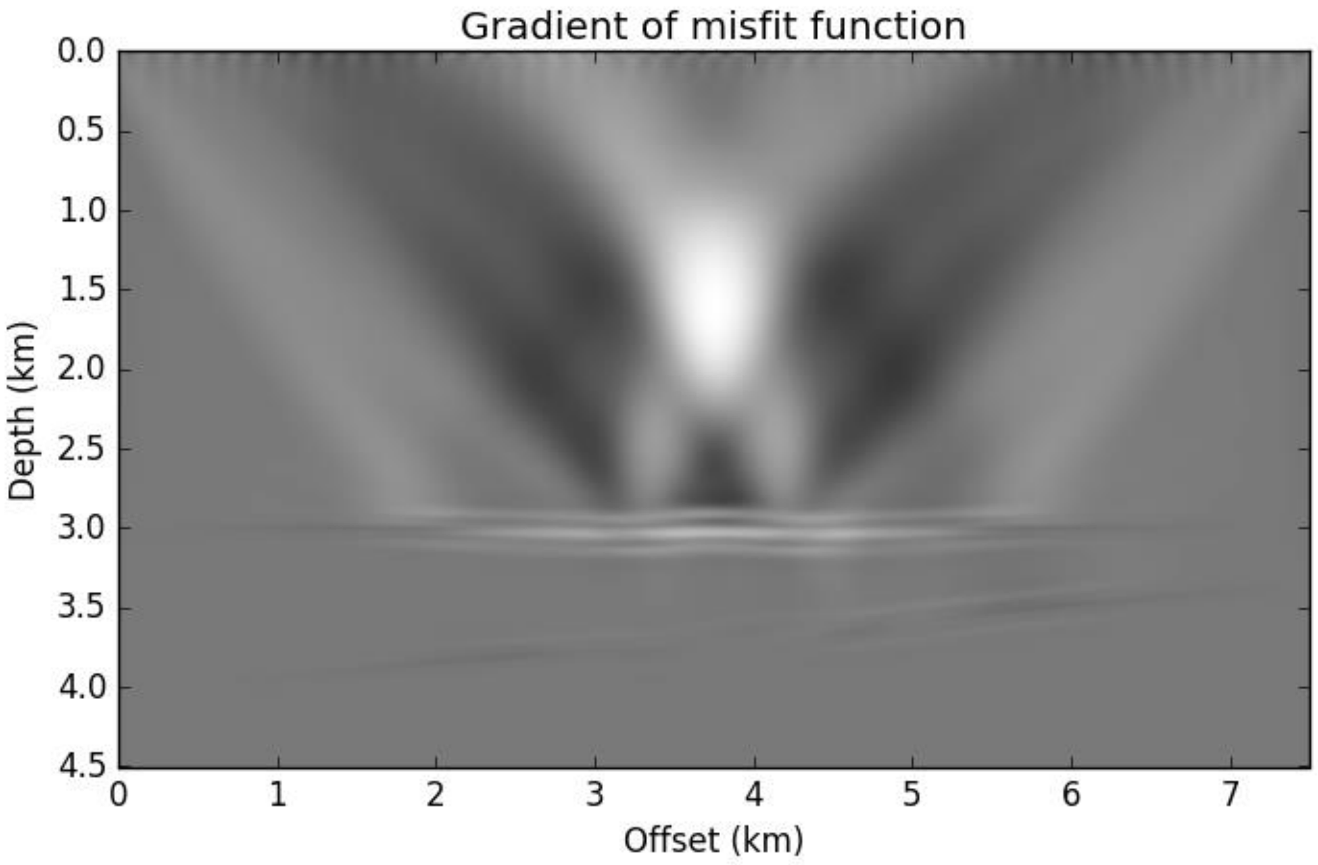
Data residual



$$d_{obs} - d_{cal} = \delta d$$

Back-propagation, Demigration 2, and Gradient



$$\left\{\begin{array}{c}\left(\dfrac{1}{v(x)^2}\dfrac{\partial^2}{\partial t^2}-\nabla^2\right)U_r(\vec{x},t;\vec{x}_s)=0\\ U_r(\vec{x}_r,t;\vec{x}_s)=\delta d(\vec{x}_r,t;\vec{x}_s)\end{array}\right\}$$

$$\left(\frac{1}{v(x)^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right)\delta U_r(\vec{x},t;\vec{x}_s)=I(\vec{x})\cdot U_r(\vec{x},t;\vec{x}_s)$$

$$k_s=\sum_{x_s}U_r(\vec{x},t;\vec{x}_s)\cdot\delta U_s(\vec{x},t;\vec{x}_s)$$

$$k_r=\sum_{x_s}U_s(\vec{x},t;\vec{x}_s)\cdot\delta U_r(\vec{x},t;\vec{x}_s)$$

$$G=k_s+k_r$$