

Target-oriented imaging and velocity analysis using Marchenko-redatumed data

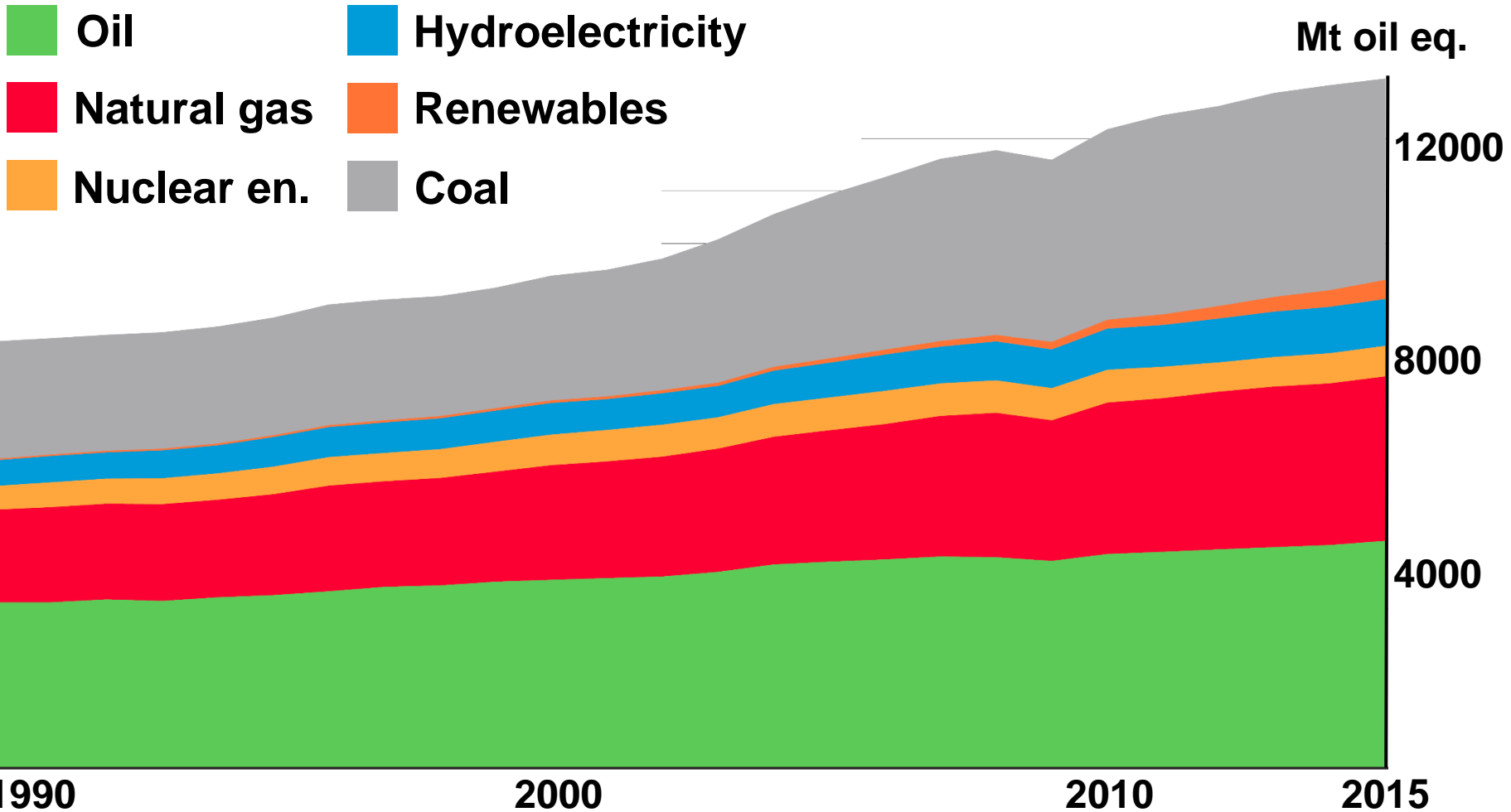
Constantin Mildner

Frontiers in Energy Research

... imaging and velocity analysis ...

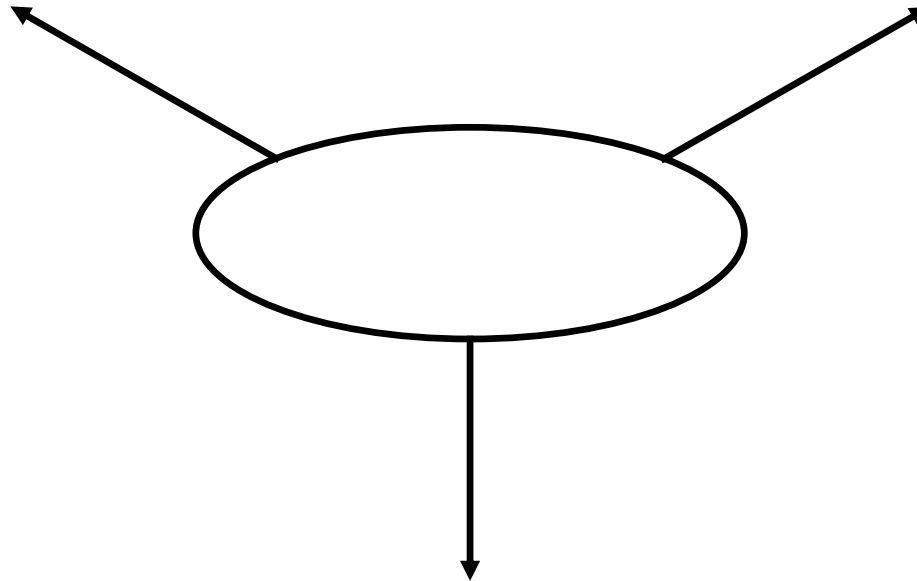
Energy Research

World primary energy consumption

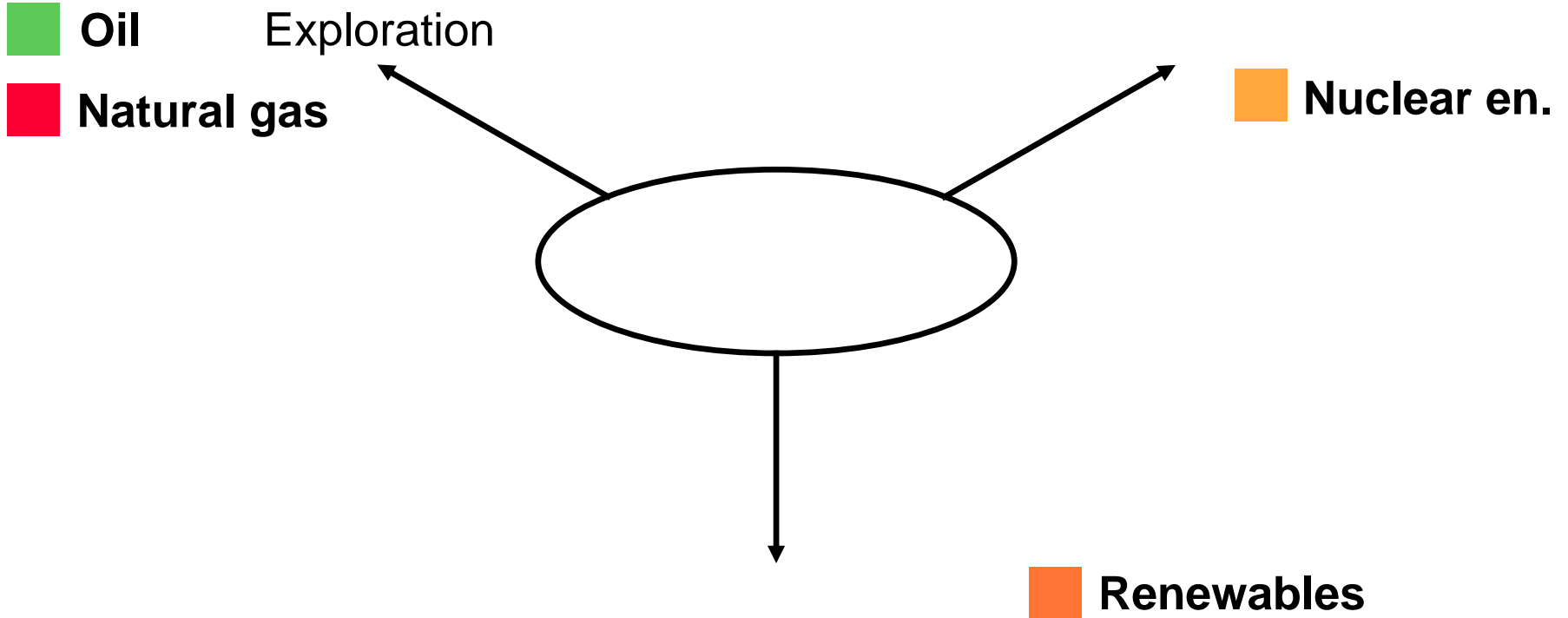


(BP Statistical Review of World Energy, 2016)

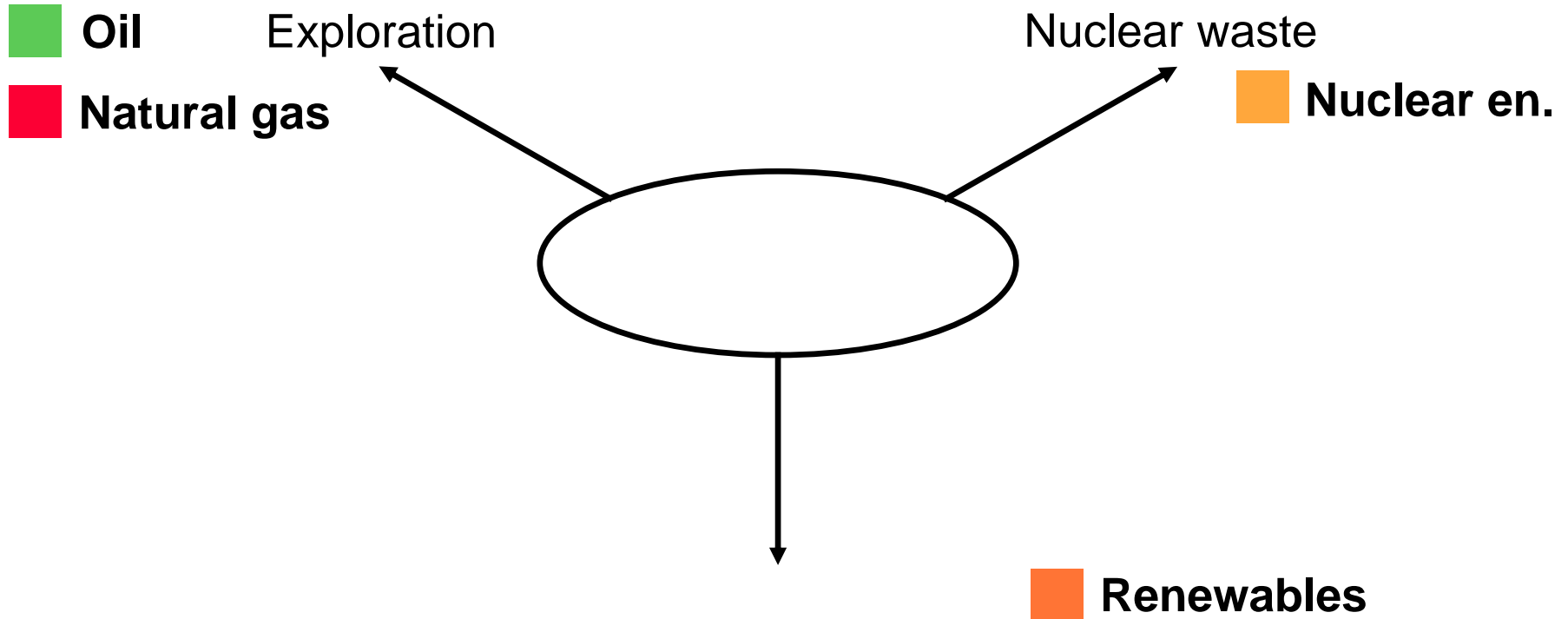
Fields of application

 Oil Natural gas Nuclear en. Renewables

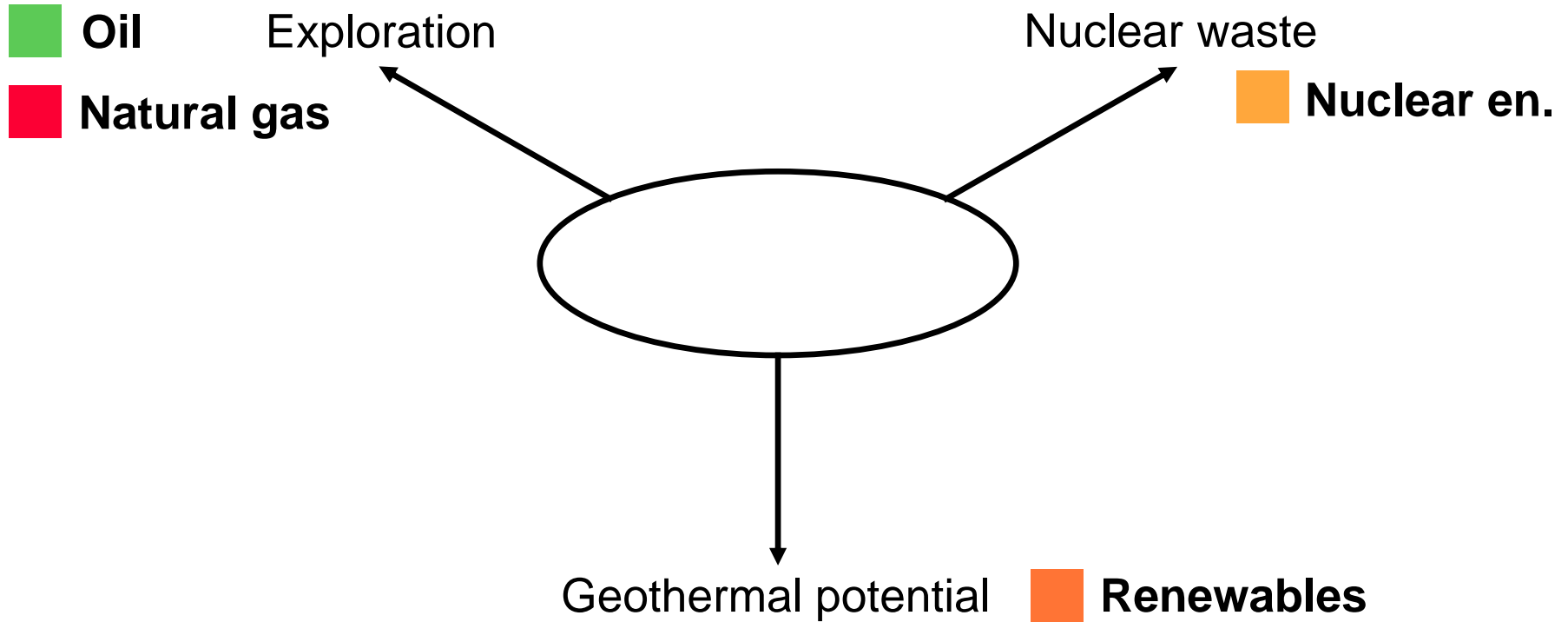
Fields of application



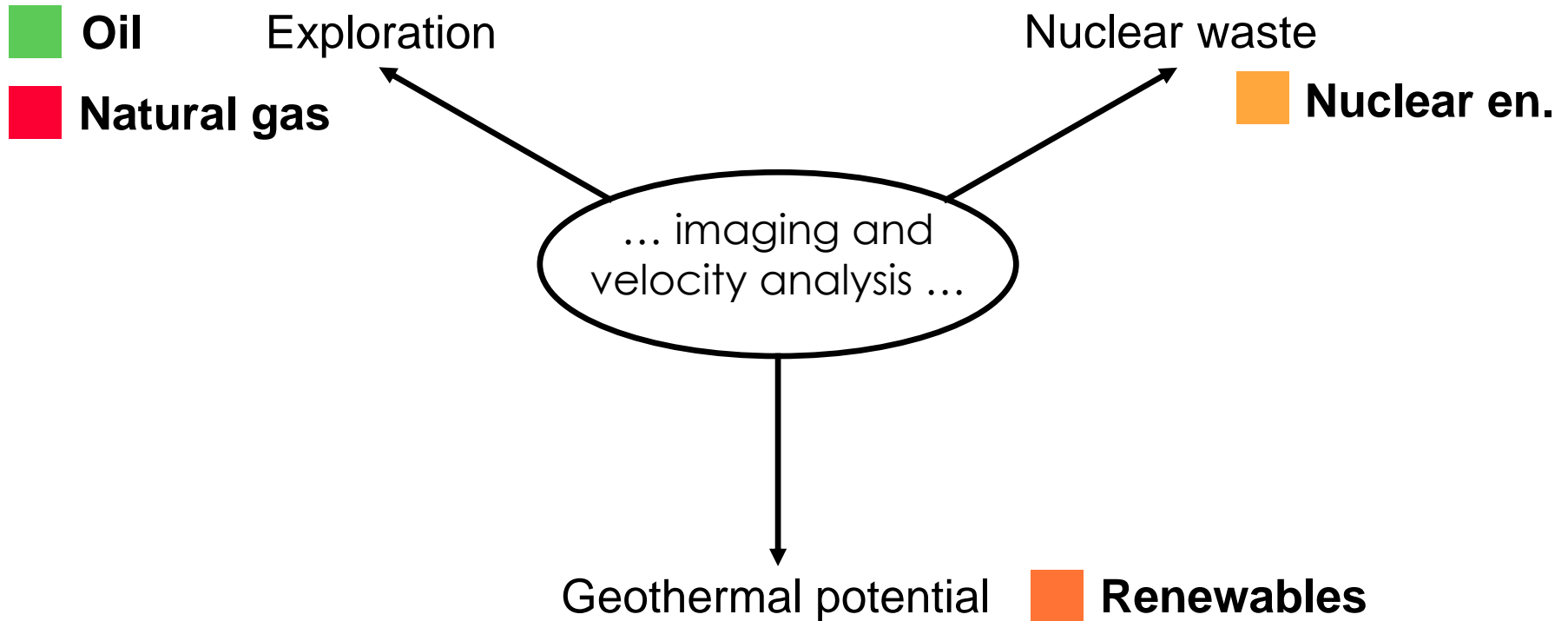
Fields of application



Fields of application

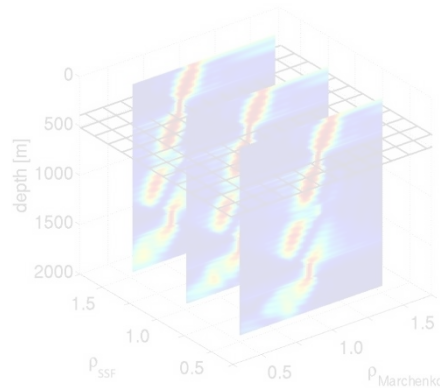
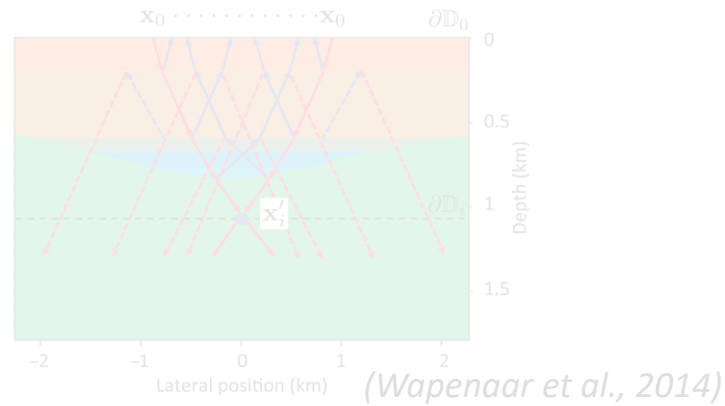
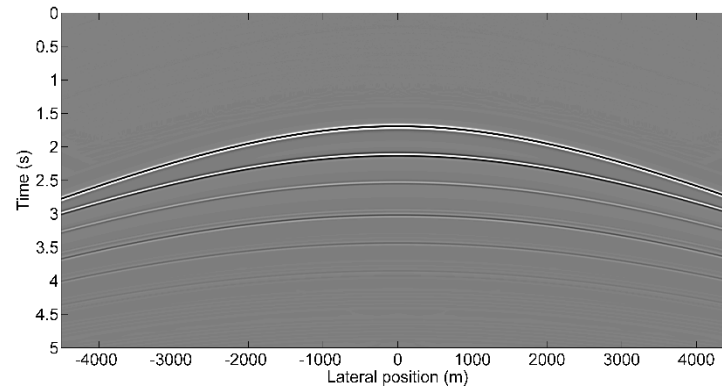


Fields of application



→ Detailed knowledge of the subsurface required

- Seismic data and images
- Marchenko redatuming and imaging
- Velocity analysis using redatumed data



Acquiring seismic data



Acquiring seismic data



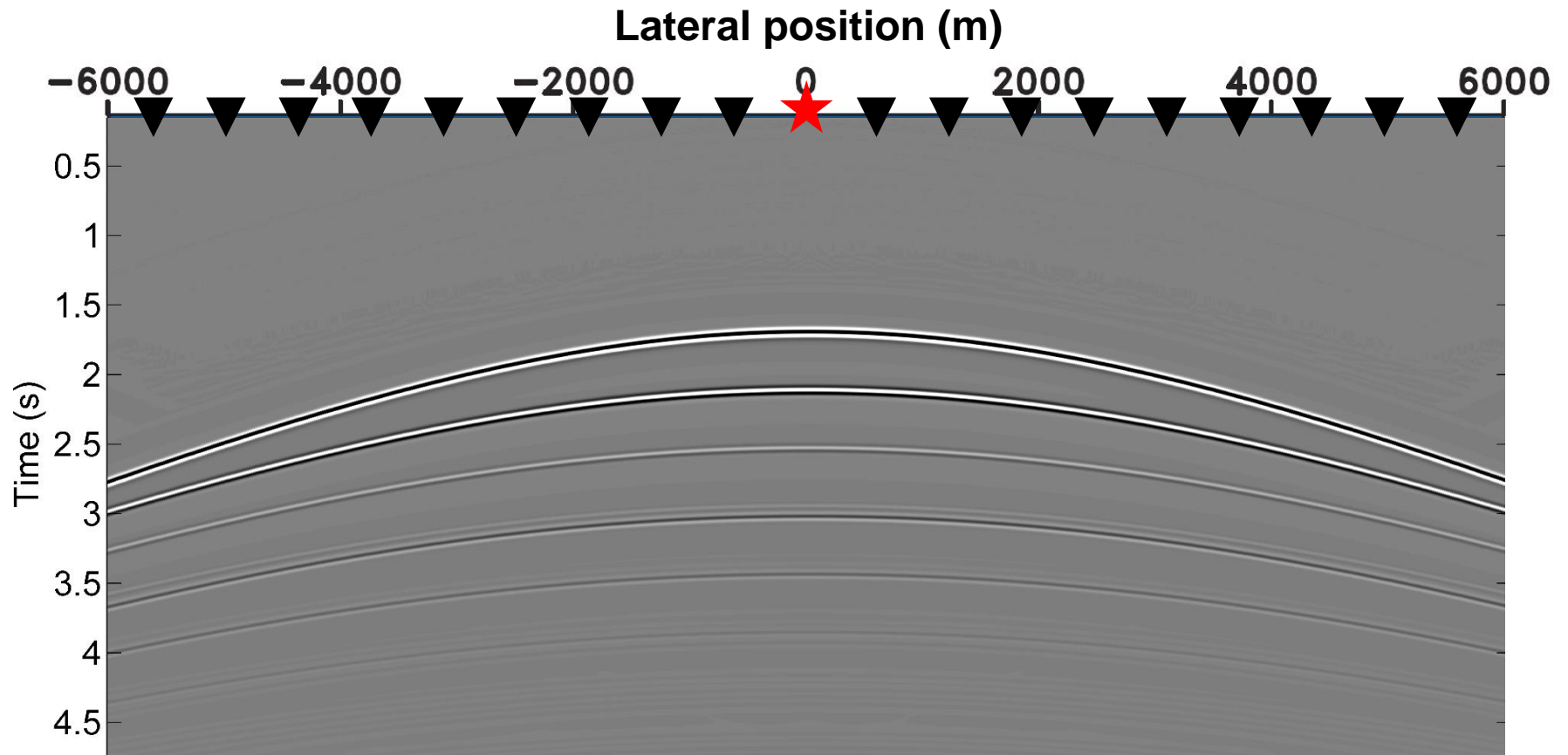
inforenews.co.nz



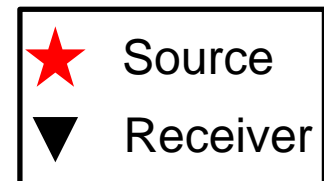
informatik.hu-berlin.de

| | |
|---|----------|
| ★ | Source |
| ▼ | Receiver |

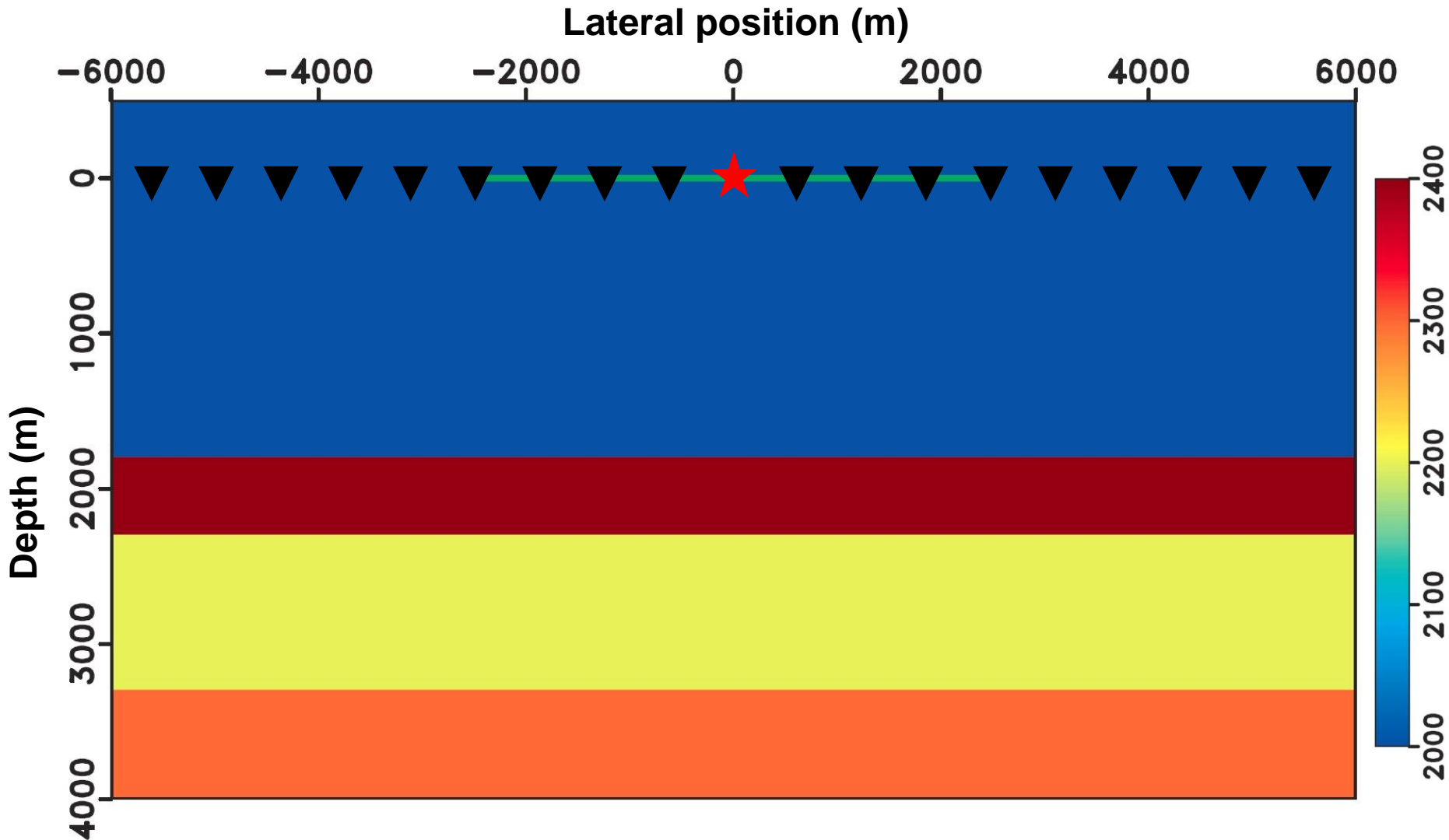
Acquiring seismic data



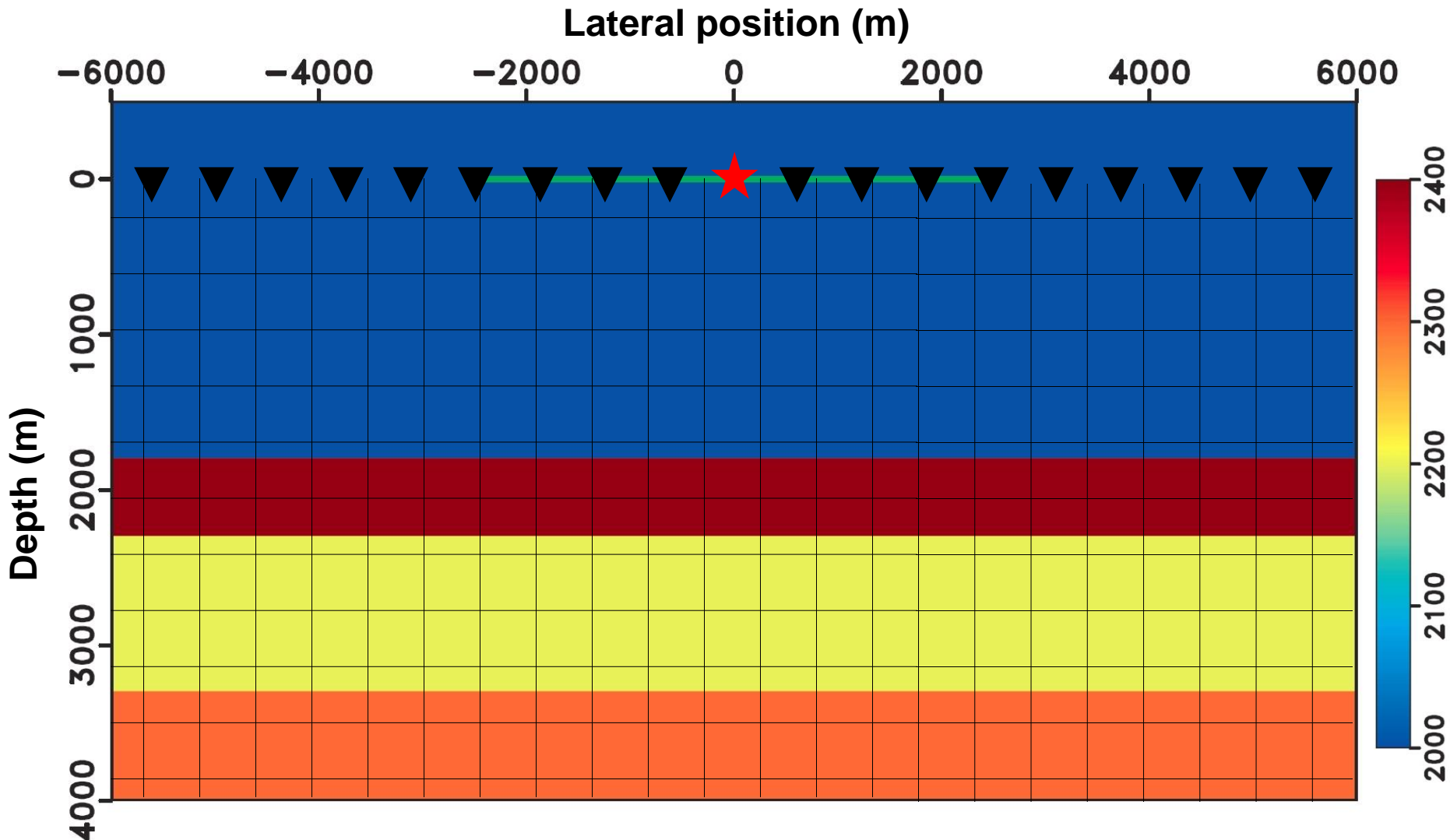
Surface reflection response for one source position



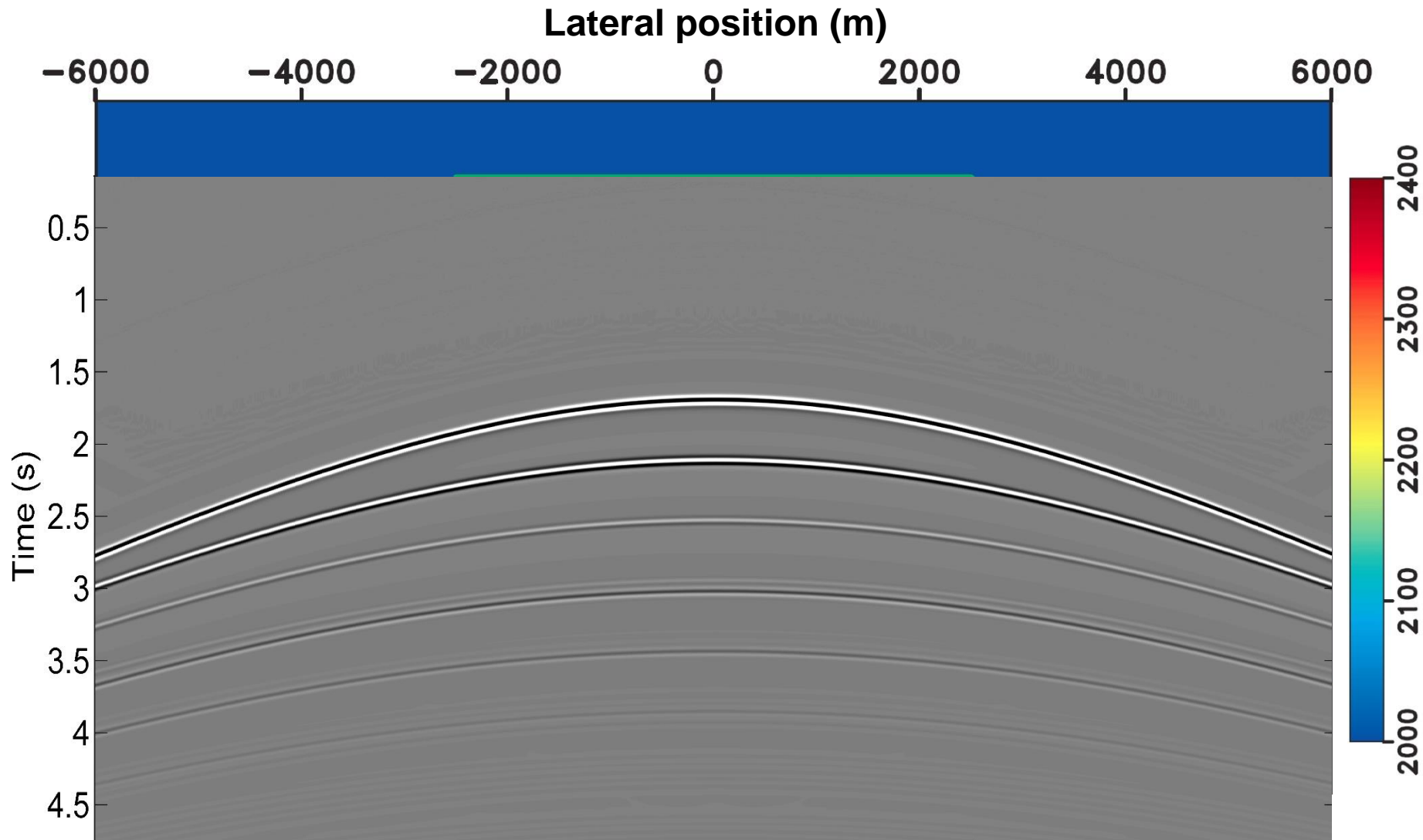
Modeling seismic data



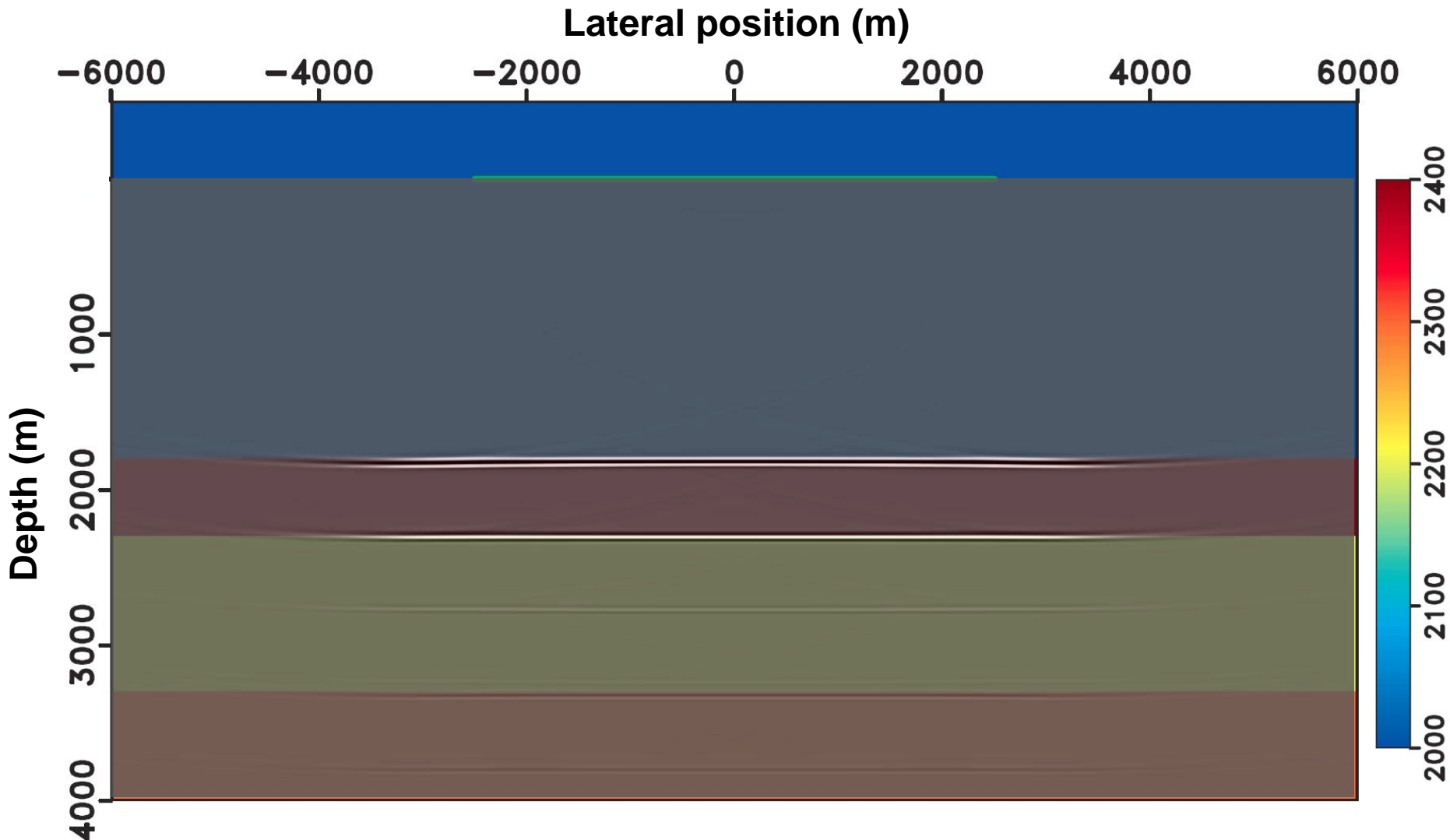
Modeling seismic data with finite differences



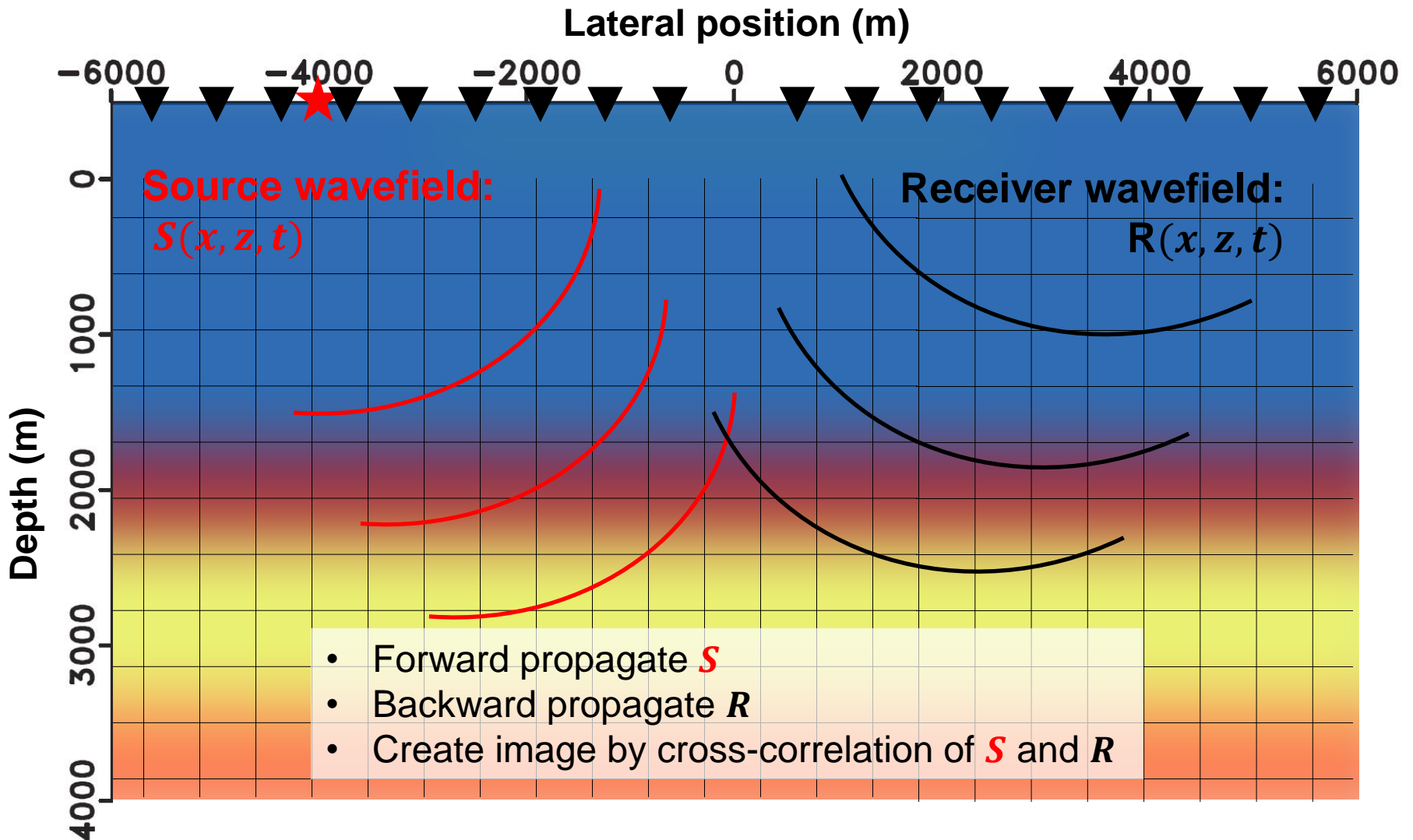
Modeling seismic data: data example



Modeling seismic data: image example



Creating images with seismic data: Reverse time migration (RTM)



Creating images with seismic data: Reverse time migration (RTM)

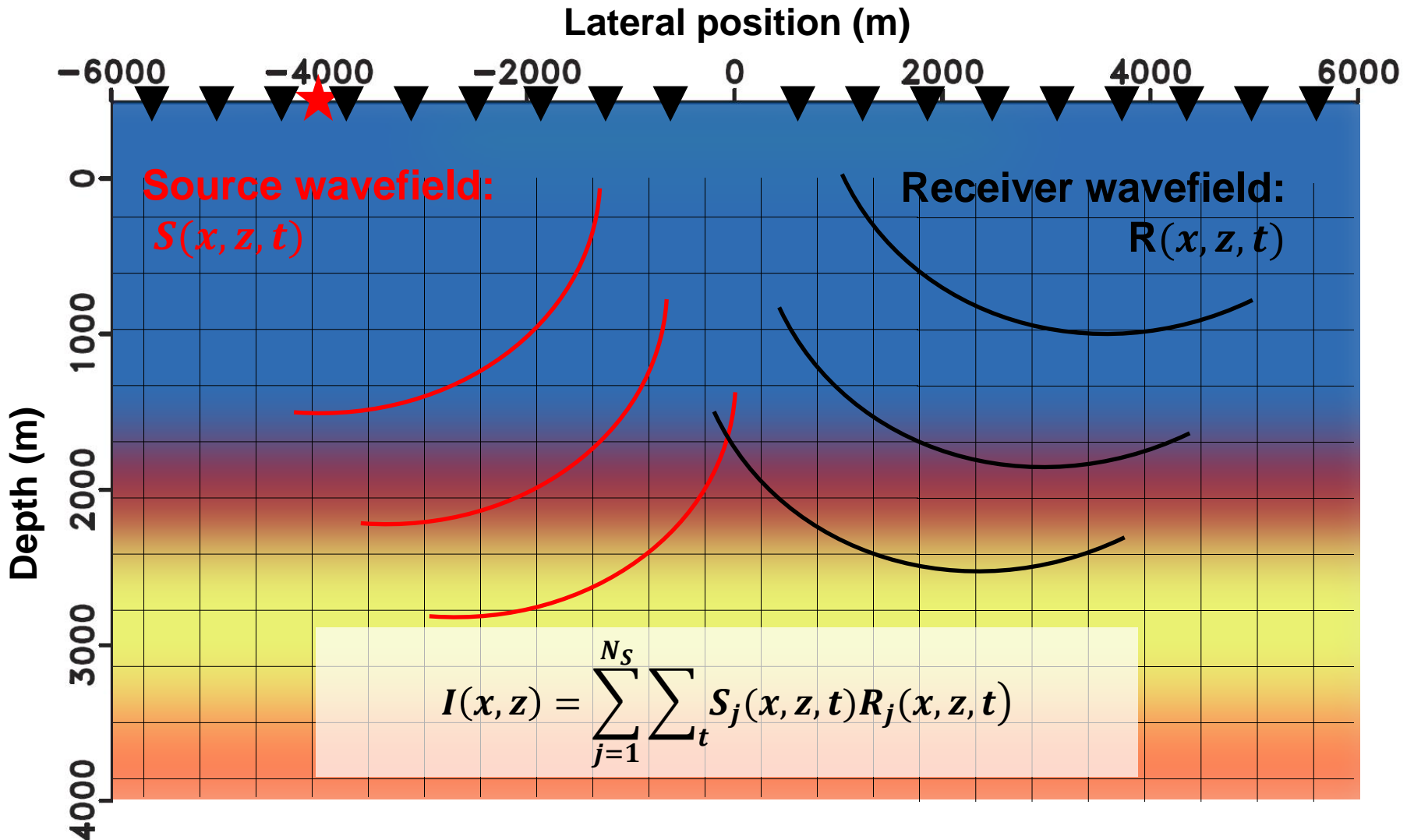


Image created with RTM and 901 shot positions

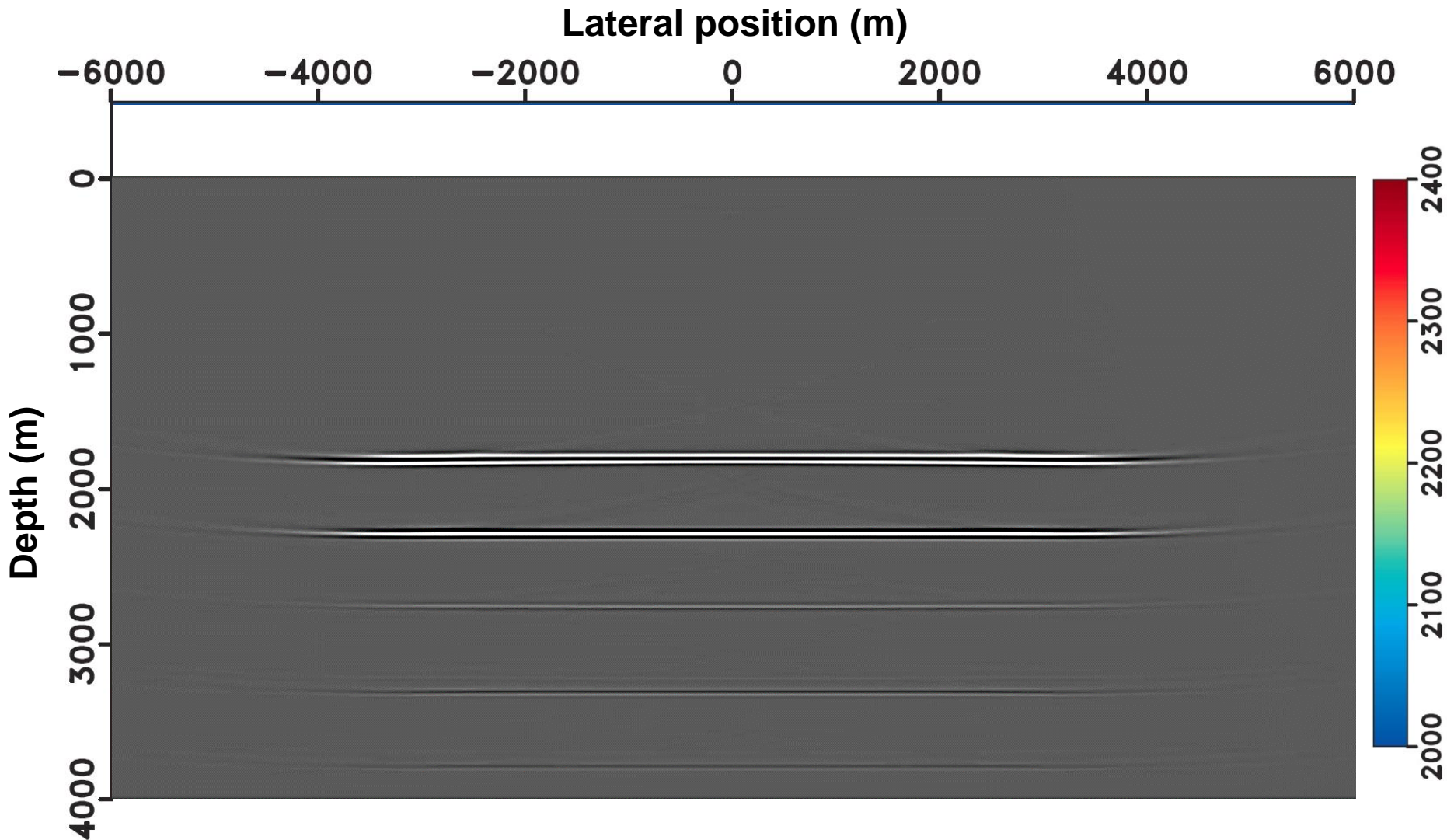


Image: primary reflections and internal multiples

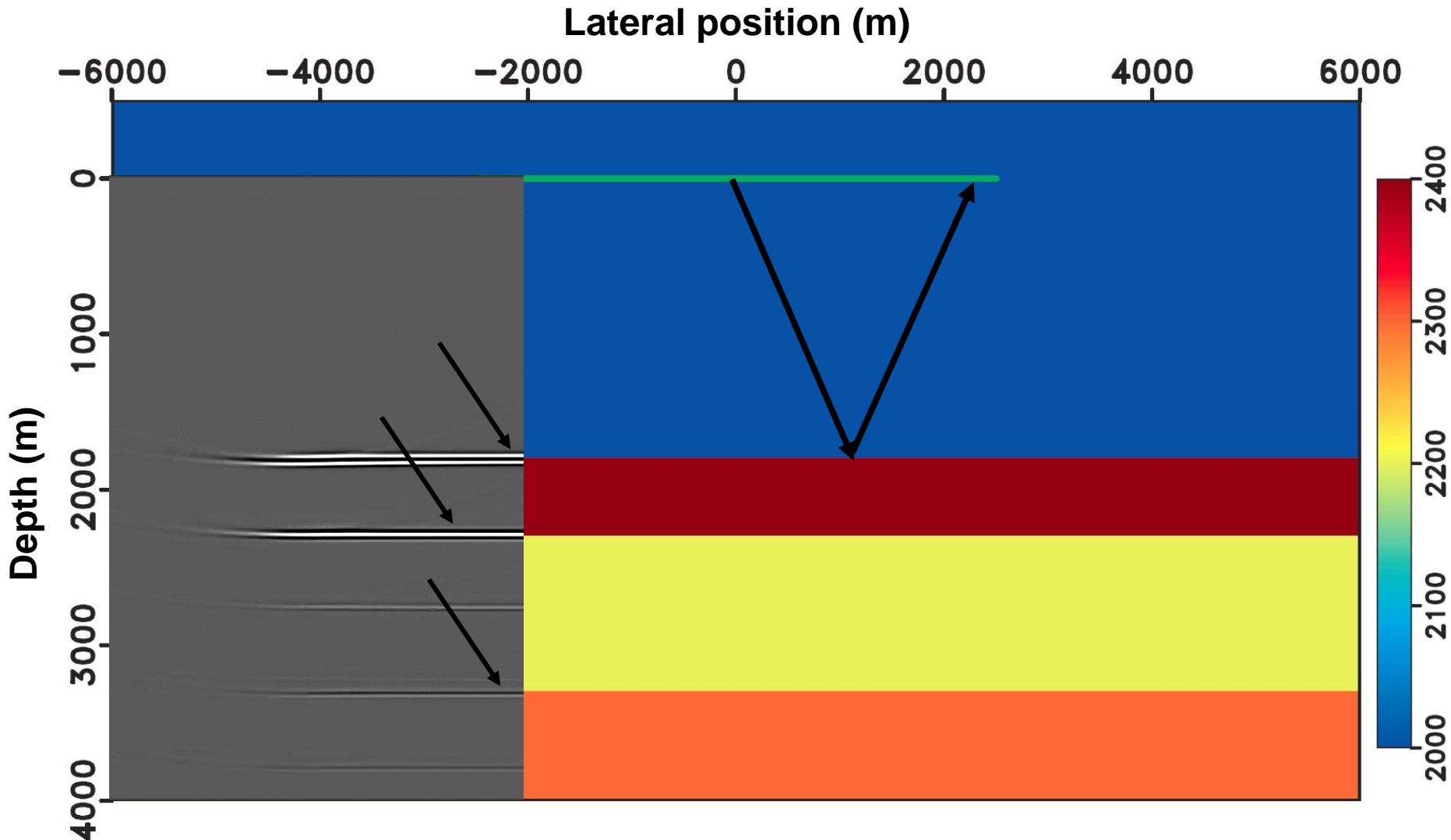


Image: primary reflections and internal multiples

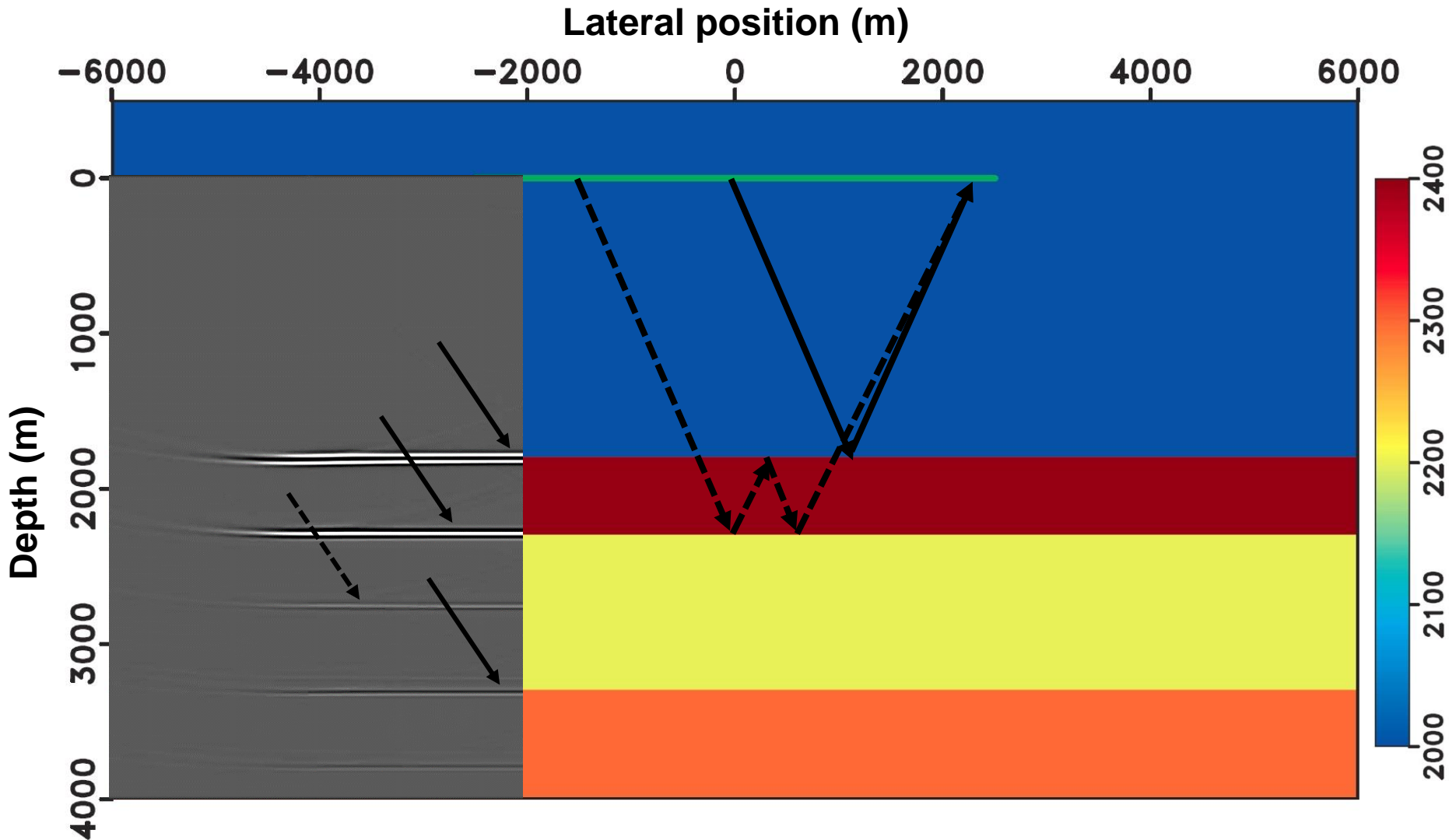


Image: primary reflections and internal multiples

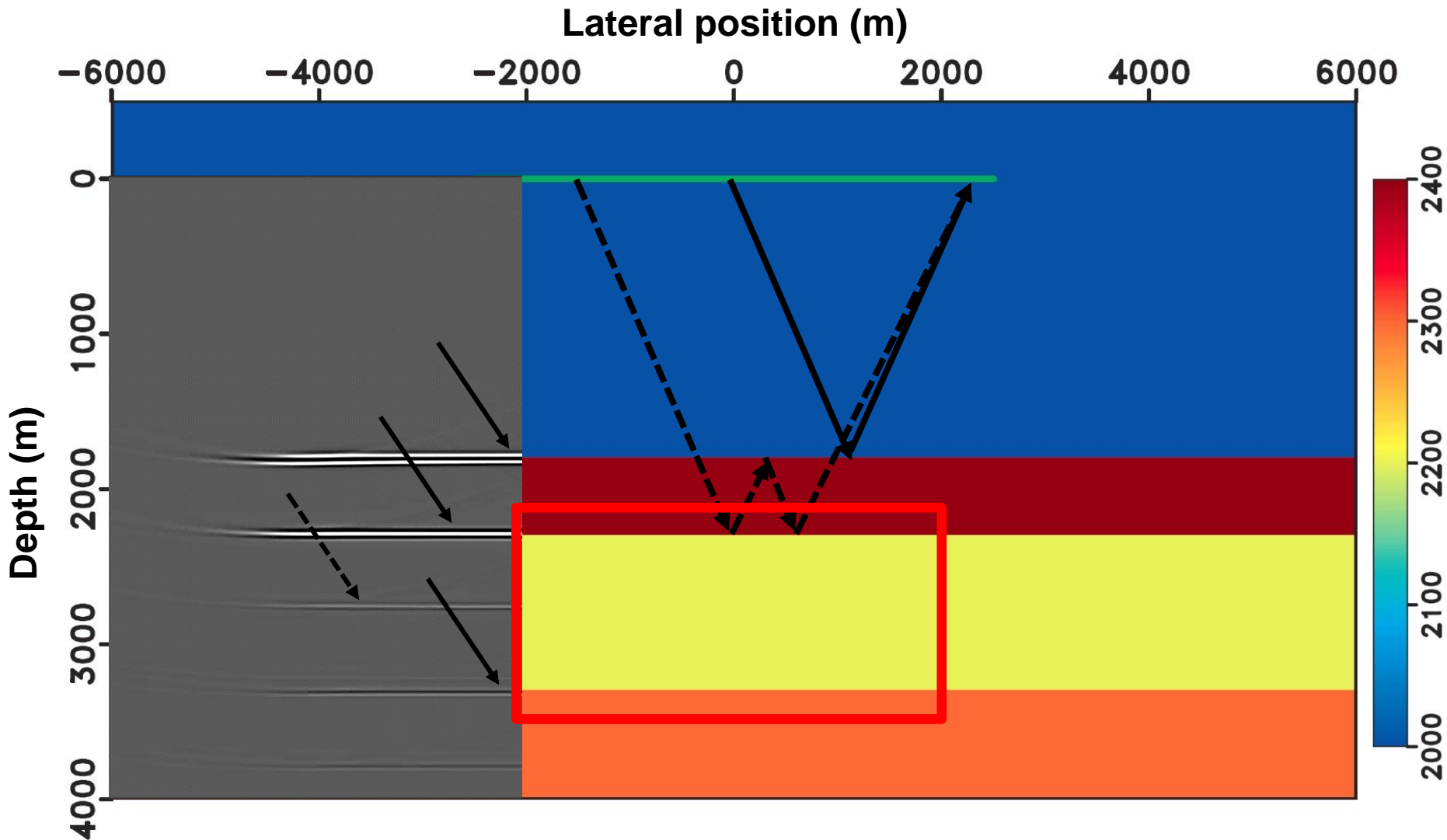
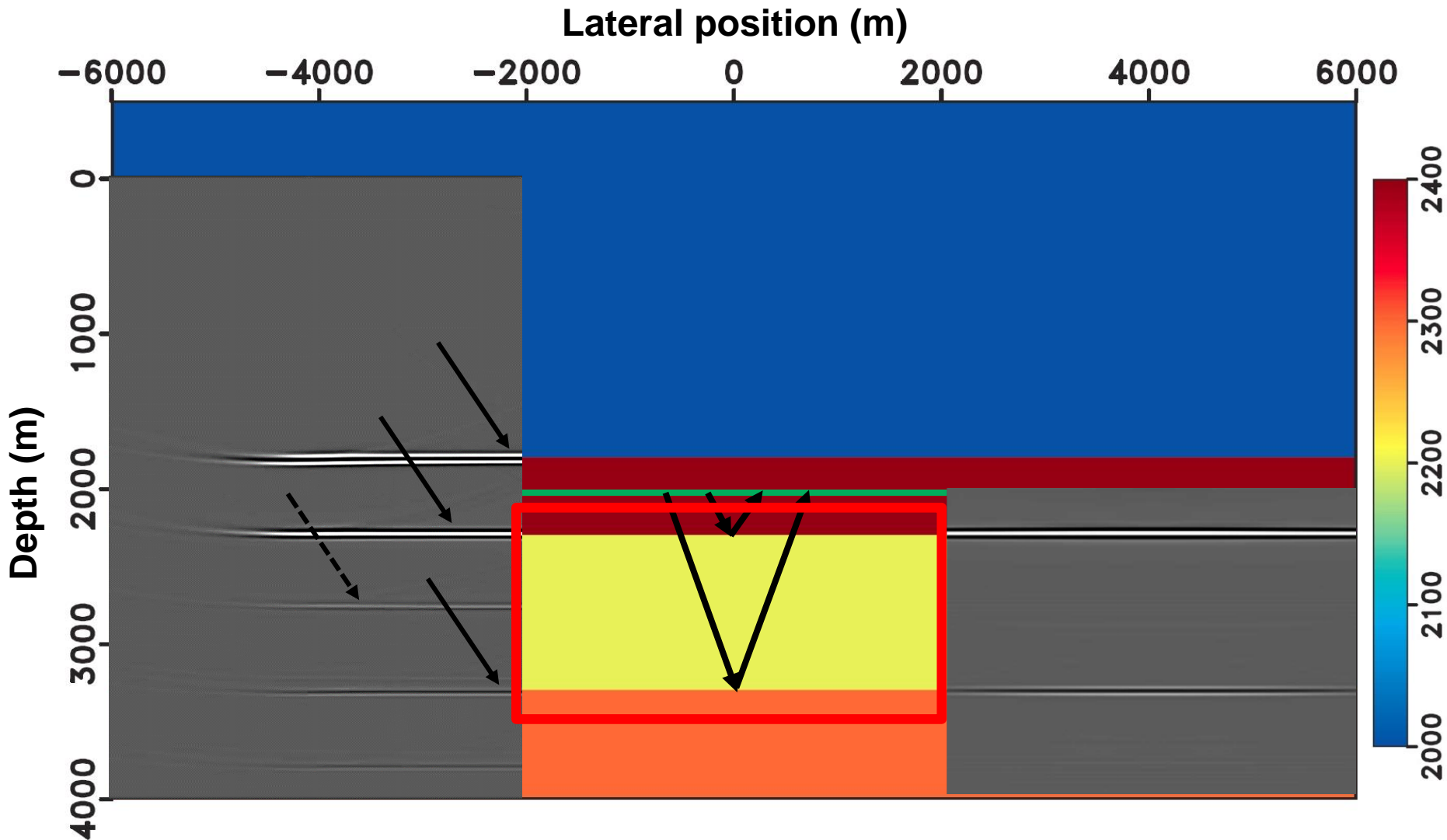
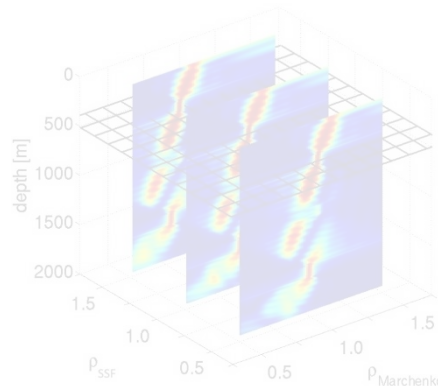
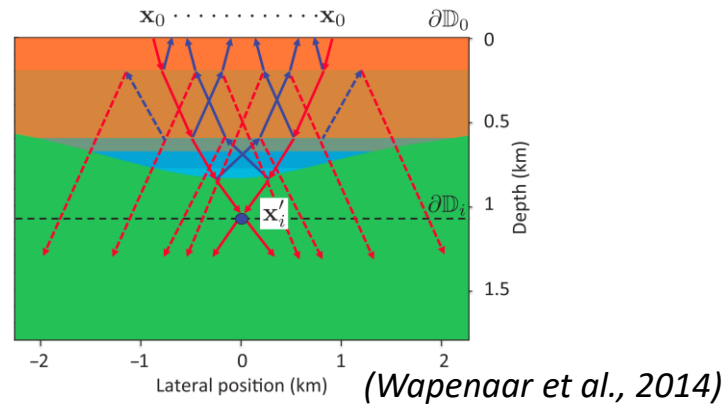
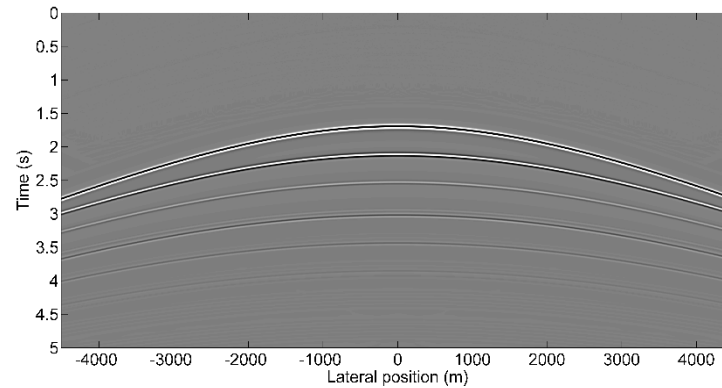


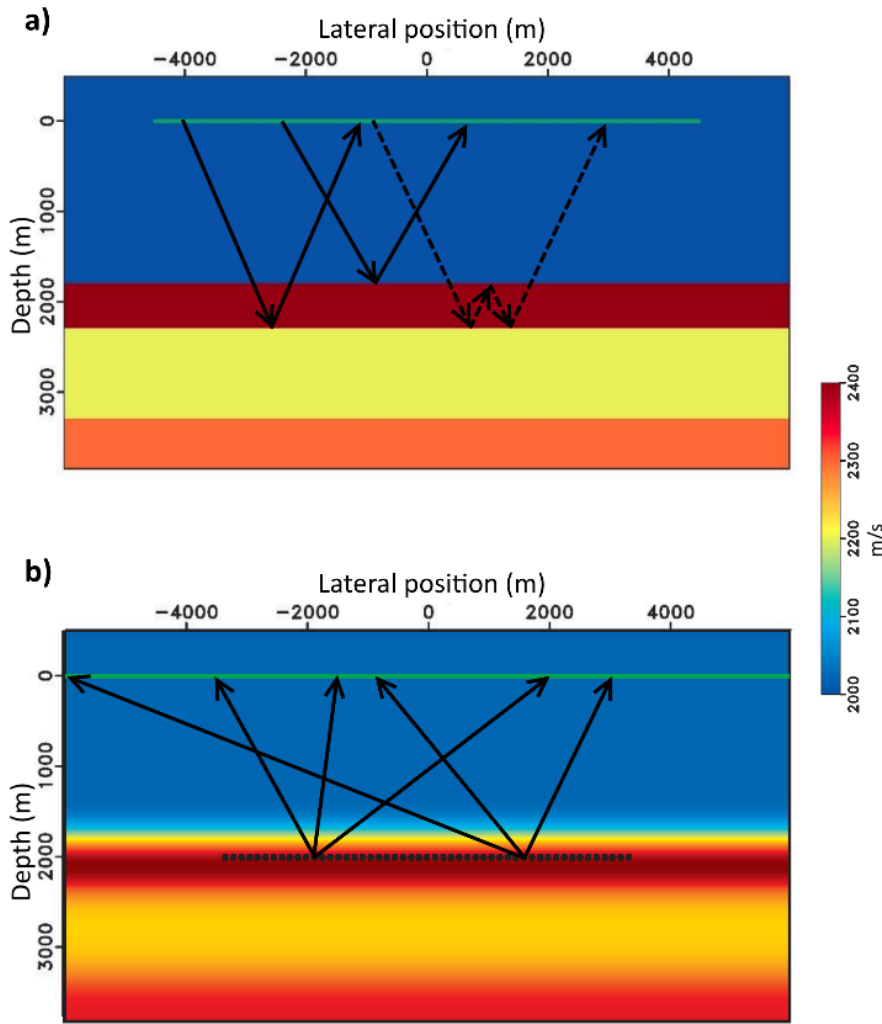
Image: sources and receivers in the subsurface



- Seismic data and images
- Marchenko redatuming and imaging
- Velocity analysis using redatumed data



Marchenko redatuming: a two-step redatuming process

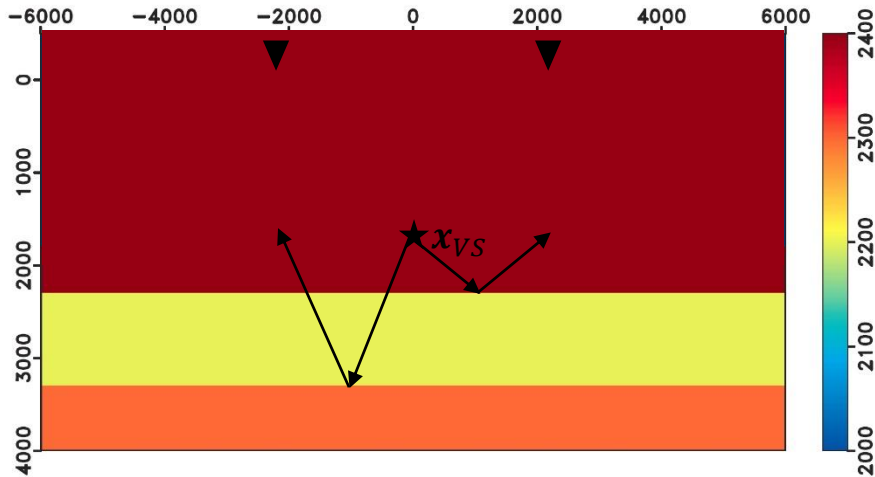


(Wapenaar et al., 2014; Broggini et al., 2014)

(i) Redatuming of sources (with an iterative Marchenko scheme)

- required inputs:
 - Surface reflection response (a)
 - Estimate of first arrival (b)
- results in $G^+(\mathbf{x}_{VS}, \mathbf{x}, t)$ and $G^-(\mathbf{x}_{VS}, \mathbf{x}, t)$

Marchenko redatuming: a two-step redatuming process

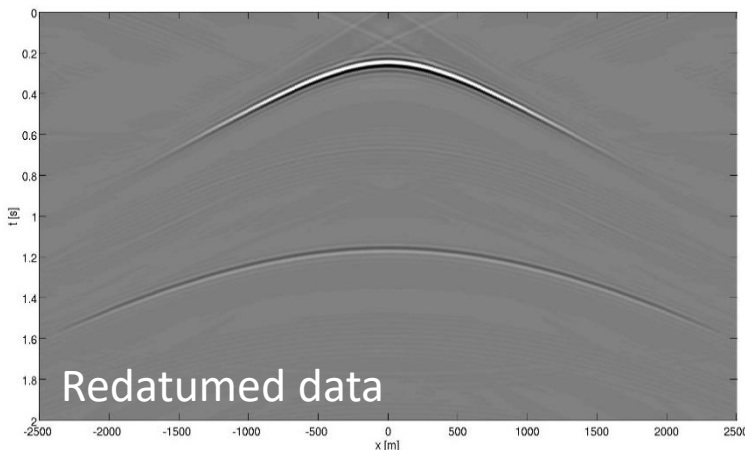


(i) Redatuming of sources (with an iterative Marchenko scheme)

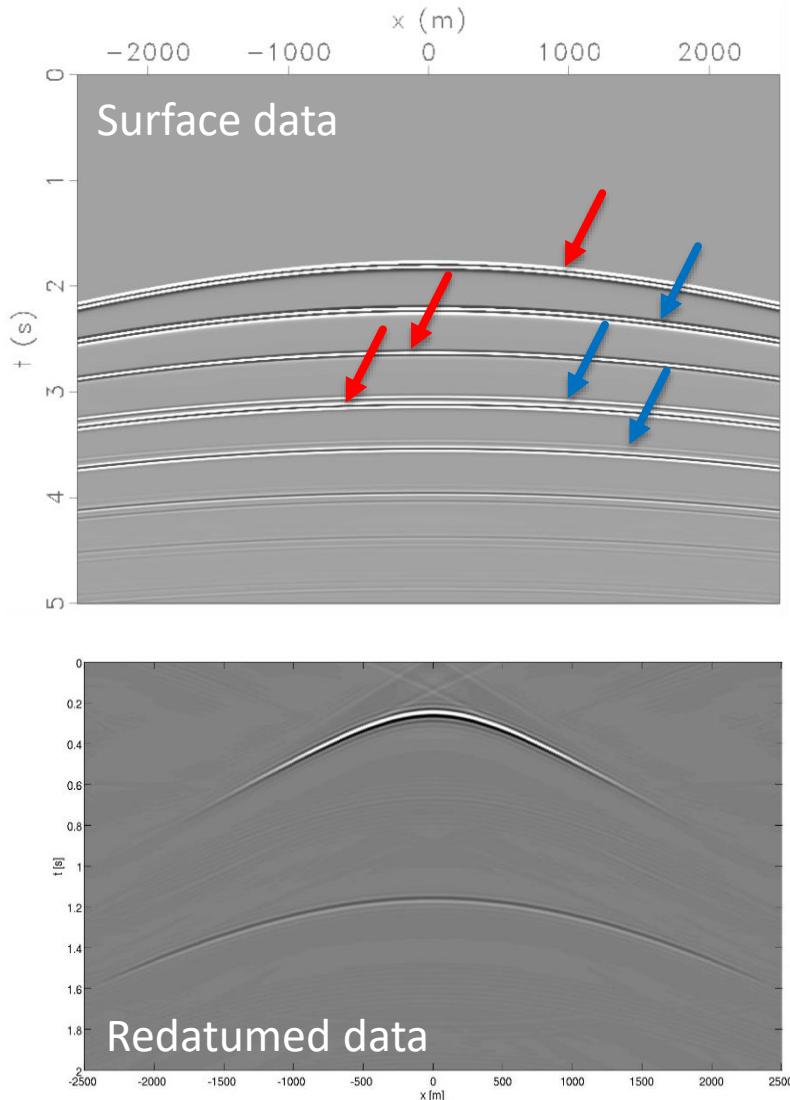
- required inputs:
 - Surface reflection response (a)
 - Estimate of first arrival (b)
- results in $G^+(\mathbf{x}_{VS}, \mathbf{x}, t)$ and $G^-(\mathbf{x}_{VS}, \mathbf{x}, t)$

(ii) Redatuming of receivers with multi-dimensional deconvolution (MDD)

- using $G^+(\mathbf{x}_{VS}, \mathbf{x}, t)$ and $G^-(\mathbf{x}_{VS}, \mathbf{x}, t)$
- results in reflection response for a medium with a homogenous overburden



Marchenko redatuming: a two-step redatuming process



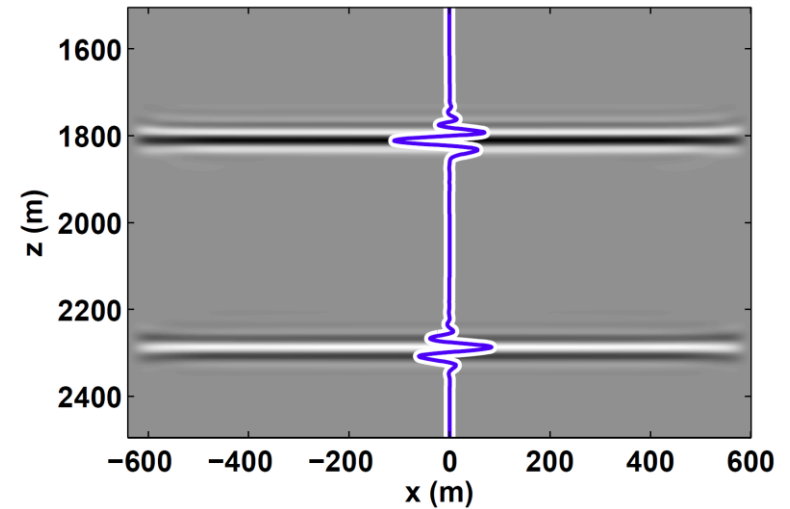
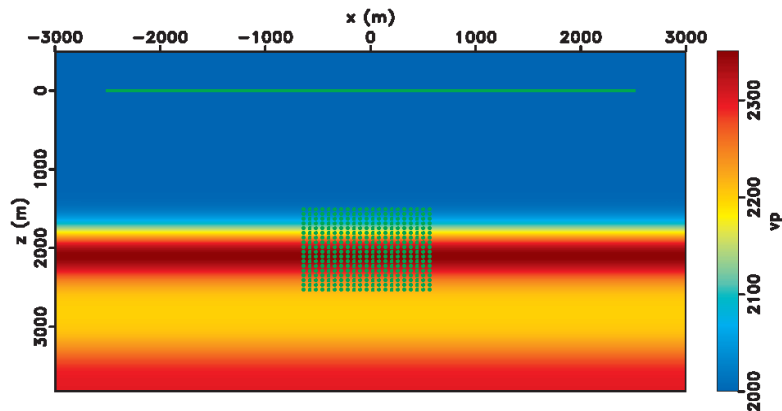
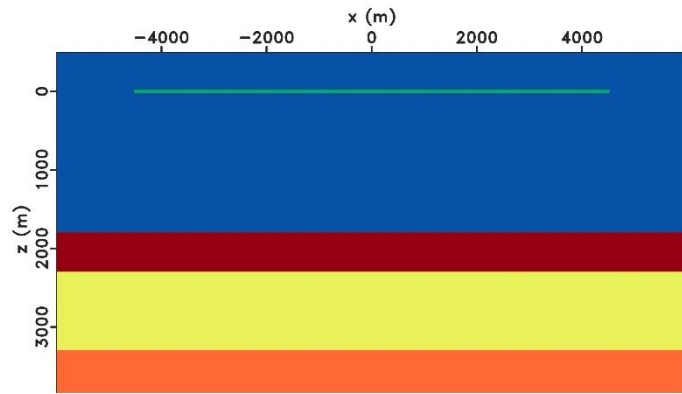
(i) Redatuming of sources (with an iterative Marchenko scheme)

- required inputs:
 - Surface reflection response (a)
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(ii) Redatuming of receivers with multi-dimensional deconvolution (MDD)

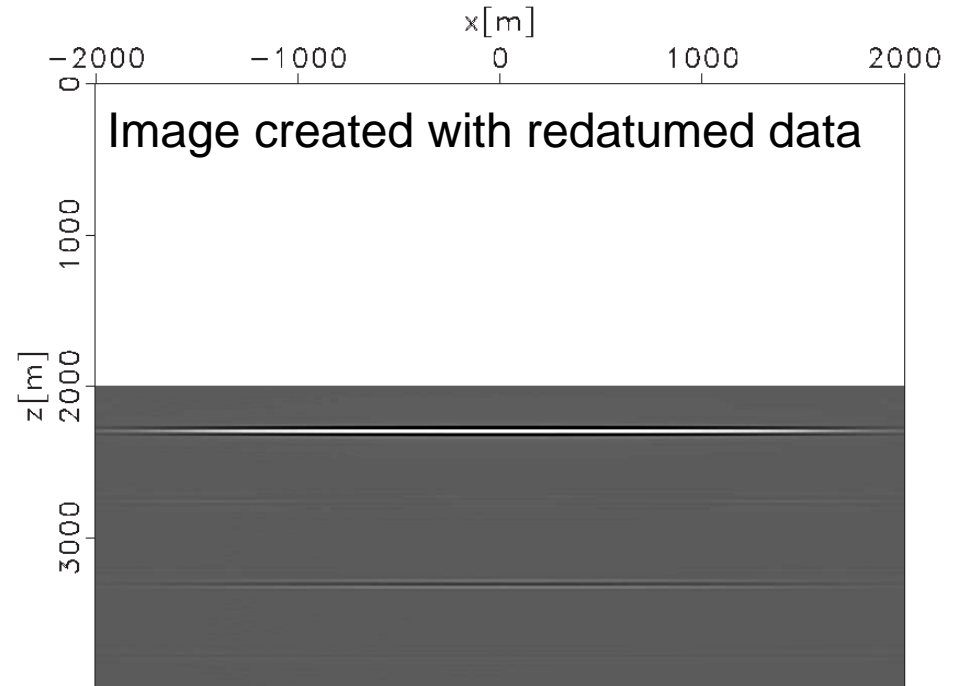
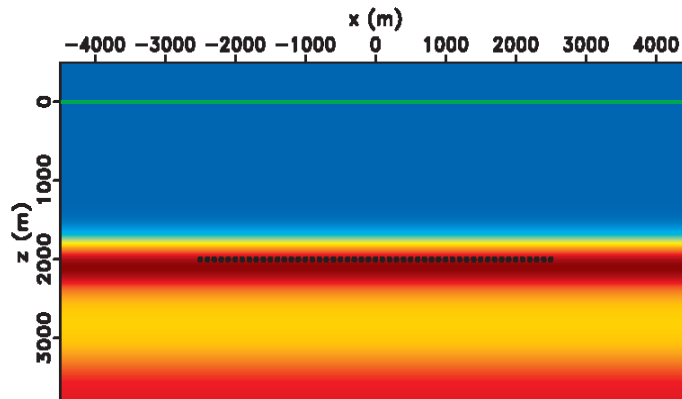
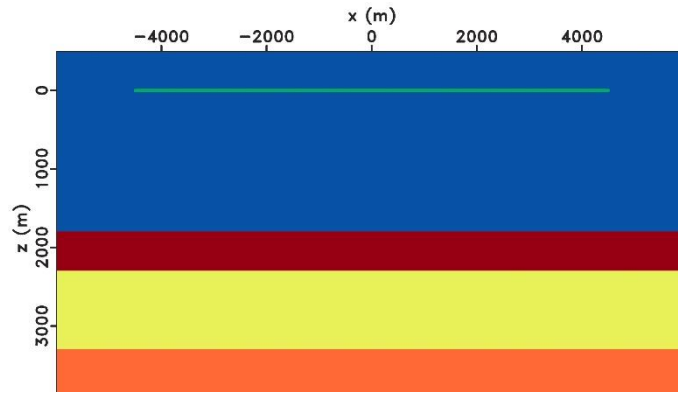
- using $G^+(\mathbf{x}_{VS}, \mathbf{x}, t)$ and $G^-(\mathbf{x}_{VS}, \mathbf{x}, t)$
- results in reflection response for a medium with a homogenous overburden

Marchenko redatuming:
imaging with MDD and a 2-D array of virtual sources



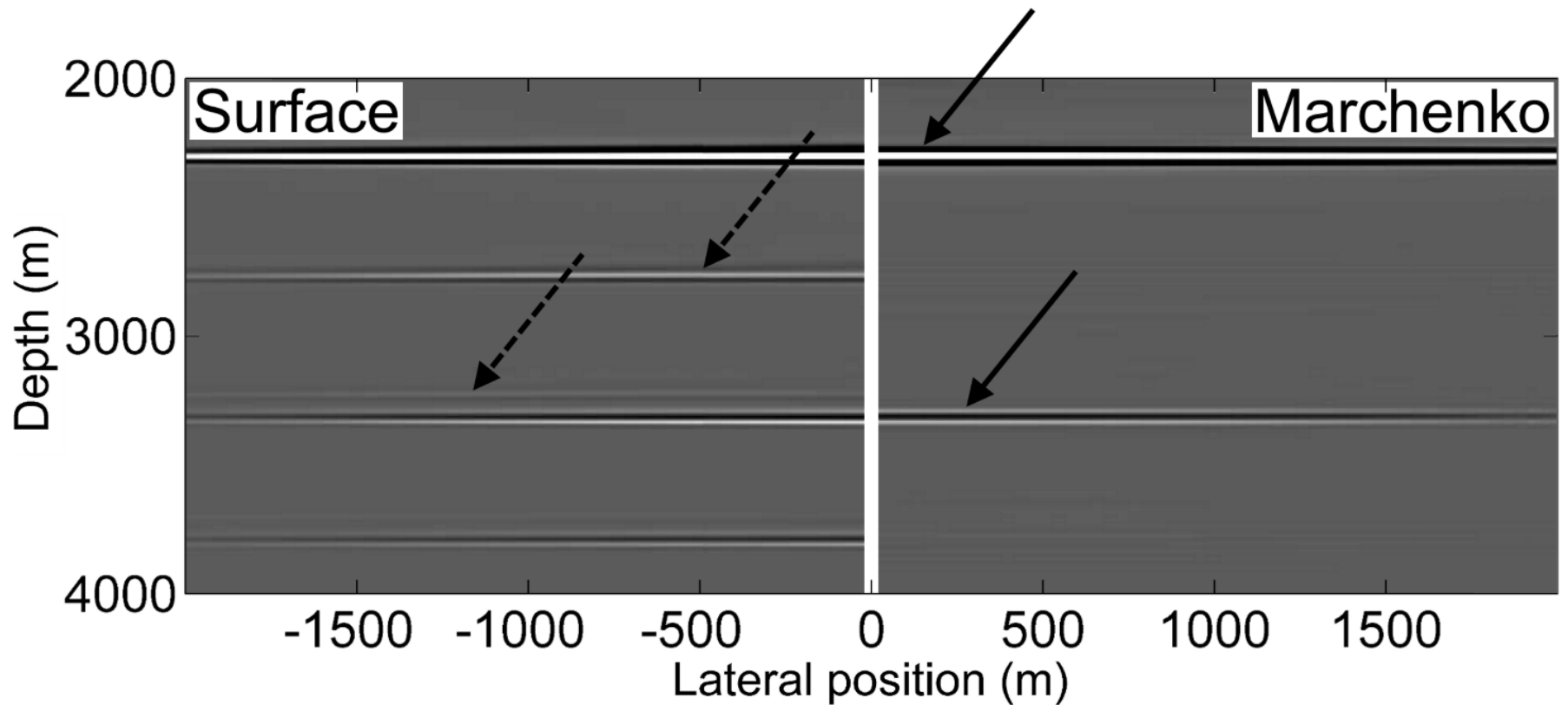
$t = x = 0$
component of redatumed
reflection response

Marchenko redatuming: imaging with MDD and RTM

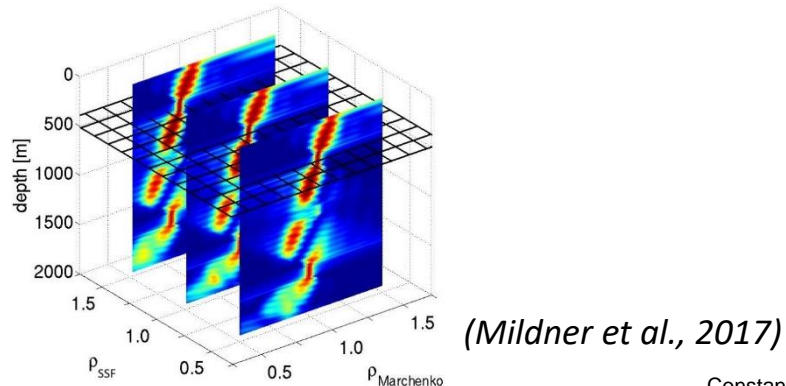
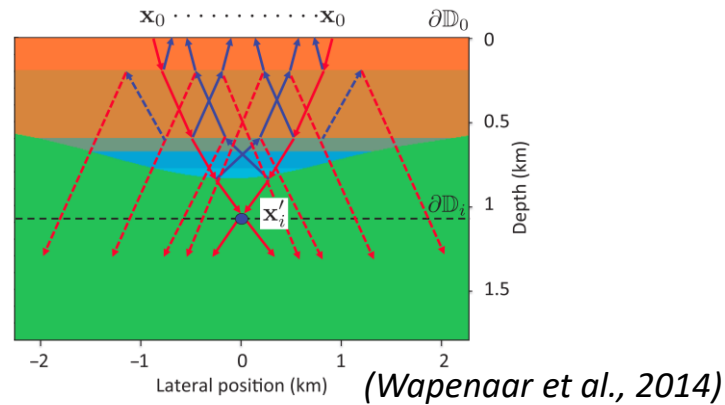
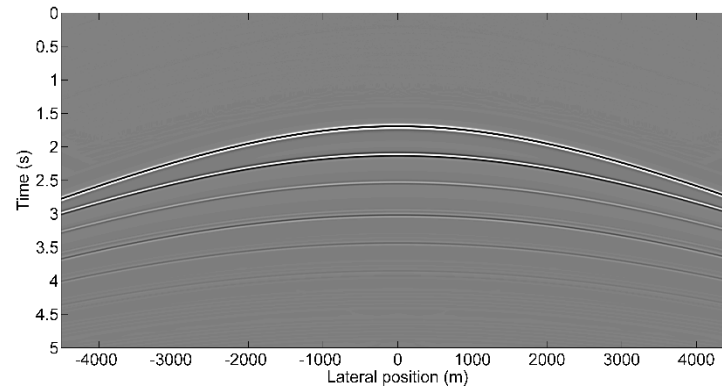


$$I(x, z) = \sum_{j=1}^{N_S} \sum_t S_j(x, z, t) R_j(x, z, t)$$

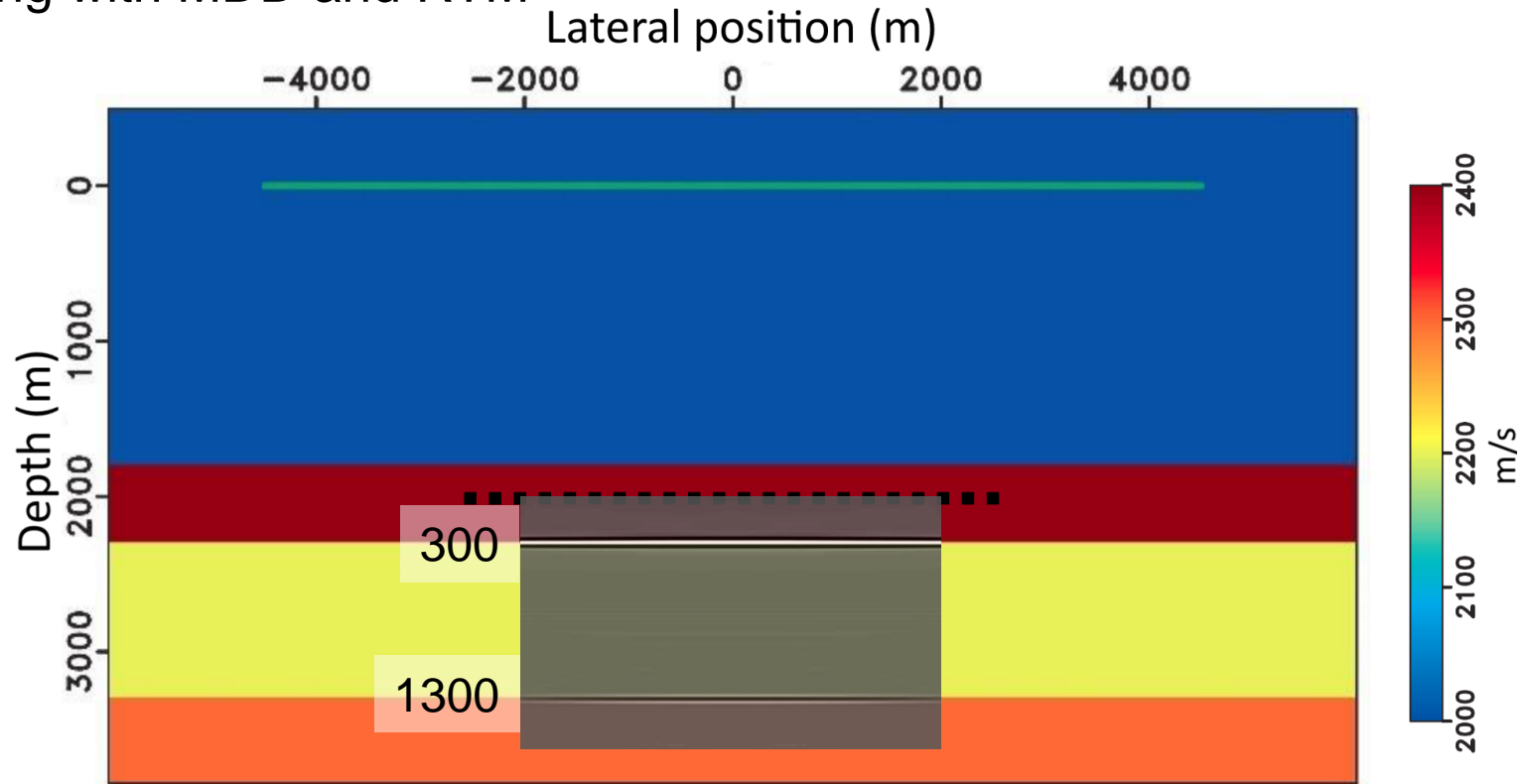
Images created with RTM using surface data and Marchenko-redatumed data



- Seismic data and images
- Marchenko redatuming and imaging
- Velocity analysis using redatumed data



Marchenko redatuming:
imaging with MDD and RTM



$$I(\mathbf{x}, z) = \sum_{j=1}^{N_S} \sum_t \mathcal{S}_j(\mathbf{x}, z, t) \mathcal{R}_j(\mathbf{x}, z, t)$$

Velocity analysis using redatumed data
Angle-domain common image gathers (ADCIG)

$$I(\mathbf{x}, \mathbf{z}) = \sum_{j=1}^{N_S} \sum_t \mathbf{S}_j(\mathbf{x}, \mathbf{z}, t) \mathbf{R}_j(\mathbf{x}, \mathbf{z}, t)$$

(Sava and Fomel, 2006)

Velocity analysis using redatumed data
Angle-domain common image gathers (ADCIG)

$$I(\mathbf{x}, \mathbf{z}, \mathbf{h}) = \sum_{j=1}^{N_S} \sum_t S_j(\mathbf{x} - \mathbf{h}, \mathbf{z}, t) R_j(\mathbf{x} + \mathbf{h}, \mathbf{z}, t)$$

(Sava and Fomel, 2006)

Velocity analysis using redatumed data
Angle-domain common image gathers (ADCIG)

$$I(\mathbf{x}, \mathbf{z}, \mathbf{h}) = \sum_{j=1}^{N_S} \sum_t S_j(\mathbf{x} - \mathbf{h}, \mathbf{z}, t) R_j(\mathbf{x} + \mathbf{h}, \mathbf{z}, t)$$

↓ slant stacking

$$I(\mathbf{x}, \bar{\mathbf{z}}, \mathbf{p}) = \int d\mathbf{h} \int d\mathbf{z} \delta(\mathbf{z} - \bar{\mathbf{z}} - \mathbf{p}\mathbf{h}) I(\mathbf{x}, \mathbf{z}, \mathbf{h})$$

(Sava and Fomel, 2006)

Velocity analysis using redatumed data
Angle-domain common image gathers (ADCIG)

$$I(\mathbf{x}, \mathbf{z}, \mathbf{h}) = \sum_{j=1}^{N_S} \sum_t S_j(\mathbf{x} - \mathbf{h}, \mathbf{z}, t) R_j(\mathbf{x} + \mathbf{h}, \mathbf{z}, t)$$

slant stacking

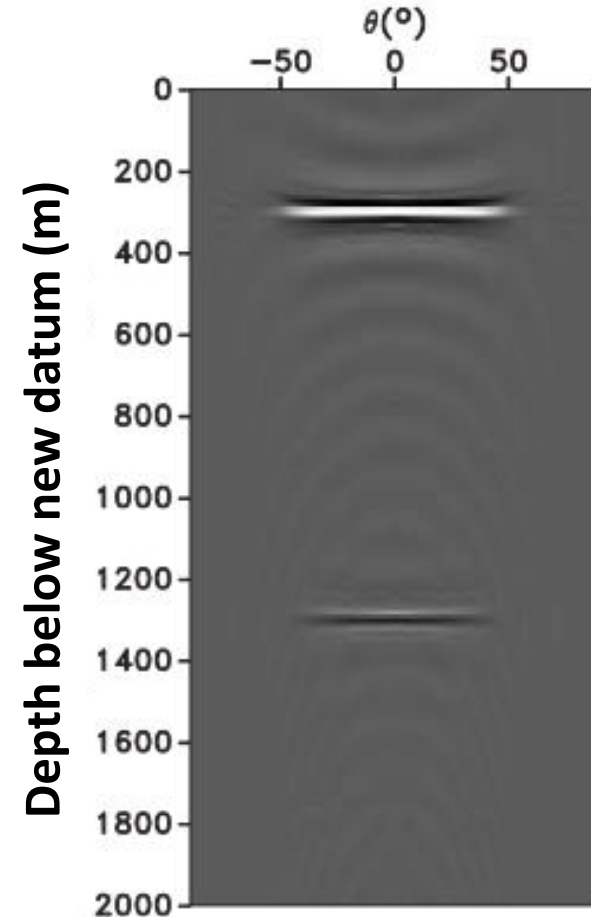
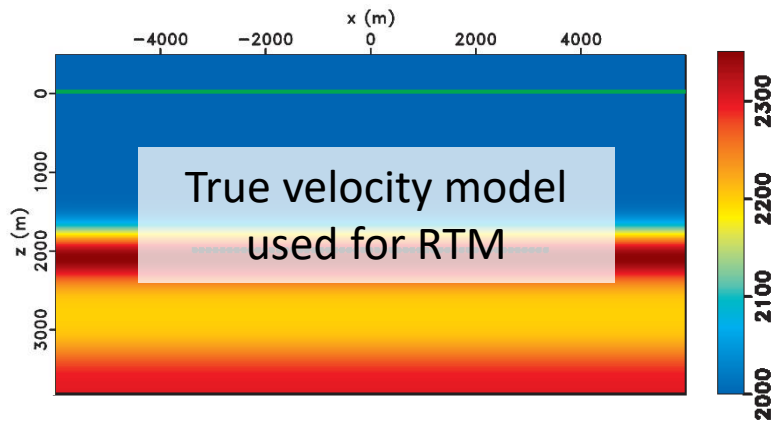
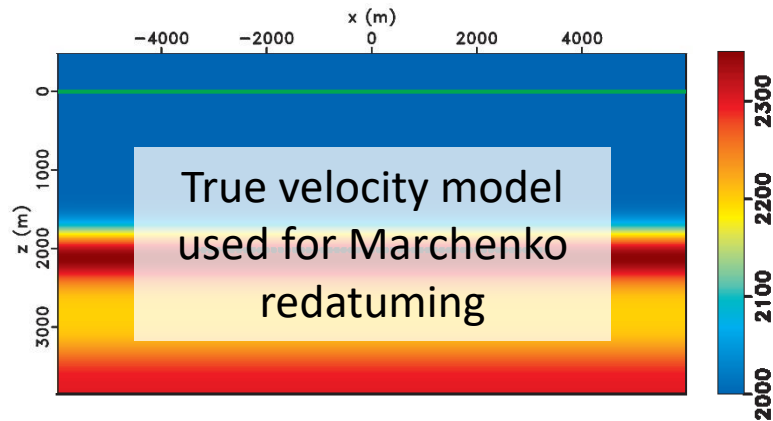
$$I(\mathbf{x}, \bar{\mathbf{z}}, \mathbf{p}) = \int d\mathbf{h} \int d\mathbf{z} \delta(\mathbf{z} - \bar{\mathbf{z}} - \mathbf{p}\mathbf{h}) I(\mathbf{x}, \mathbf{z}, \mathbf{h})$$

$$p = -\tan \theta = \frac{\partial z}{\partial h}$$

Angle-domain common image gather $I(\mathbf{x}, \bar{\mathbf{z}}, \theta)$

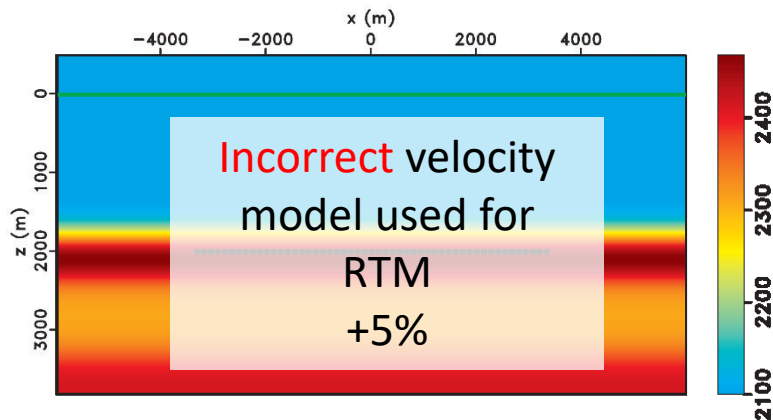
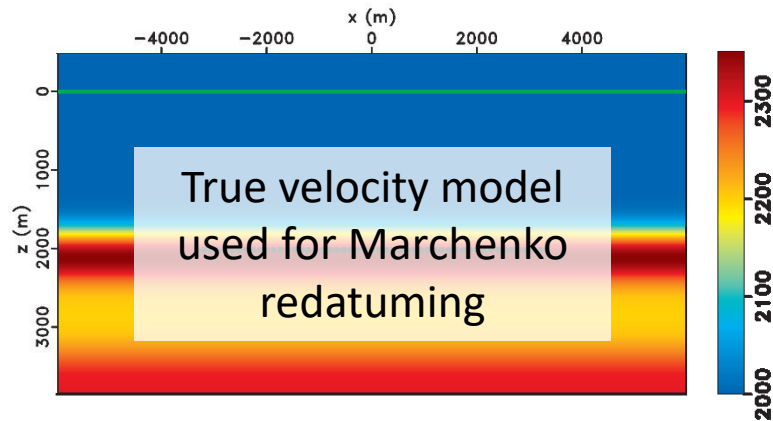
(Sava and Fomel, 2006)

Velocity analysis using redatumed data ADCIG using true velocities

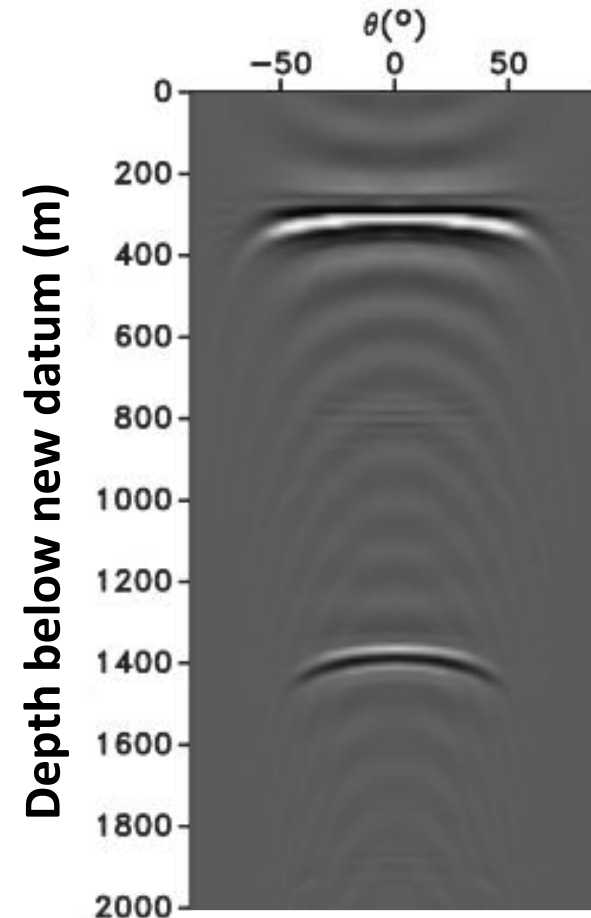


→ Flat reflections

Velocity analysis using redatumed data ADCIG using incorrect velocities for RTM



→ Residual moveout



Velocity analysis using redatumed data

Residual moveout for velocity correction

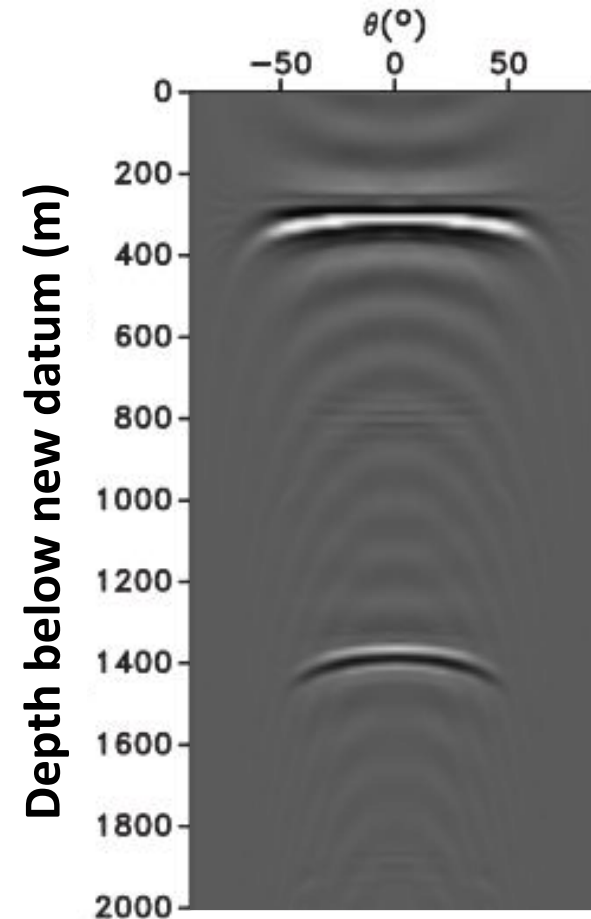
Residual moveout in ADCIG's
(Biondi and Symes, 2004):

$$\Delta \mathbf{n}_{RMO} = (\rho - 1) \tan^2(\theta) z_0 \mathbf{n}$$

z_0 : depth of reflector at $\theta = 0$

$$\text{Slowness ratio } \rho = \frac{p_{\text{wrong}}}{p_{\text{true}}} \approx 0.95$$

$$\text{Slowness } p = \frac{1}{v}$$

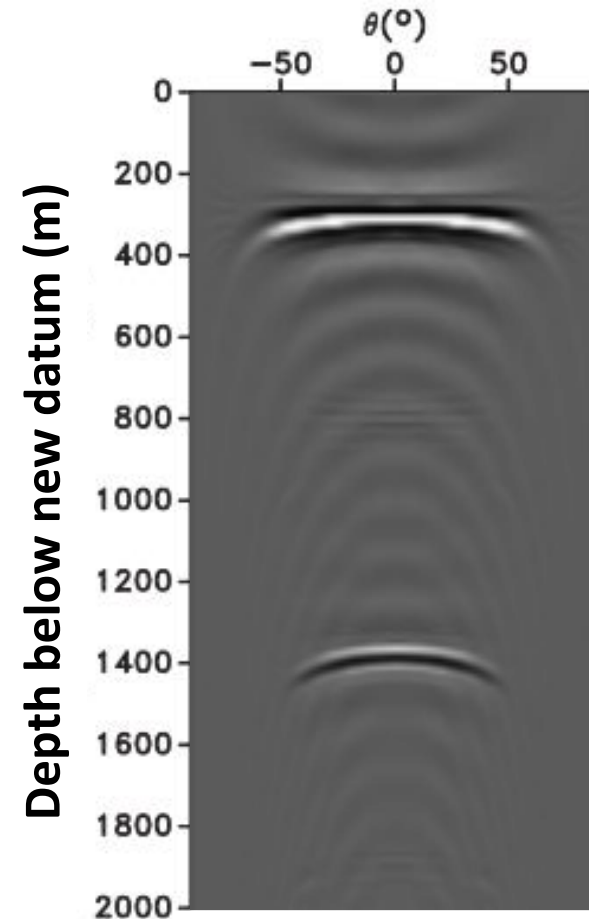


Velocity analysis using redatumed data

Residual moveout for velocity correction: semblance based analysis

Semblance: Quantitative measure of the coherence of seismic data

$$\Delta \mathbf{n}_{RMO} = (\rho - 1) \tan^2(\theta) z_0 \mathbf{n}$$



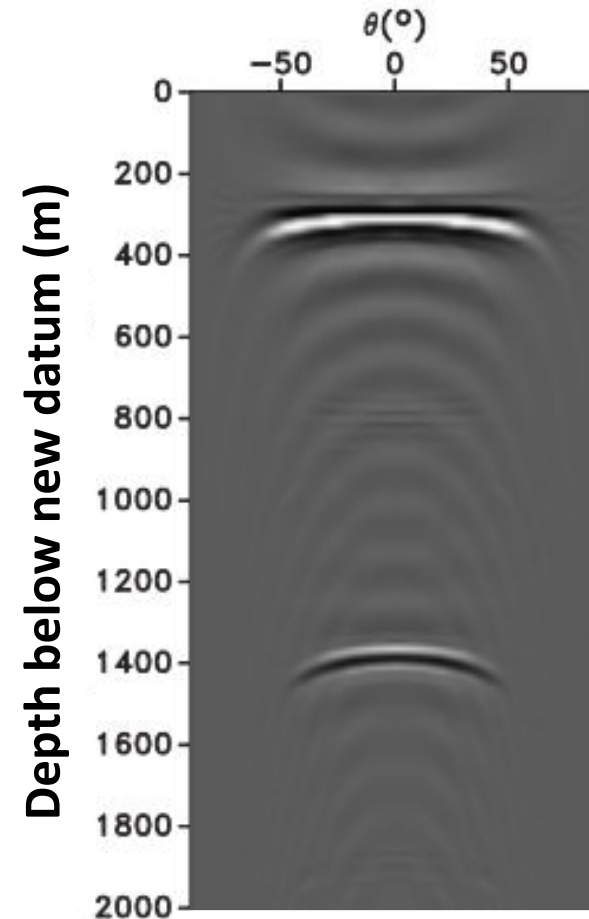
Velocity analysis using redatumed data

Residual moveout for velocity correction: semblance based analysis

Semblance: Quantitative measure of the coherence of seismic data

$$\Delta \mathbf{n}_{RMO} = (\rho - 1) \tan^2(\theta) z_0 \mathbf{n}$$

1. Correct moveout in ADCIG for different trial slowness ratios ρ
2. Calculate semblance $S(z, \rho)$ for each event in the ADCIG (z_0)
3. Obtain slowness ratio ρ by picking $\rho(\text{semblance} = \text{max})$



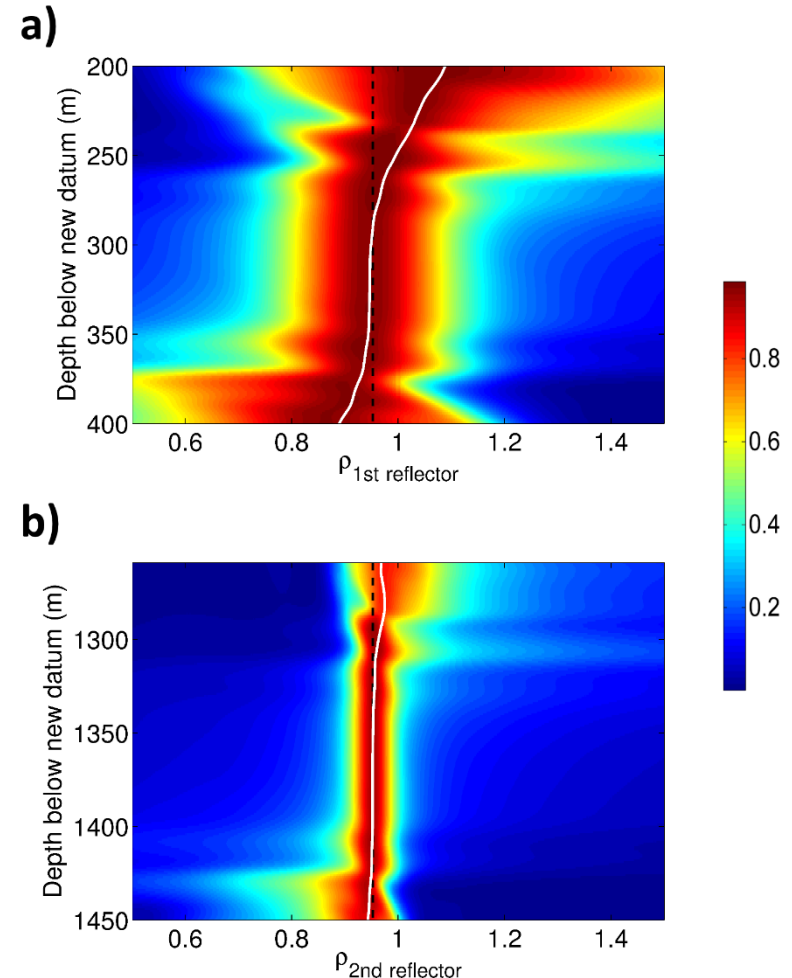
Velocity analysis using redatumed data

Residual moveout for velocity correction: semblance based analysis

Semblance: Quantitative measure of the coherence of seismic data

$$\Delta \mathbf{n}_{RMO} = (\rho - 1) \tan^2(\theta) z_0 \mathbf{n}$$

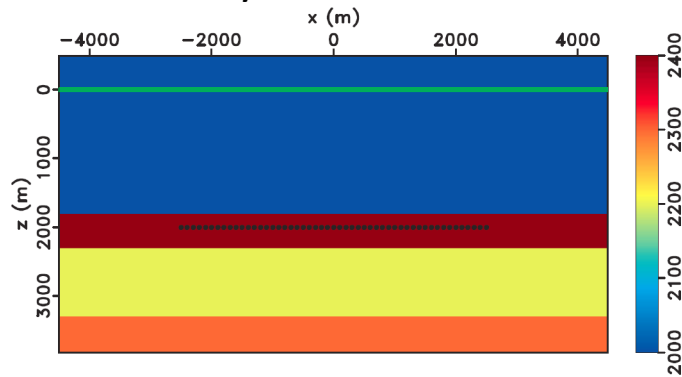
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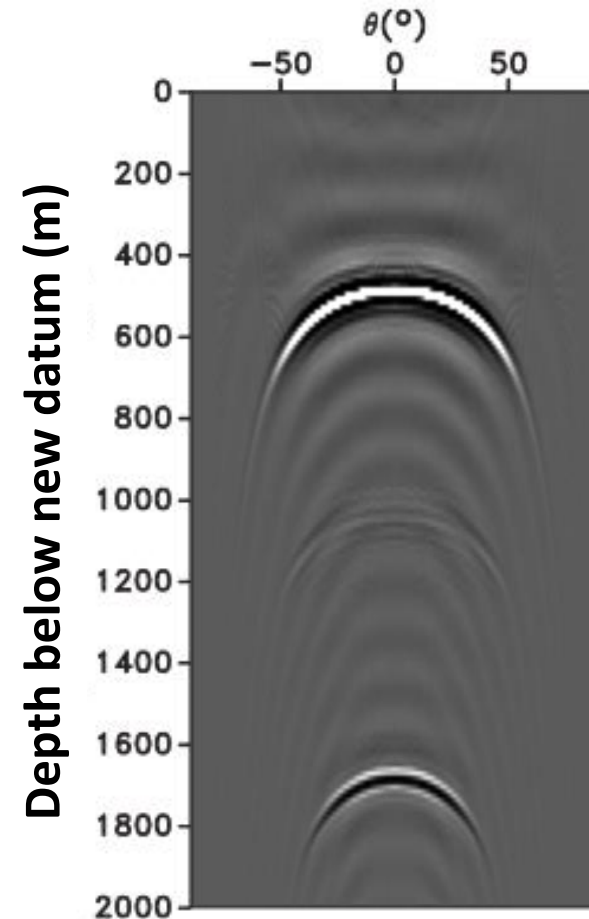
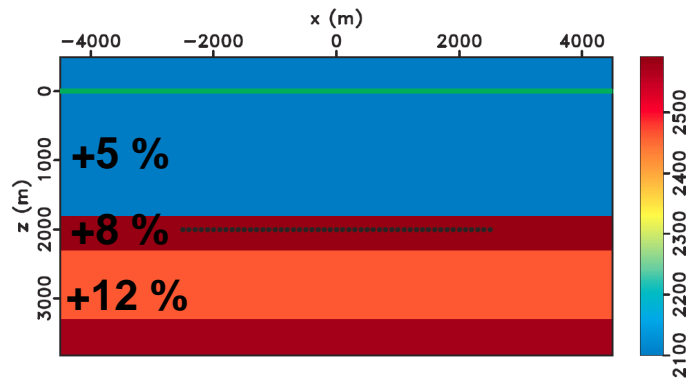
Velocity analysis using redatumed data

Incorrect velocities for redatuming and RTM

True velocity model



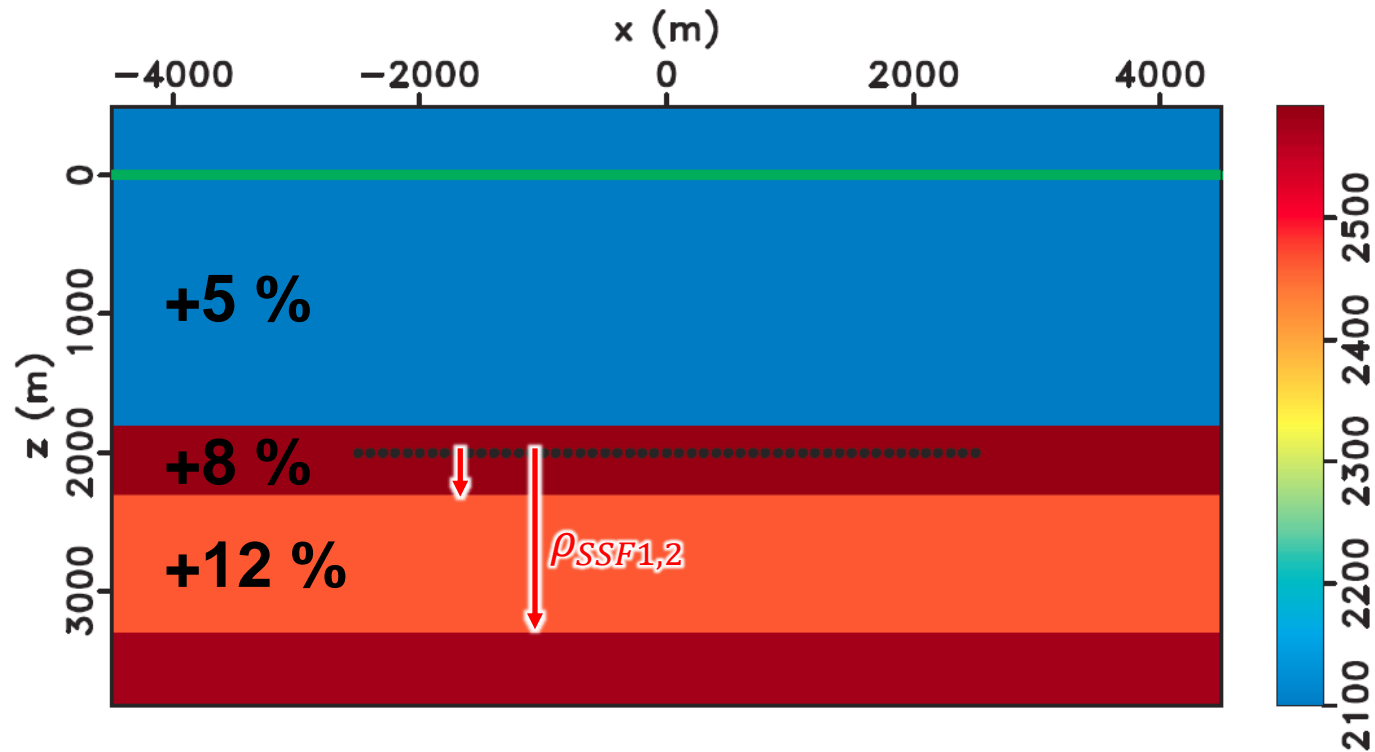
Incorrect velocity model used for redatuming and migration



Velocity analysis using redatumed data
 Incorrect velocities for redatuming and RTM

Residual moveout equation:

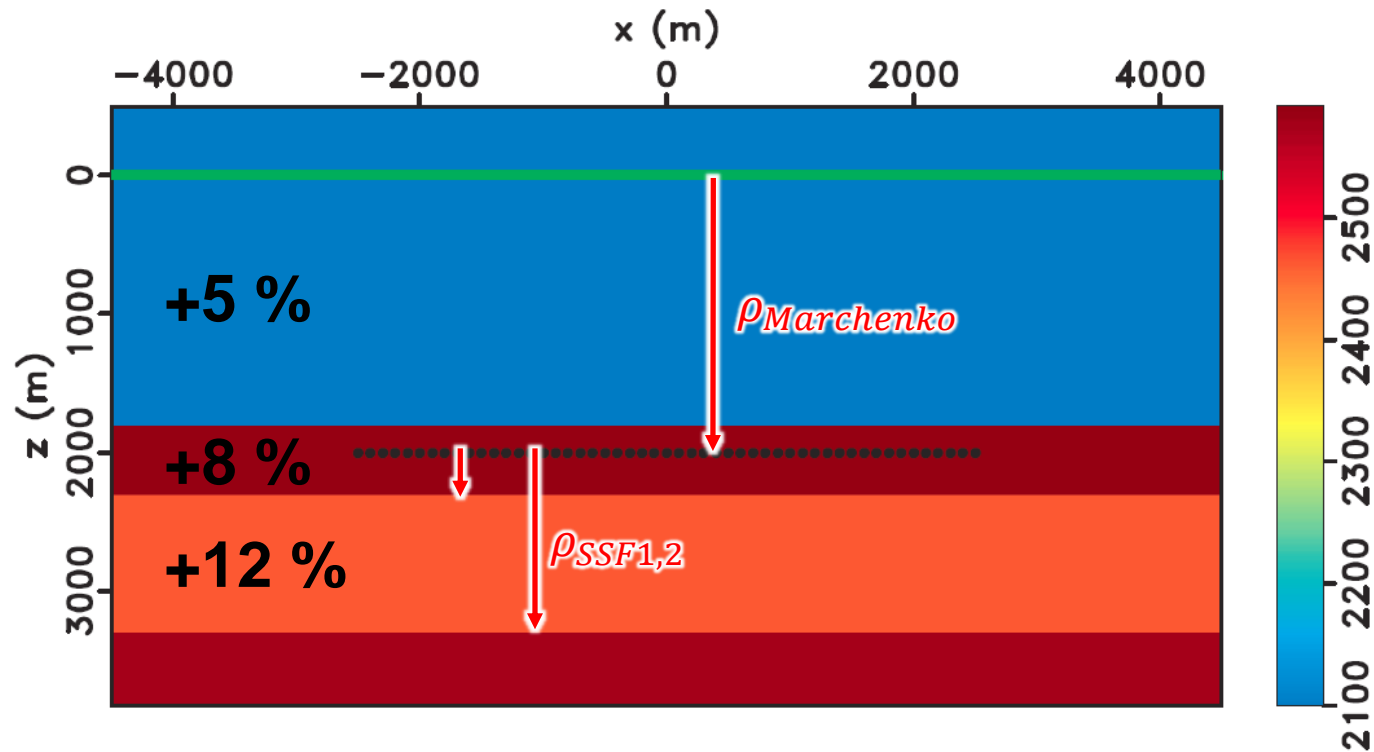
$$\Delta n_{RMO} = (\rho_{SSF} - 1) \tan^2(\theta) z_0 n$$



Velocity analysis using redatumed data
 Incorrect velocities for redatuming and RTM

Extended residual moveout equation:

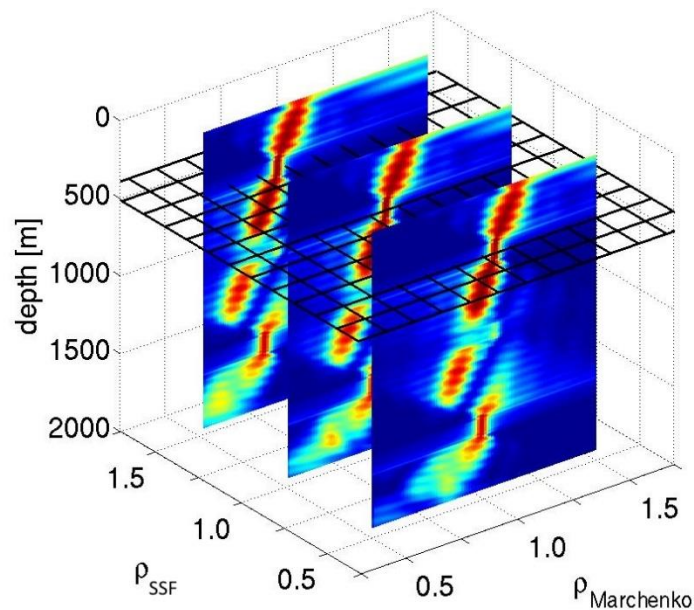
$$\Delta n_{RMO} = [(\rho_{Marchenko} - 1)z_{datum} + (\rho_{SSF} - 1)(z_0 - z_{datum})] \tan^2(\theta) n$$



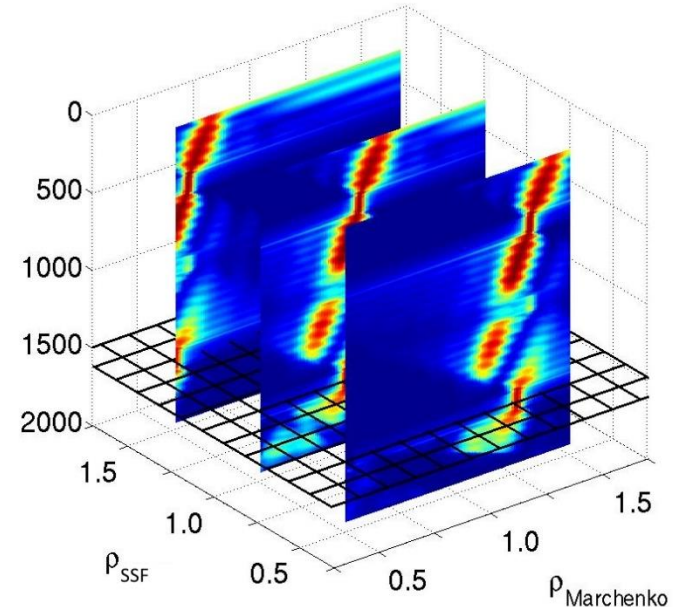
Velocity analysis using redatumed data

Incorrect velocities for redatuming and RTM: 2D semblance analysis

$$\Delta \mathbf{n}_{RMO} = [(\rho_{Marchenko} - 1)z_{datum} + (\rho_{SSF} - 1)(z_0 - z_{datum})] \tan^2(\theta) \mathbf{n}$$



First reflection

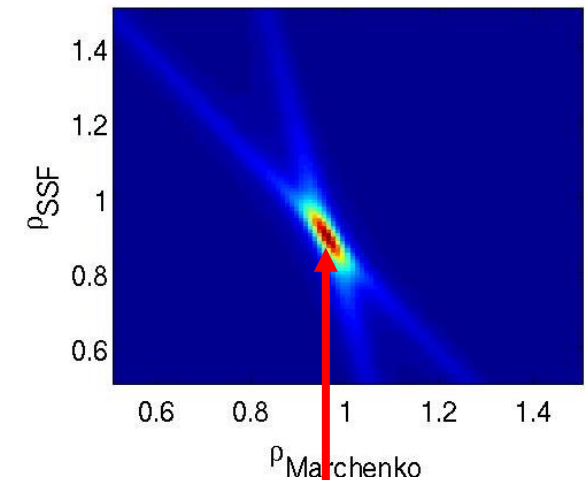
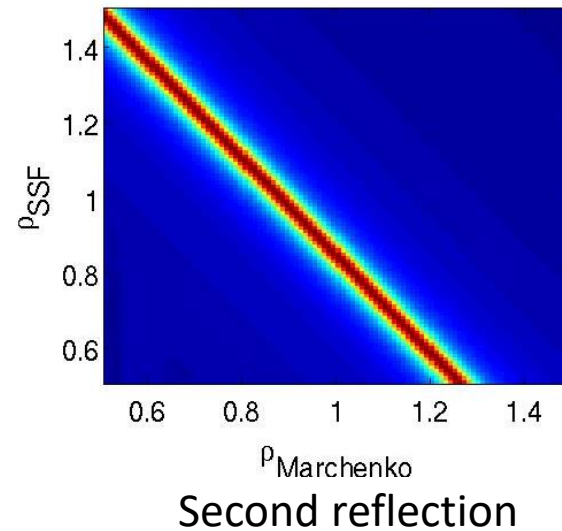
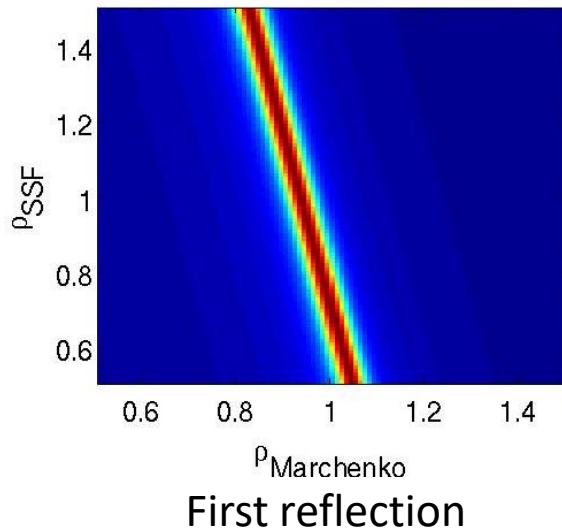


Second reflection

Velocity analysis using redatumed data

Incorrect velocities for redatuming and RTM: 2D semblance analysis

$$\Delta \mathbf{n}_{RMO} = [(\rho_{Marchenko} - 1)z_{datum} + (\rho_{SSF} - 1)(z_0 - z_{datum})] \tan^2(\theta) \mathbf{n}$$

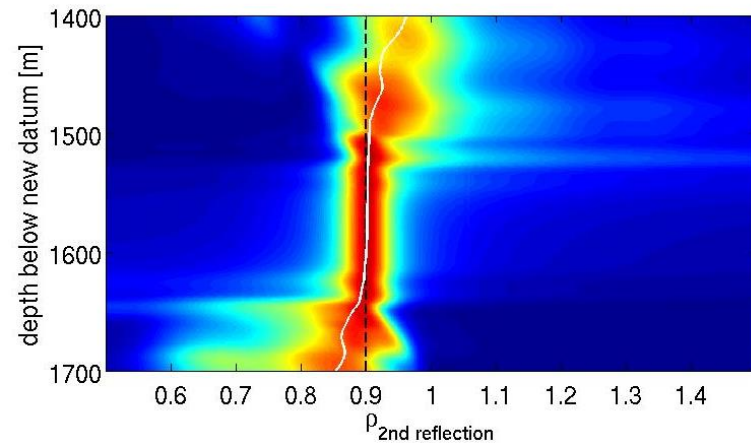
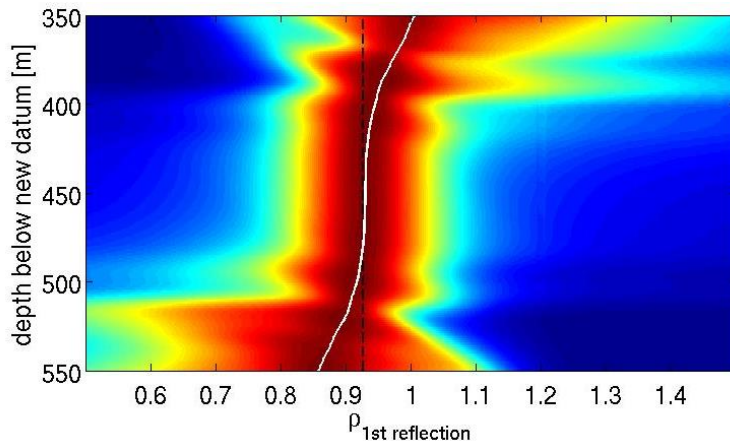


$$\rho_{Marchenko} \approx 0.95$$

Velocity analysis using redatumed data

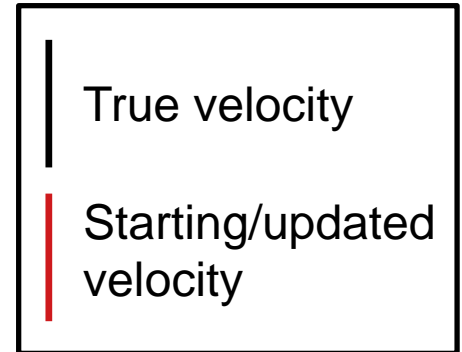
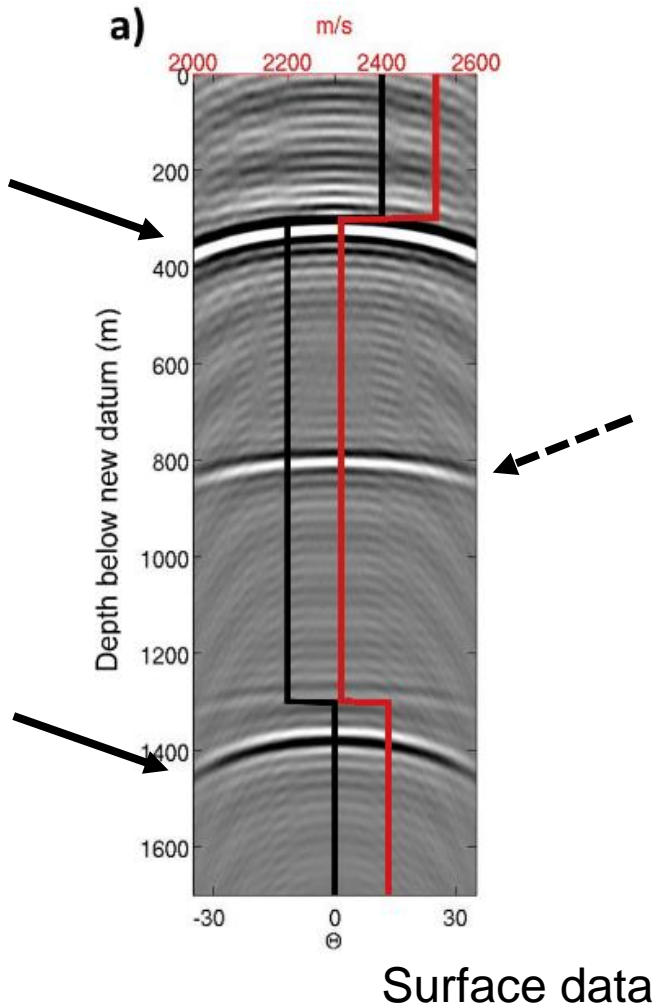
Incorrect velocities for redatuming and RTM: 2D semblance analysis

$$\Delta \mathbf{n}_{RMO} = [(0.95 - 1)z_{datum} + (\rho_{SSF} - 1)(z_0 - z_{datum})] \tan^2(\theta) \mathbf{n}$$

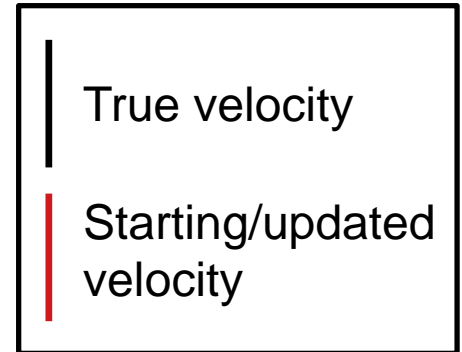
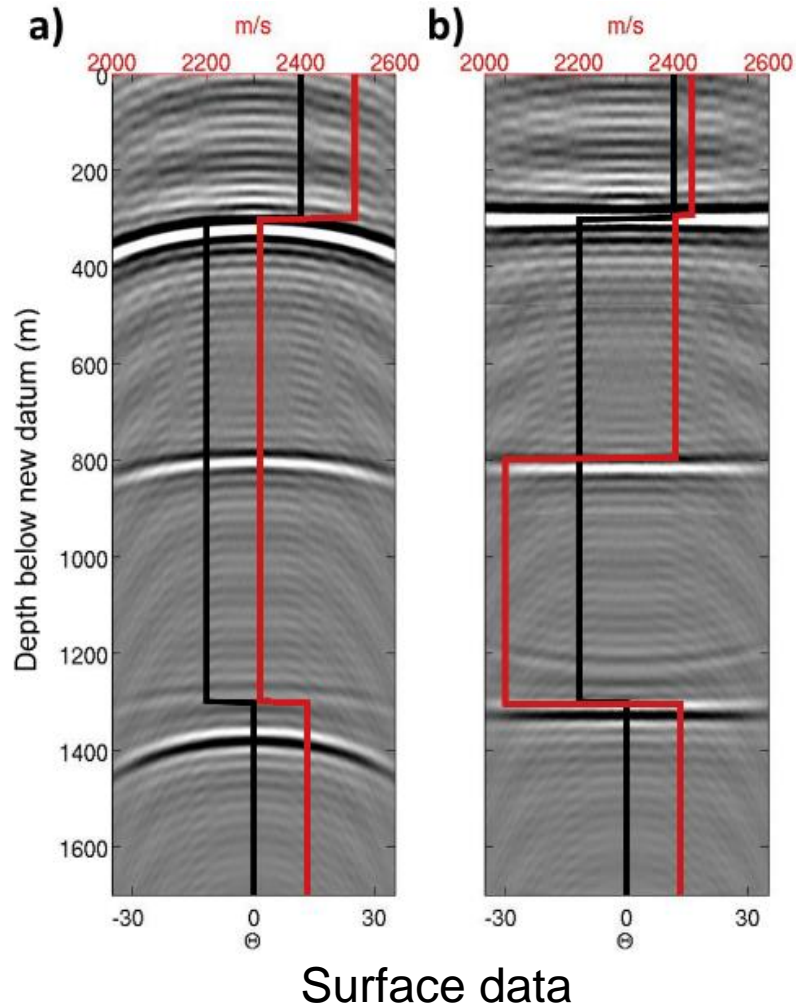


$$vel_{SSF}^{updated} = \rho \cdot vel_{SSF}$$

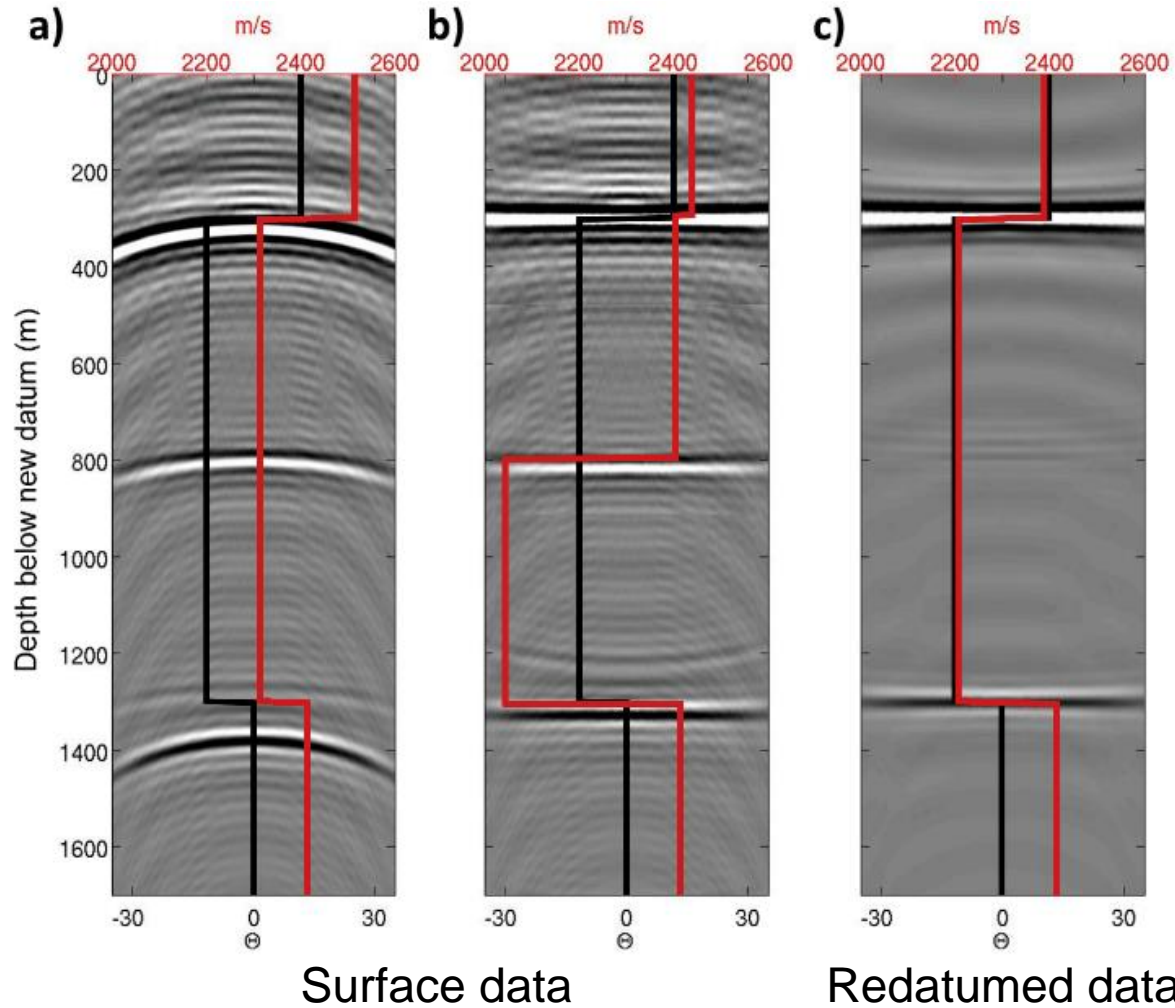
Comparison of surface and redatumed data



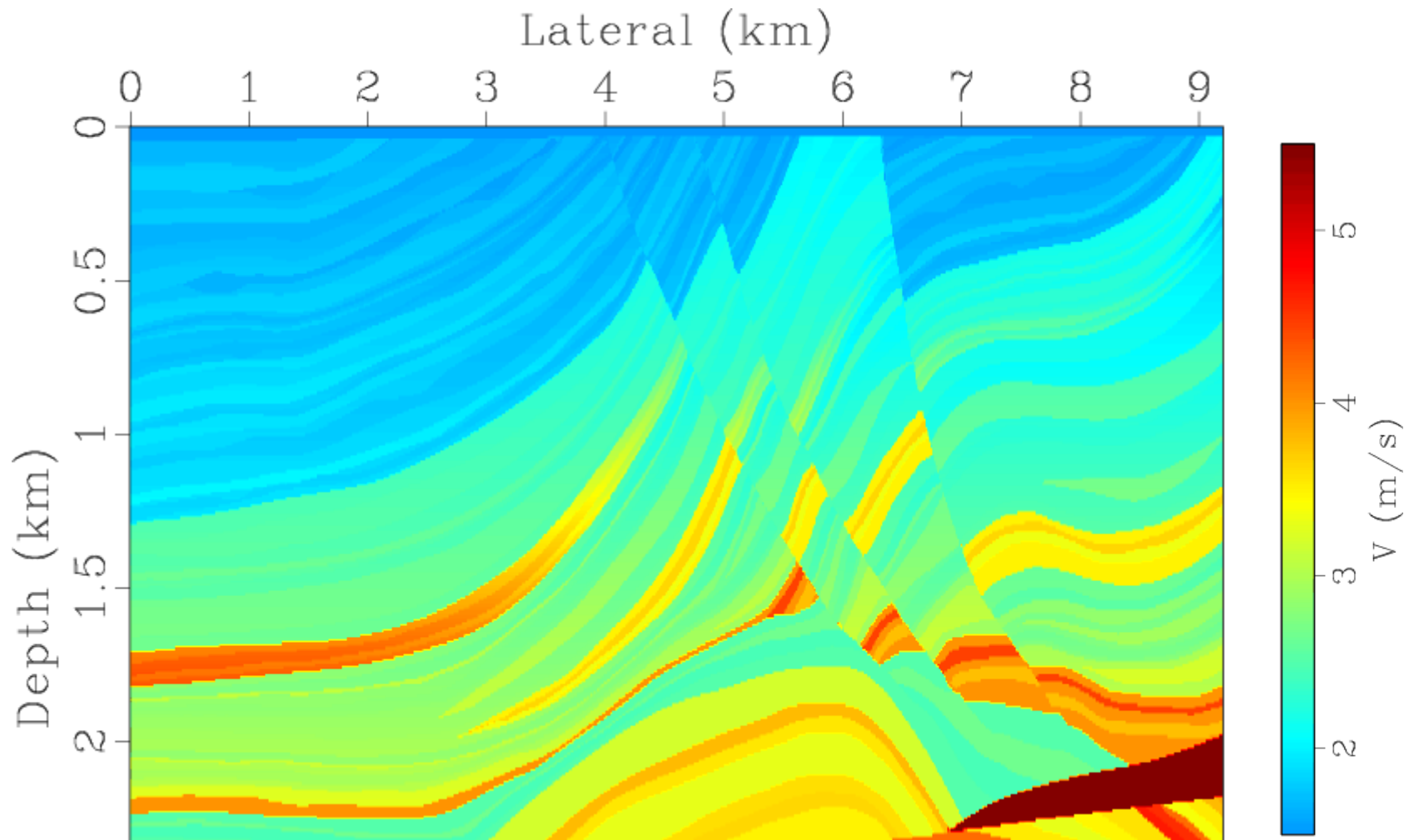
Comparison of surface and redatumed data



Comparison of surface and redatumed data

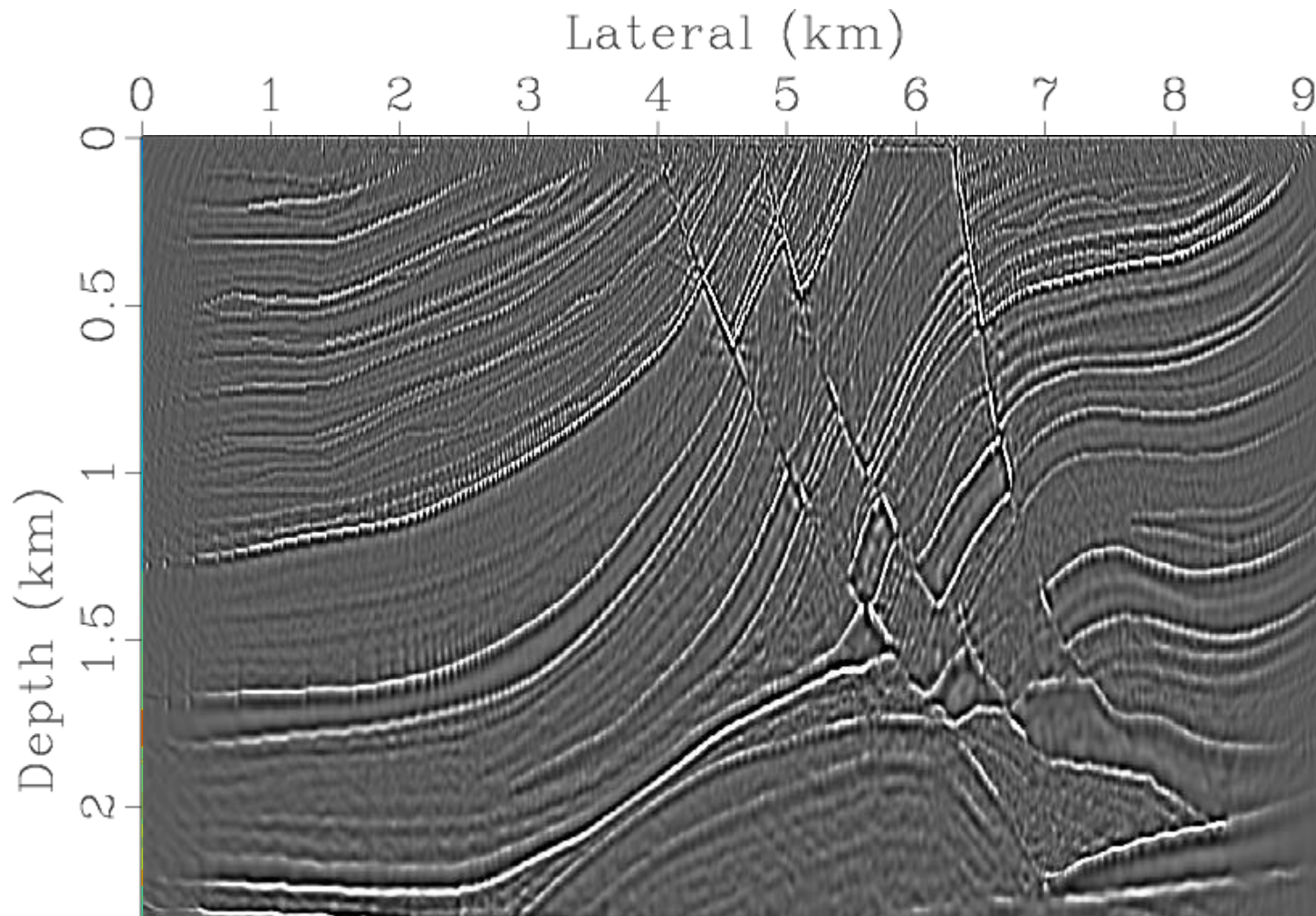


More complex velocity model



(Yang, et al., 2014)

Image of complex model



(Yang, et al., 2014)

- **Marchenko redatumed data can be used to create images free of internal multiples**
 - **First application of Marchenko redatumed data for velocity analysis using ADCIG's**
 - **Redatuming is sensitive to incorrect velocities**
 - **Velocity errors can be referred by combining different reflections in ADCIG's leading to correct velocity updates**
- Marchenko redatuming enables more accurate imaging and analysis of target zone**