Joint Imaging with streamer and ocean bottom data

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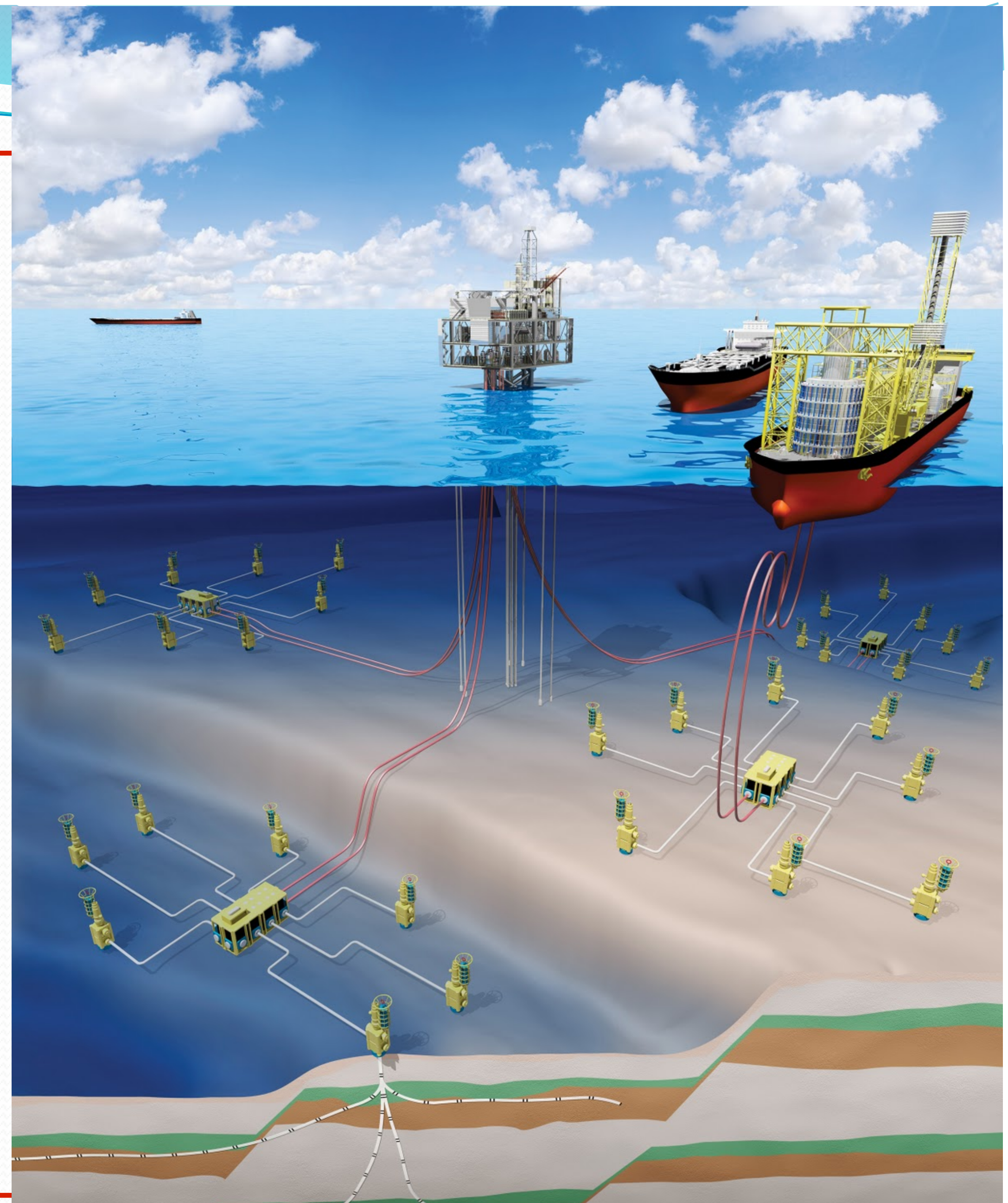
Overview

- Motivation
- Theory
  - Linearized joint inversion
  - Some considerations
- Synthetic Example
  - Marmousi model
- Conclusion

Motivation

- **Time-lapse monitoring**
- **Imaging around production facility**
  - **Restrictions on seismic vessels**

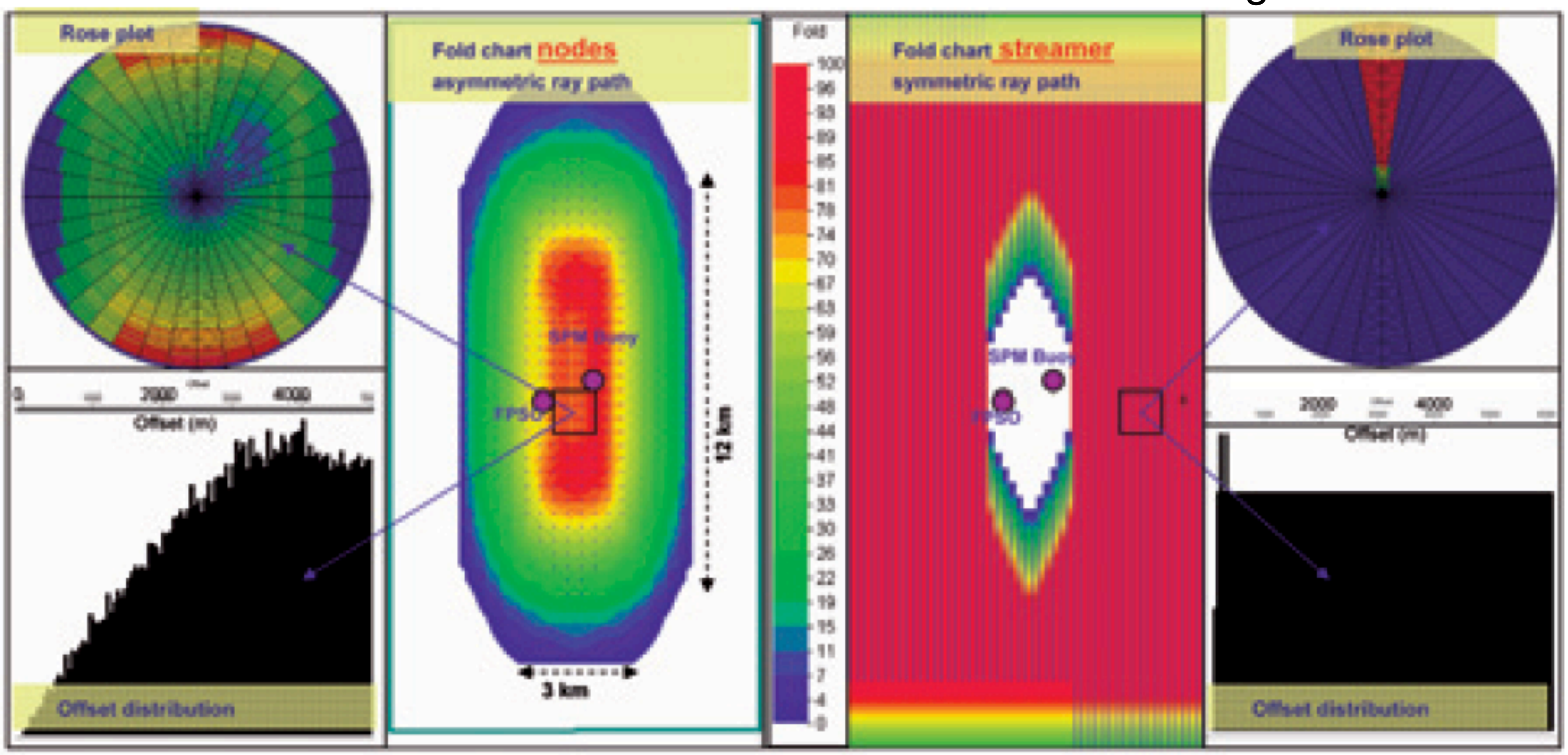


“Equipment Offshore Drilling.” Digital image. “Petroleum Engineering Blog” 11 Apr. 2011. 13 May 2012 <http://ilmumigas.blogspot.com/2011_04_01_archive.html>

Imaging around production facility

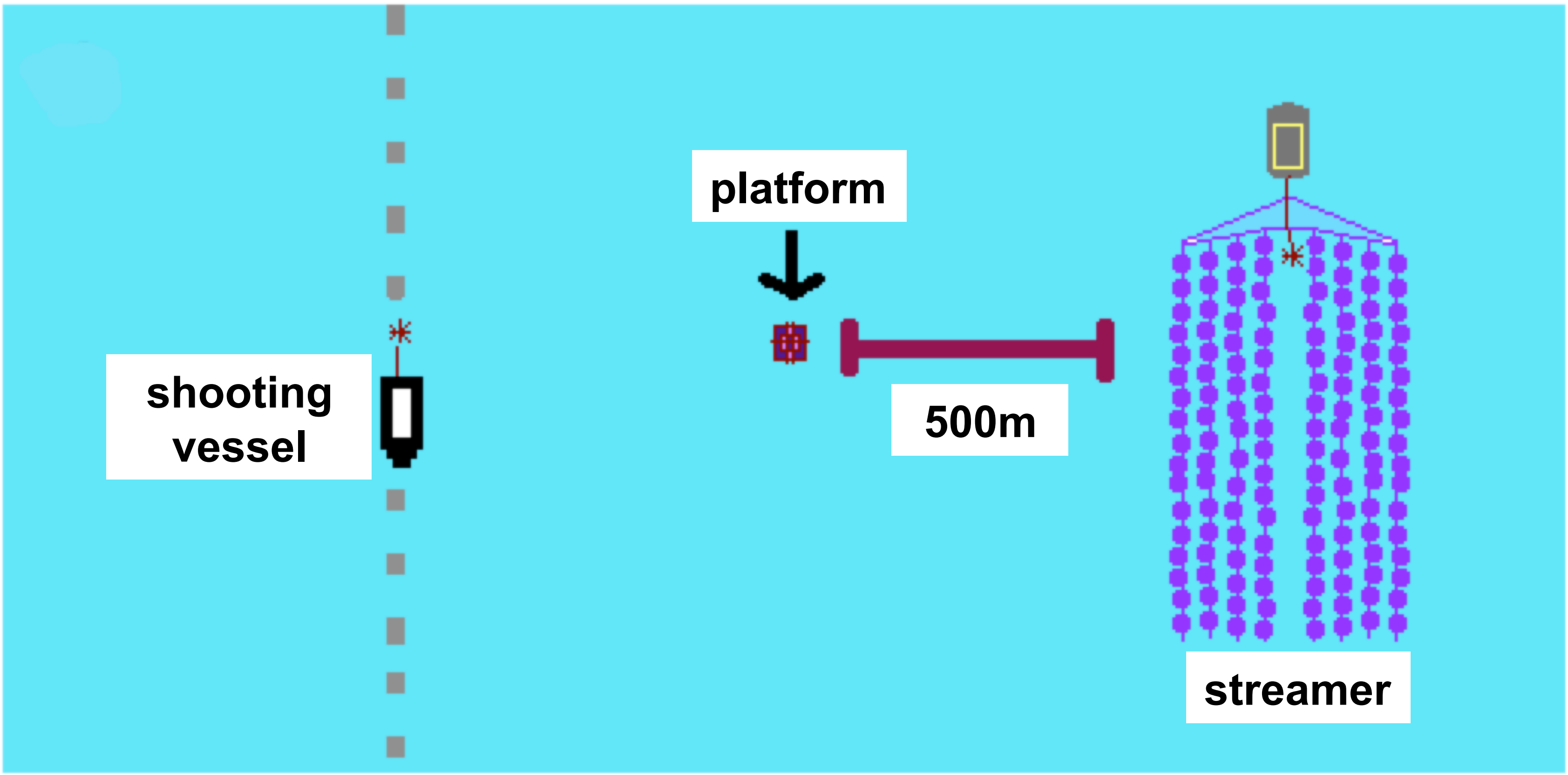
- Operational challenge
  - Streamer boat > 500m from platform
  - Shooting vessel > at least 50m from platform
  - Shadow zone

Ceragioli et al. 2006



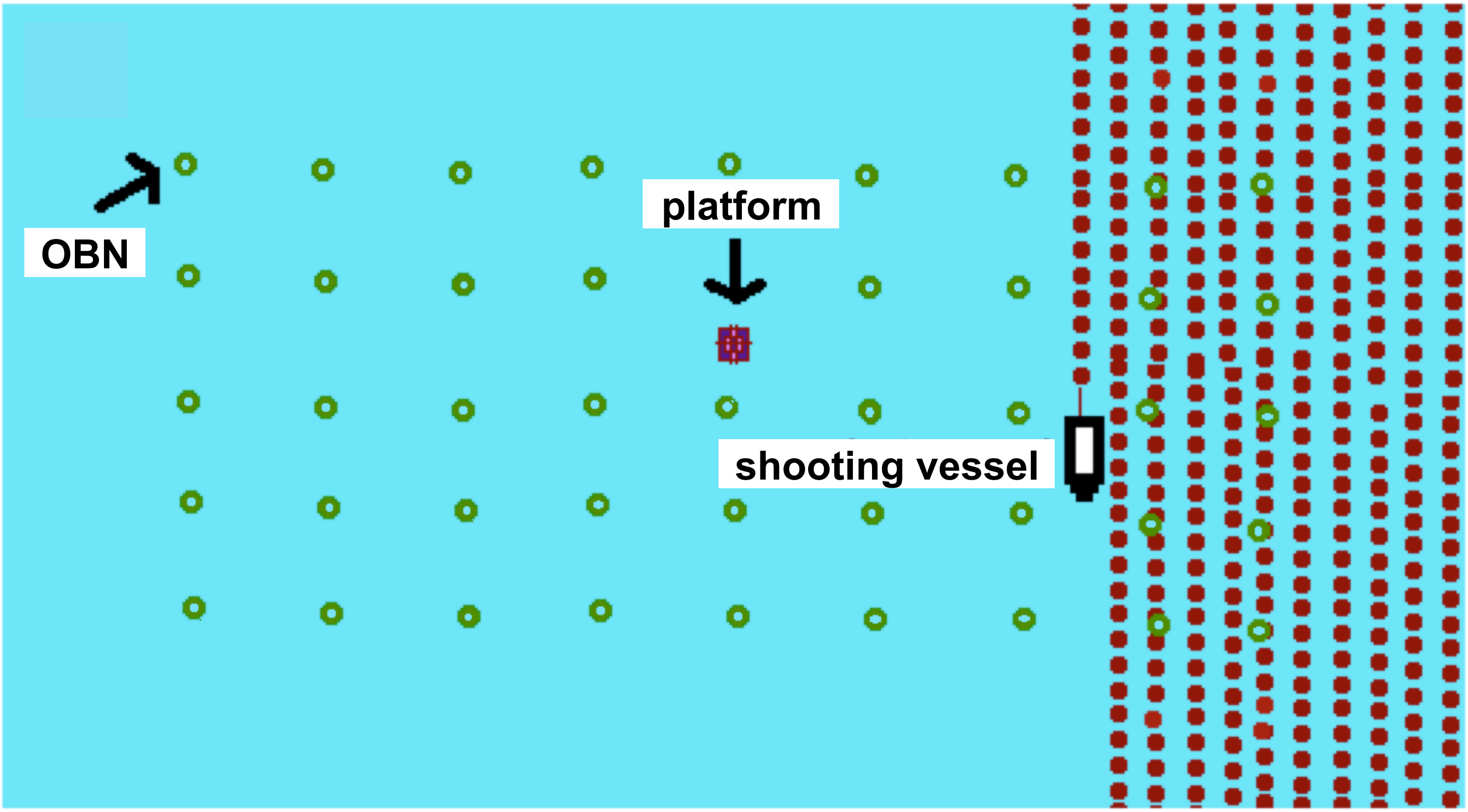
Undershooting

- **Utilizes independent shot and streamer vessels to navigate around obstacles**



Imaging around production facility

- autonomous ocean-bottom nodes (OBN)
- Autonomous receivers can be planted close to the production facility



Imaging around production facility

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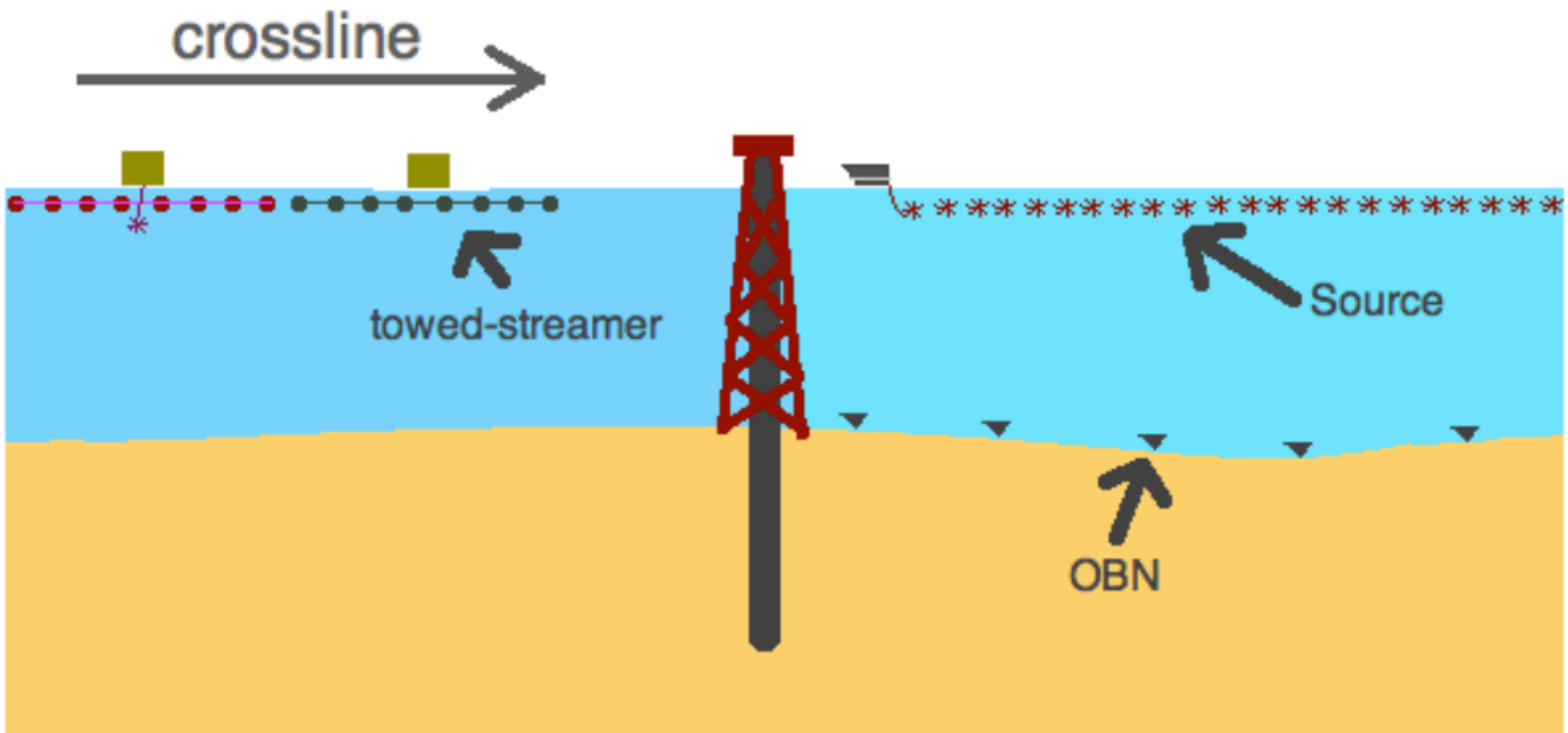

Imaging around production facility

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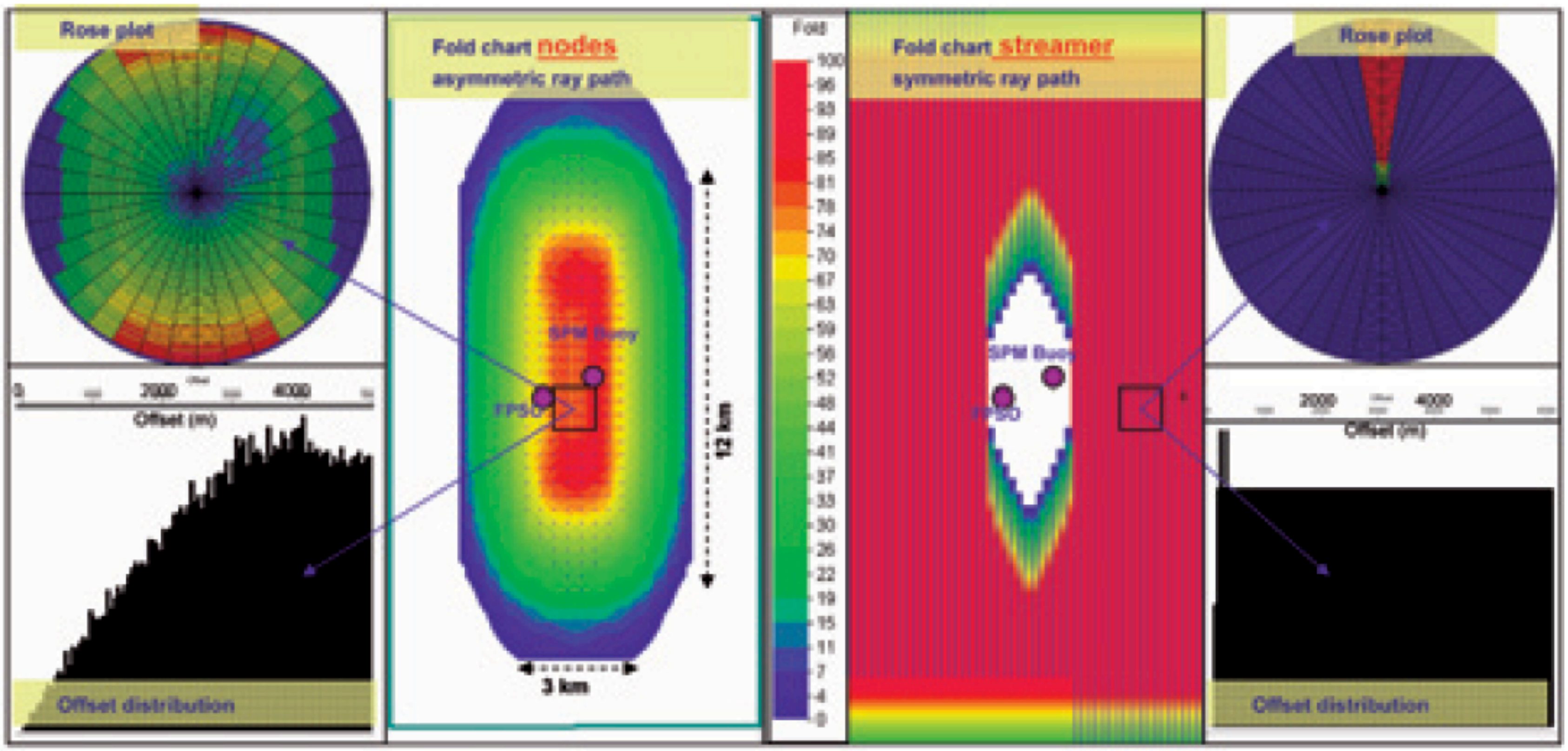
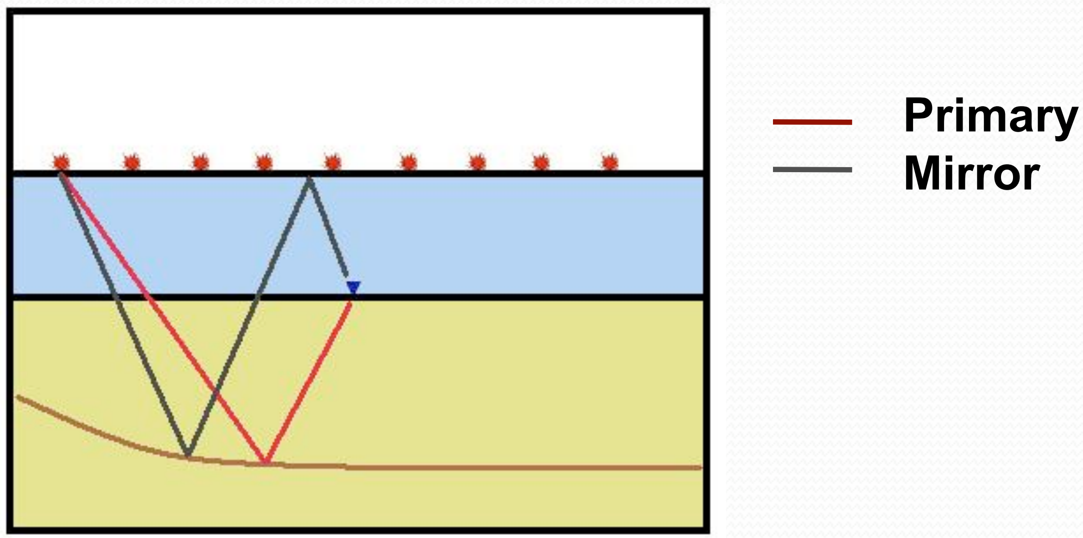
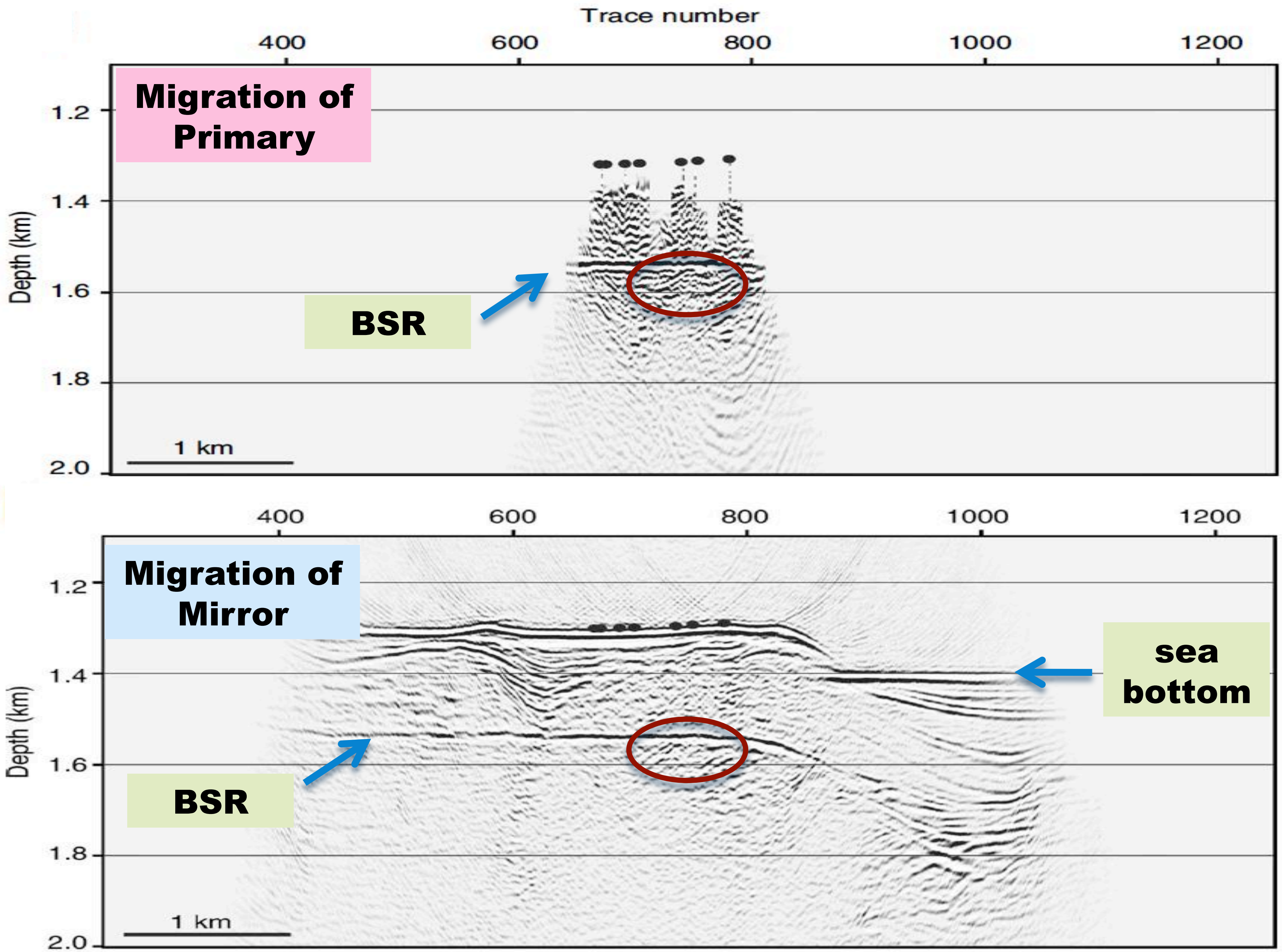


Ceragioli et.al. 2006

P-wave Processing for OBS Data

- Migration of Mirror
  - mirror Imaging
  - Godfrey et al., 1998; Ronen et al., 2005; Grion et al., 2007; Dash et al., 2009

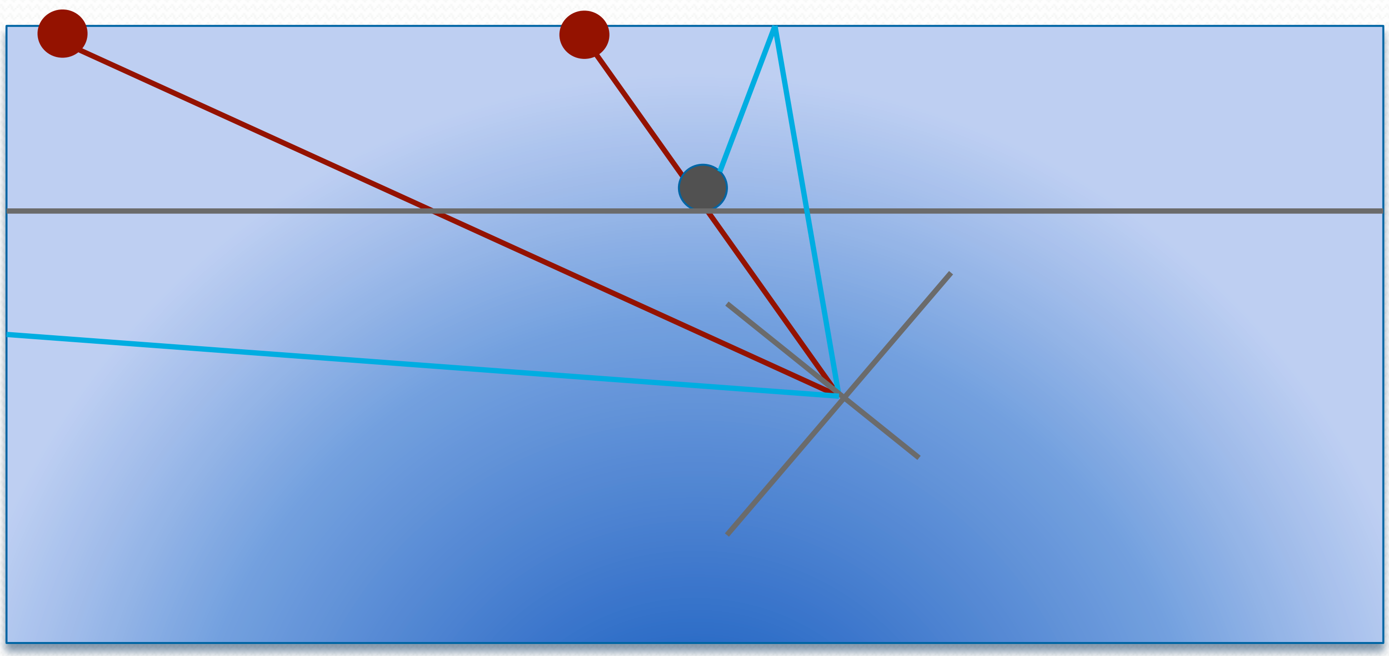




Dash et al. 2009

Why using streamer signal at all?

- Denser subsurface illumination
- Can better illuminate dipping reflectors



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  - Linearized joint inversion
  - Field data considerations
- Synthetic Example
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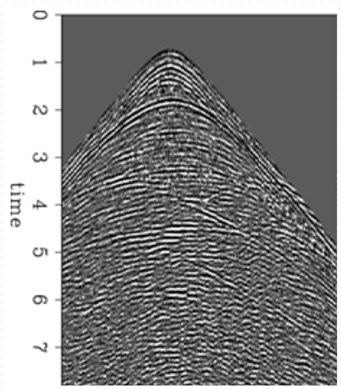
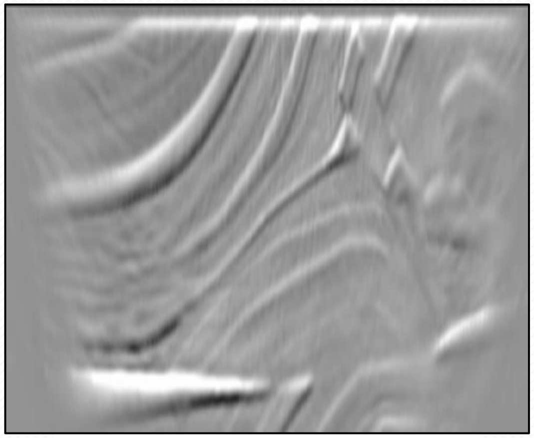
Migration vs. Linearized Inversion

Based on an estimate of the velocity, put recorded energy back to the Earth.



Field data

Migration Operator



Reflectivity model

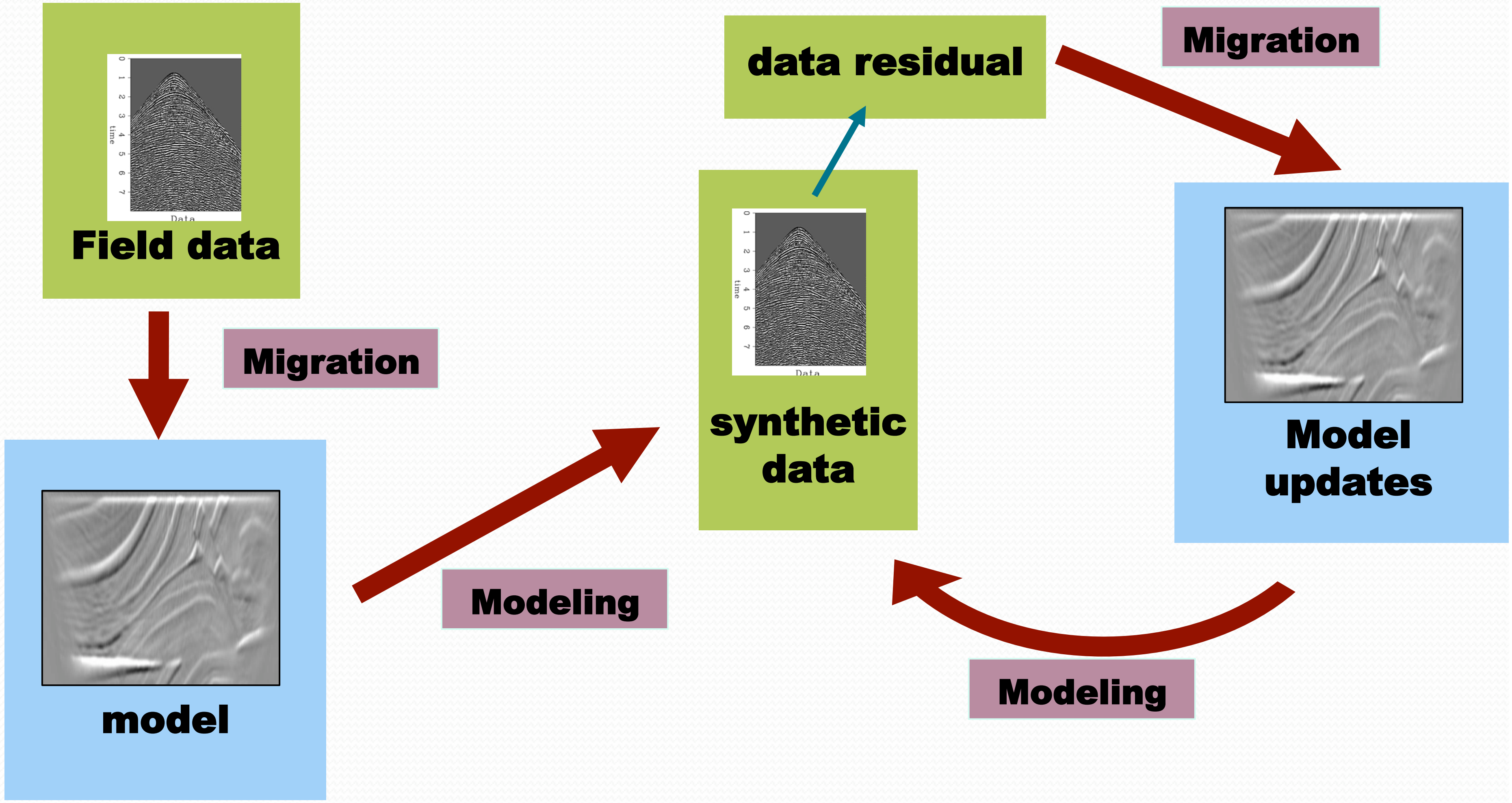
$$m = L^T d$$

model

Field data

Migration vs. Linearized Inversion

Image is obtained by minimizing the difference between the modeled data and the field data.



Joint Inversion

$$0 \approx \begin{bmatrix} \mathbf{L}_{str} \\ \mathbf{L}_{OBN\downarrow} \end{bmatrix} \mathbf{m} - \begin{bmatrix} \mathbf{d}_{str} \\ \mathbf{d}_{OBN\downarrow} \end{bmatrix}$$

Joint Inversion

$$0 \approx \begin{bmatrix} \mathbf{L}_{str} \\ \mathbf{L}_{OBN\downarrow} \end{bmatrix} \mathbf{m} - \begin{bmatrix} \mathbf{d}_{str} \\ \mathbf{d}_{OBN\downarrow} \end{bmatrix}$$

Field data considerations

- Matching of streamer and OBN images
  - Different source wavelet
  - Need deconvolution to make the phase consistent (ex. zero phase)
- Reflection position mismatch
  - Water velocity and static corrections
  - One can consider applying warping in the image space

$$\begin{aligned}\Delta \mathbf{m} &= \Delta \mathbf{m}_{str} + \mathbf{W}\Delta \mathbf{m}_{OBN} \\ &= \mathbf{L}_{str}^T \mathbf{r}_{str} + \mathbf{W}\mathbf{L}_{OBN}^T \mathbf{r}_{OBN}\end{aligned}$$

$$\begin{aligned}\Delta \mathbf{r} &= \Delta \mathbf{r}_{str} + \Delta \mathbf{r}_{OBN} \\ &= \mathbf{L}_{str}\Delta \mathbf{m}_{str} + \mathbf{L}_{OBN}\mathbf{W}^{-1}\Delta \mathbf{m}_{OBN}\end{aligned}$$

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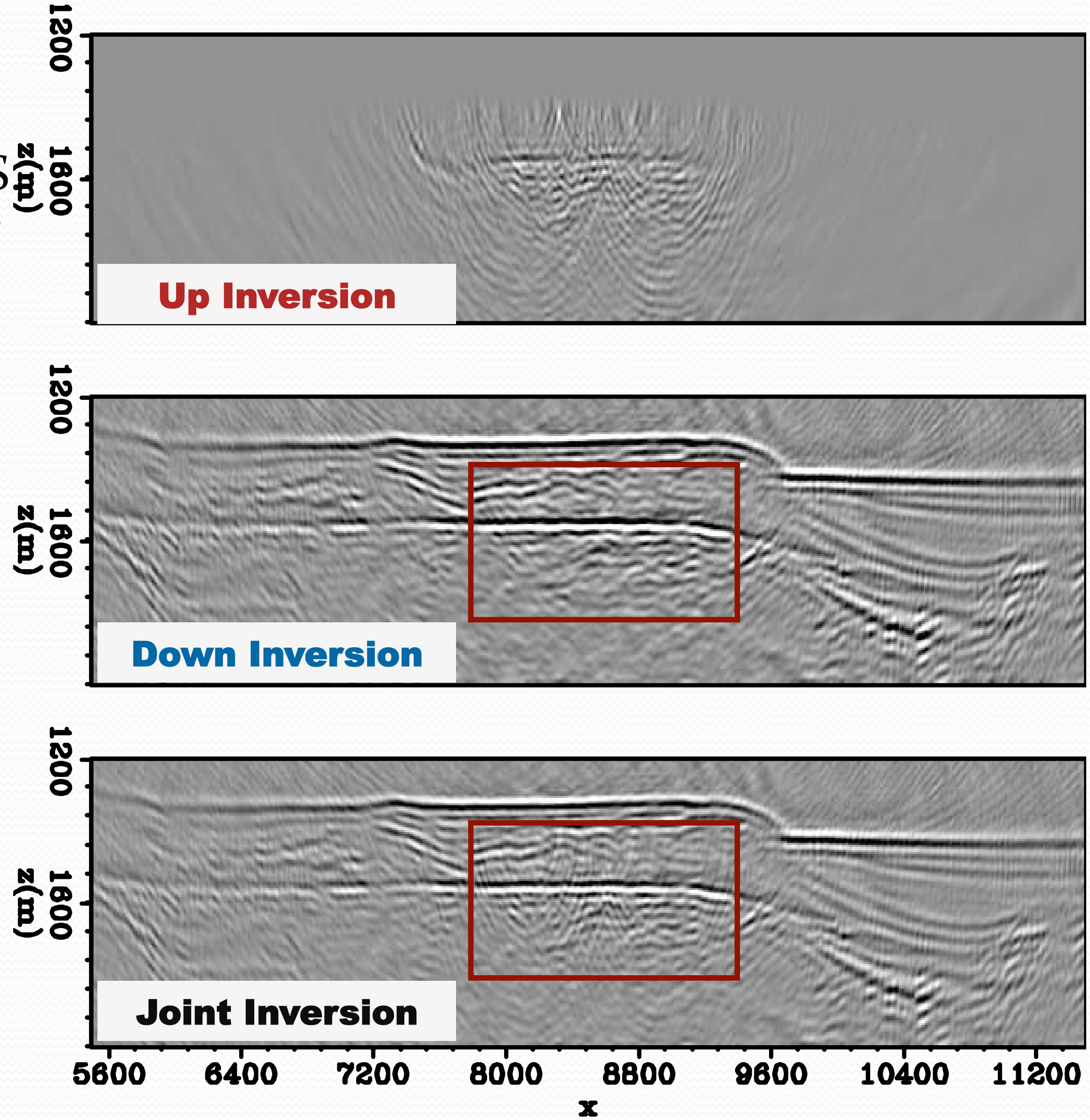
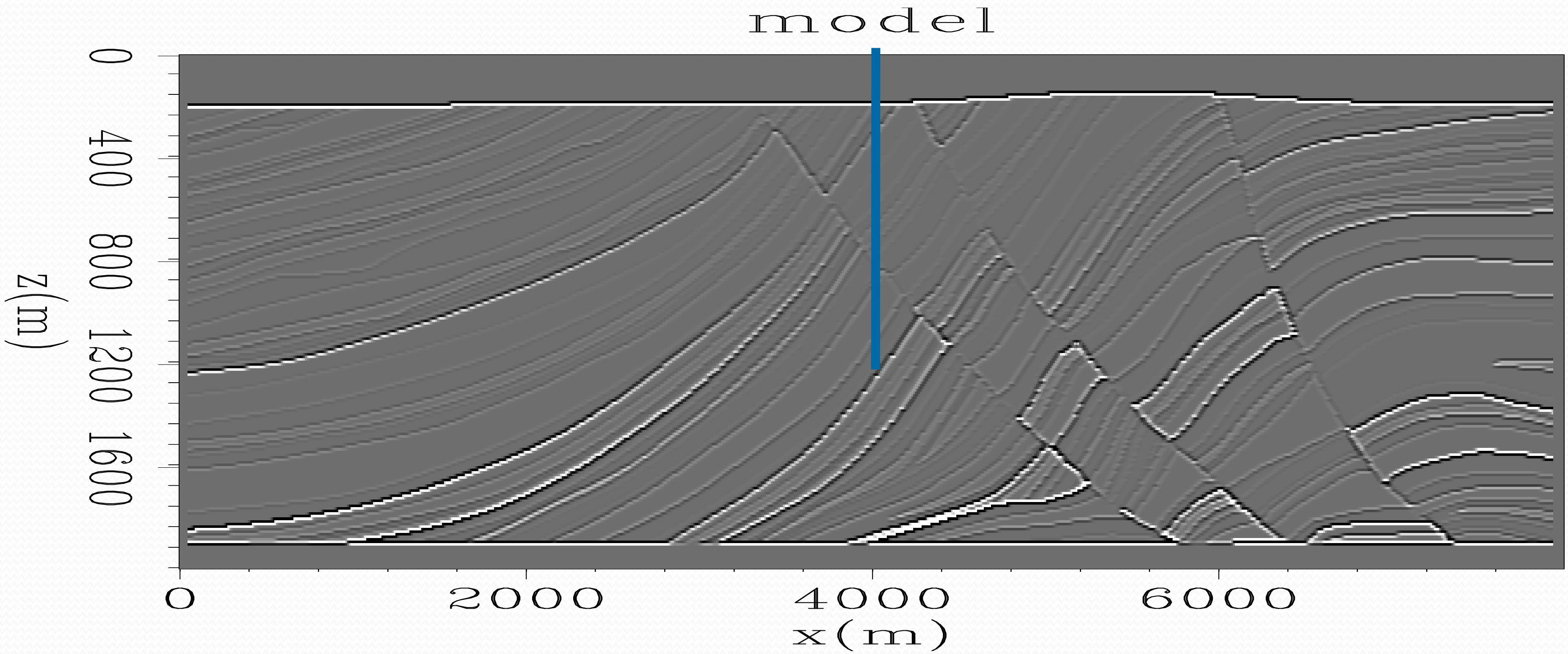
Last time …

- Wong, M., B. Biondi, and S. Ronen, 2010, Joint least-??

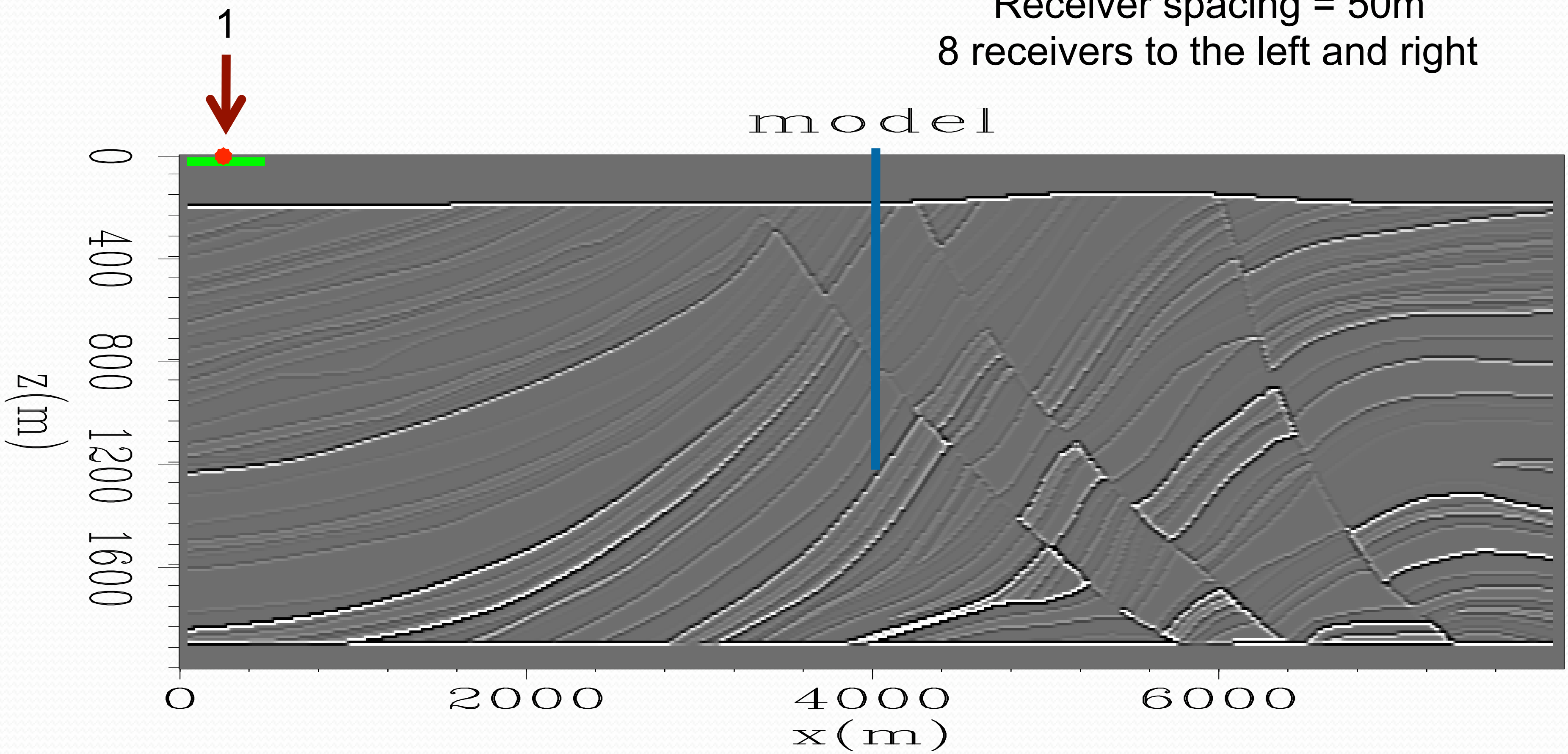


Synthetic Model



Synthetic streamer data

Shot spacing = 350m
Receiver spacing = 50m
8 receivers to the left and right



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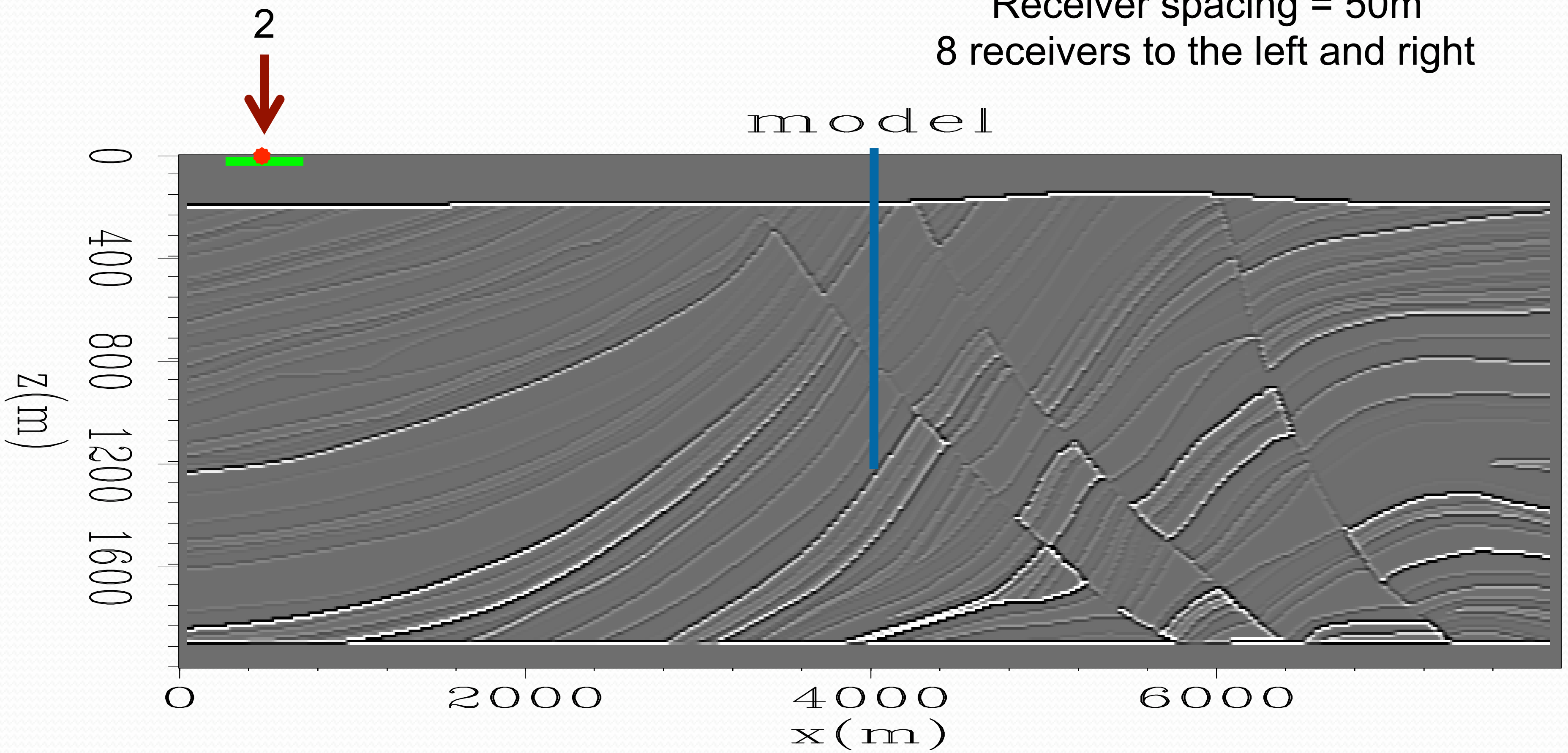

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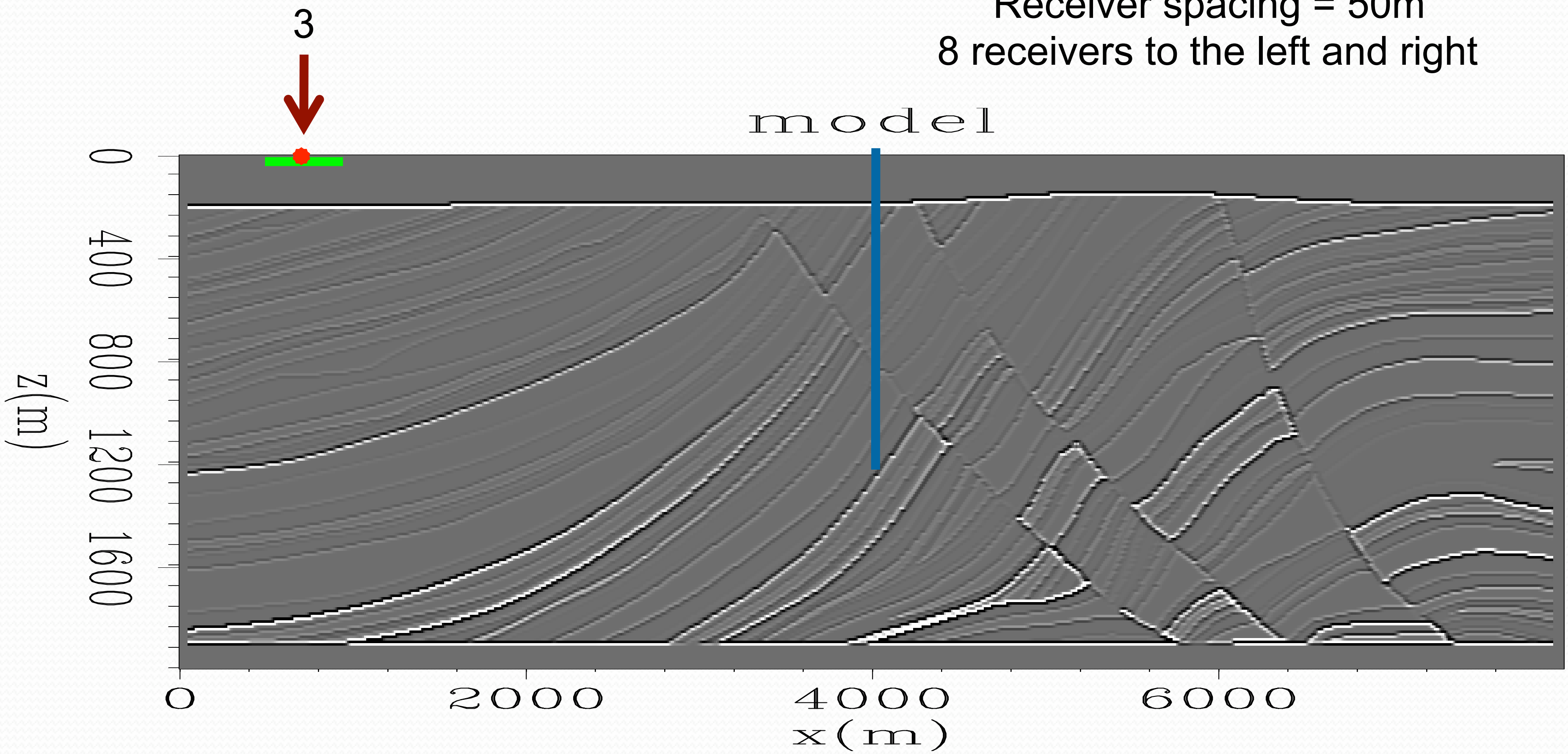
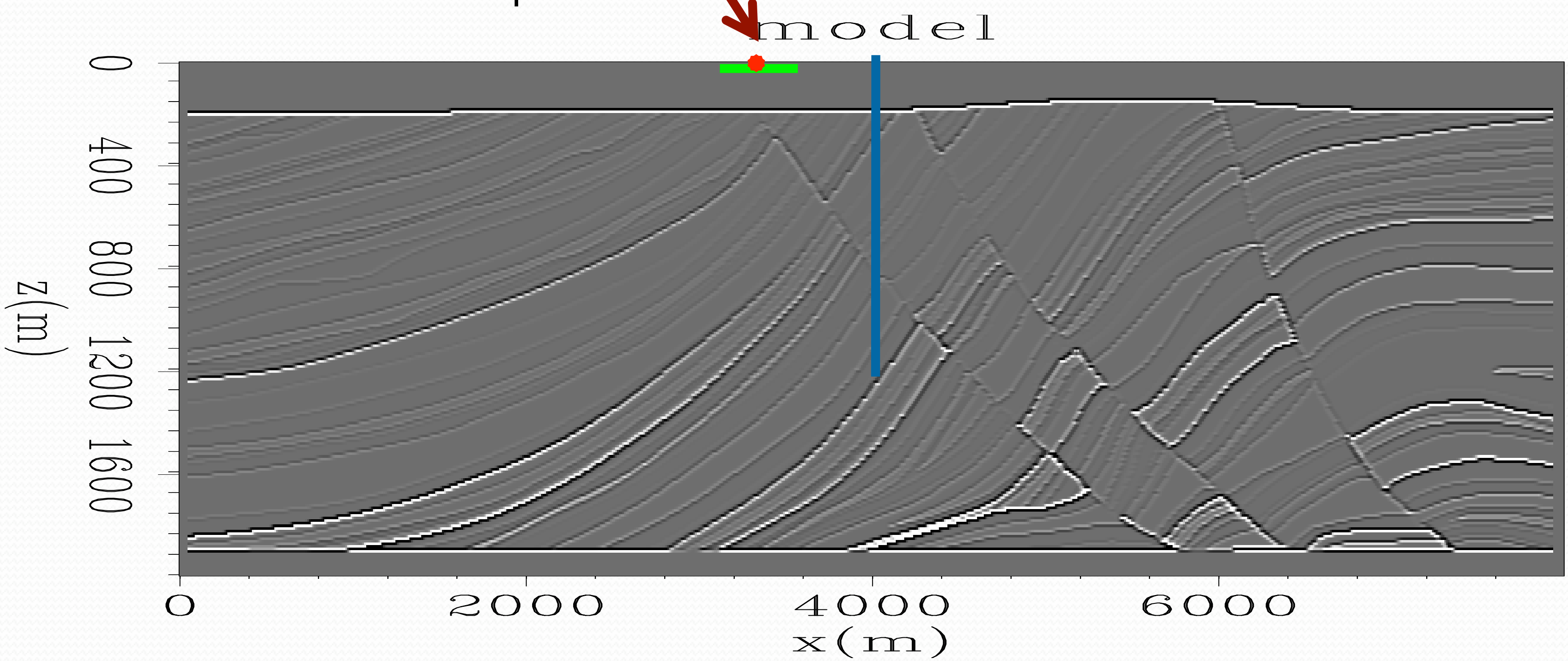


Synthetic streamer data

Streamer >500m from platform

Shot spacing = 350m
Receiver spacing = 50m
8 receivers to the left and right



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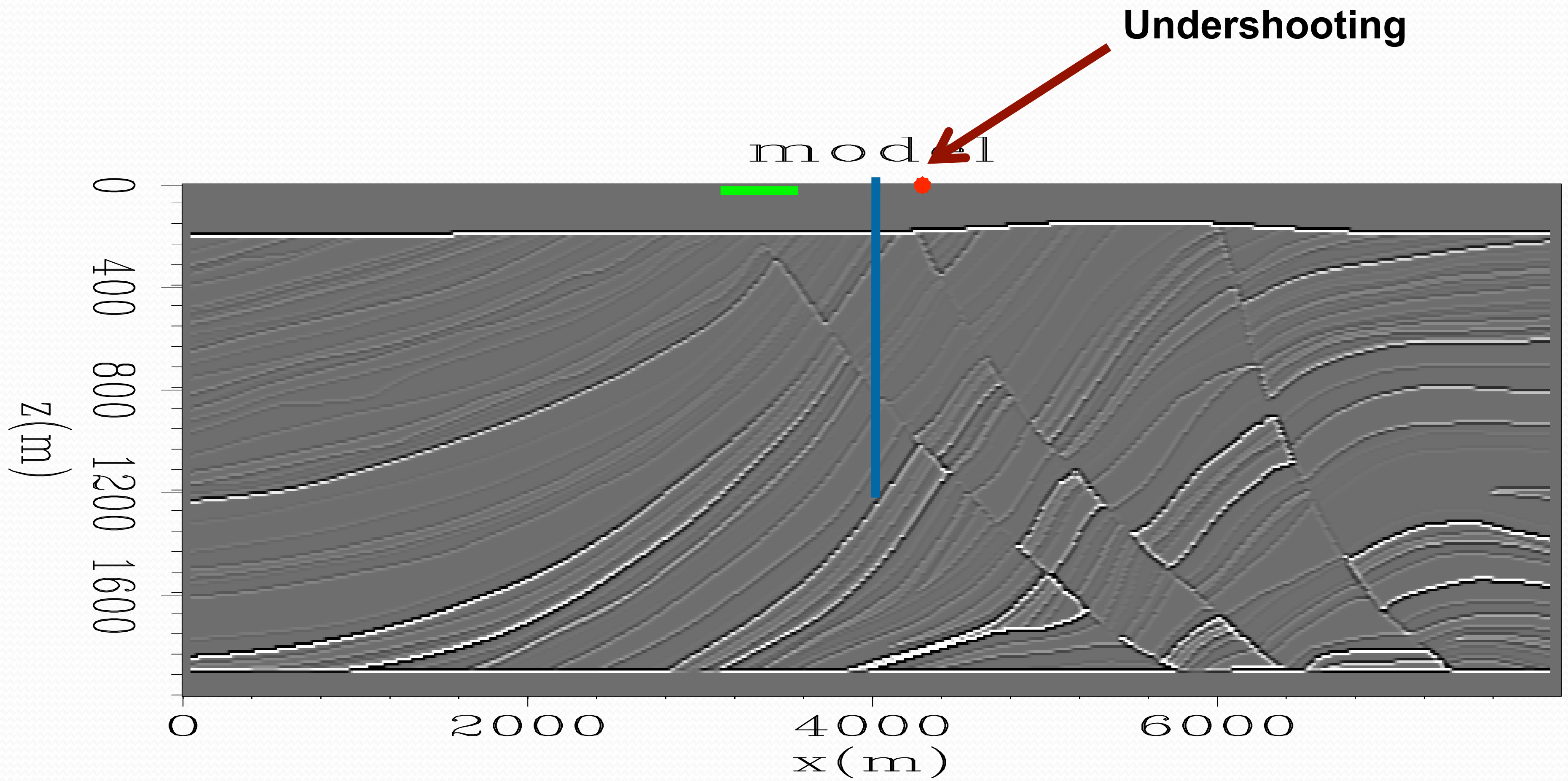
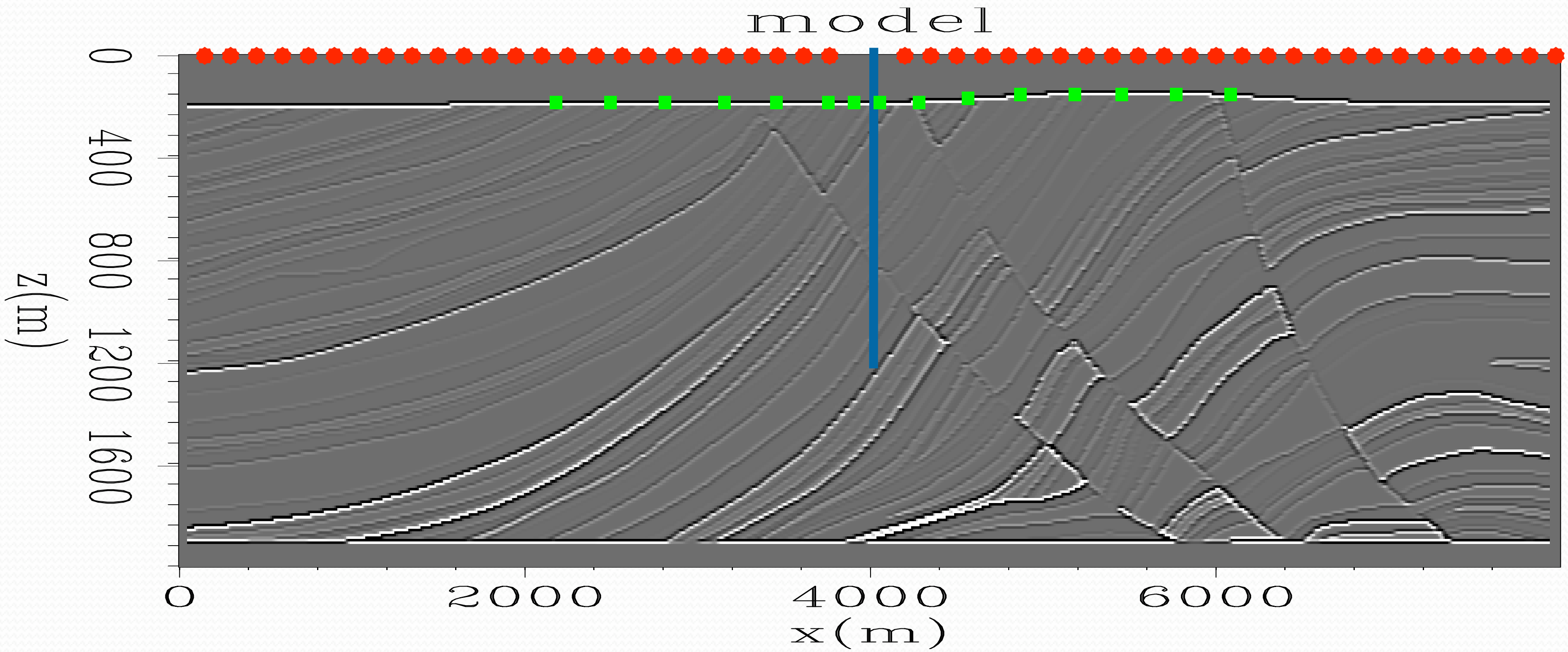
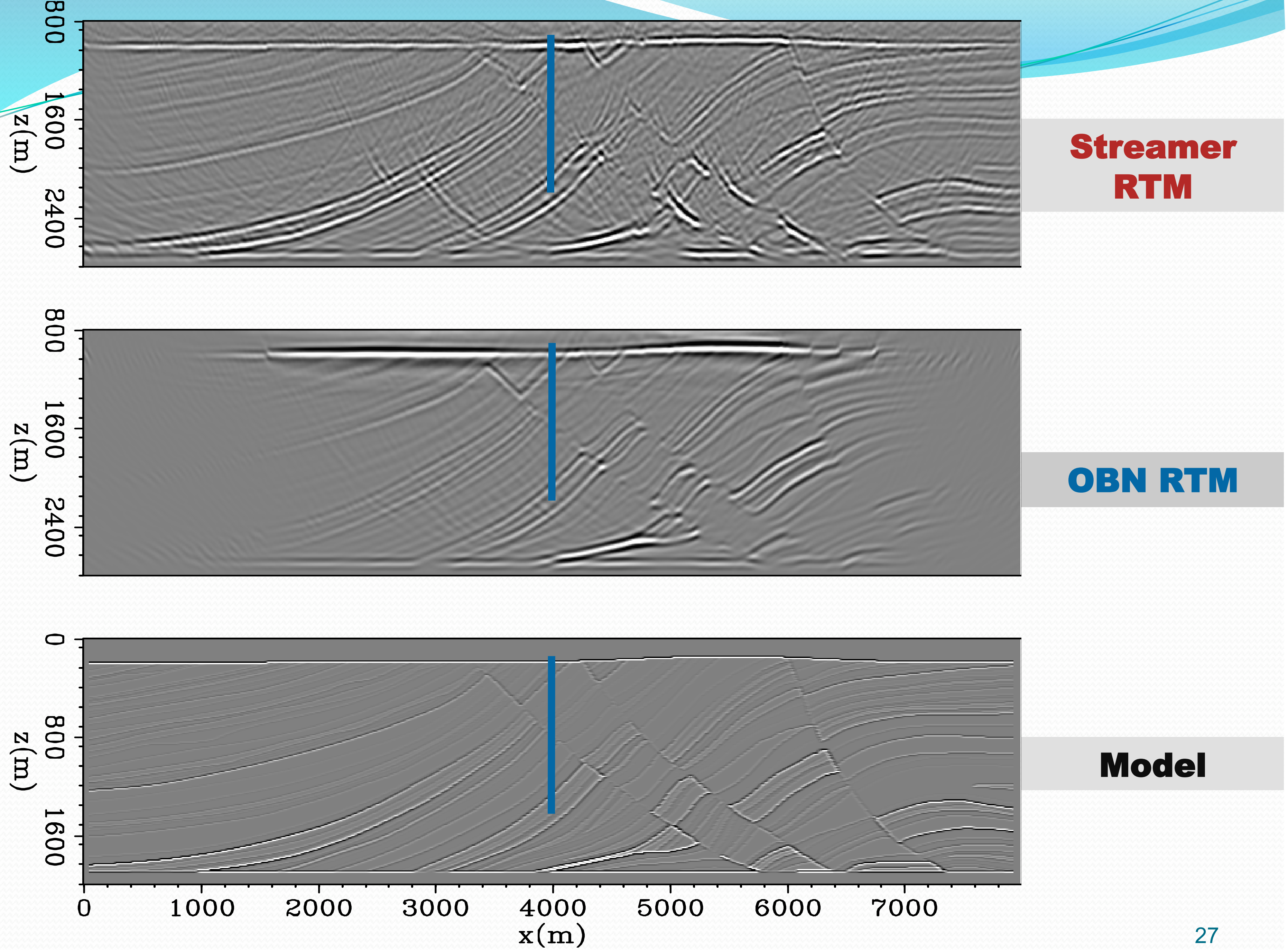
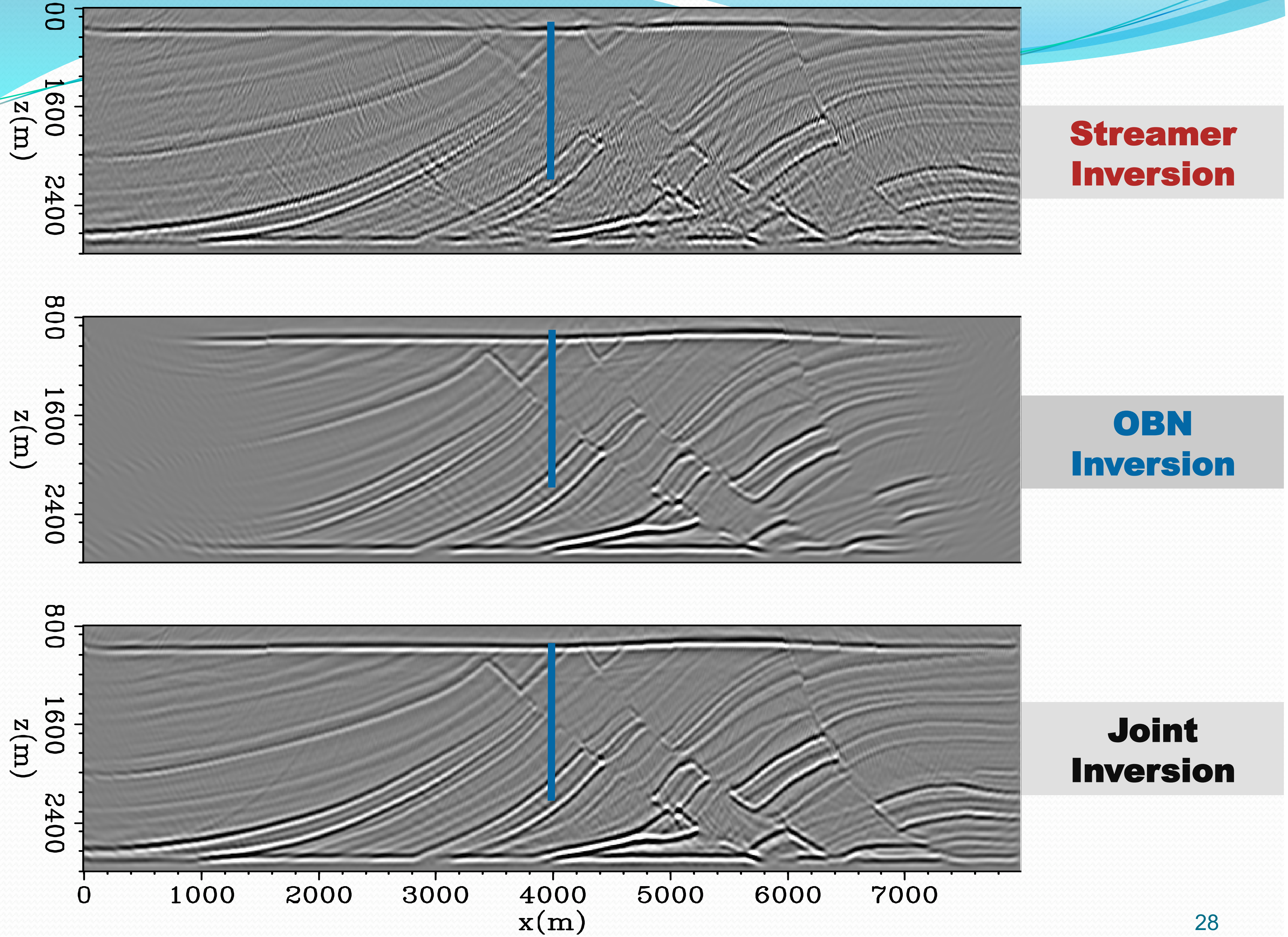


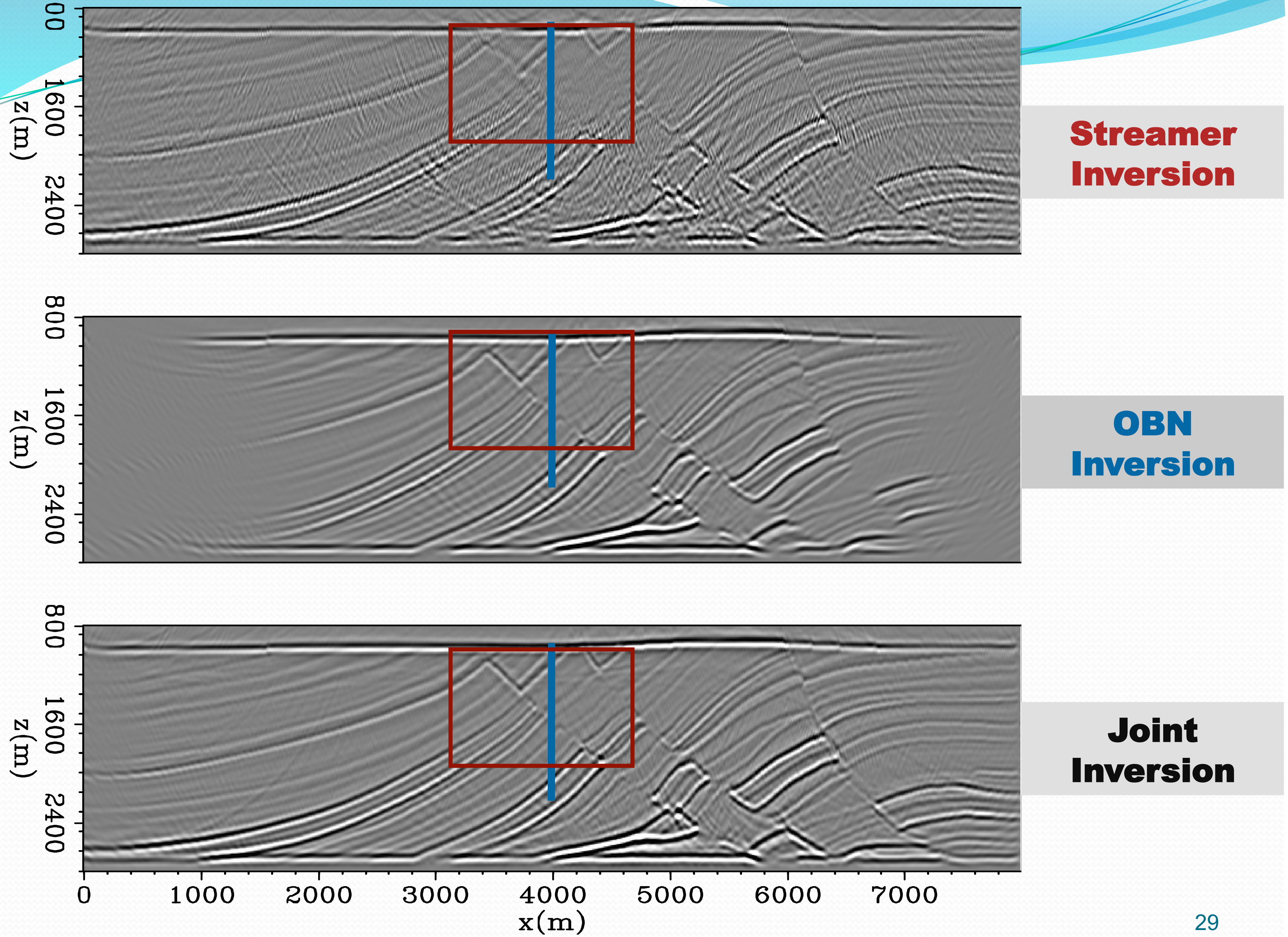
Synthetic OBN data



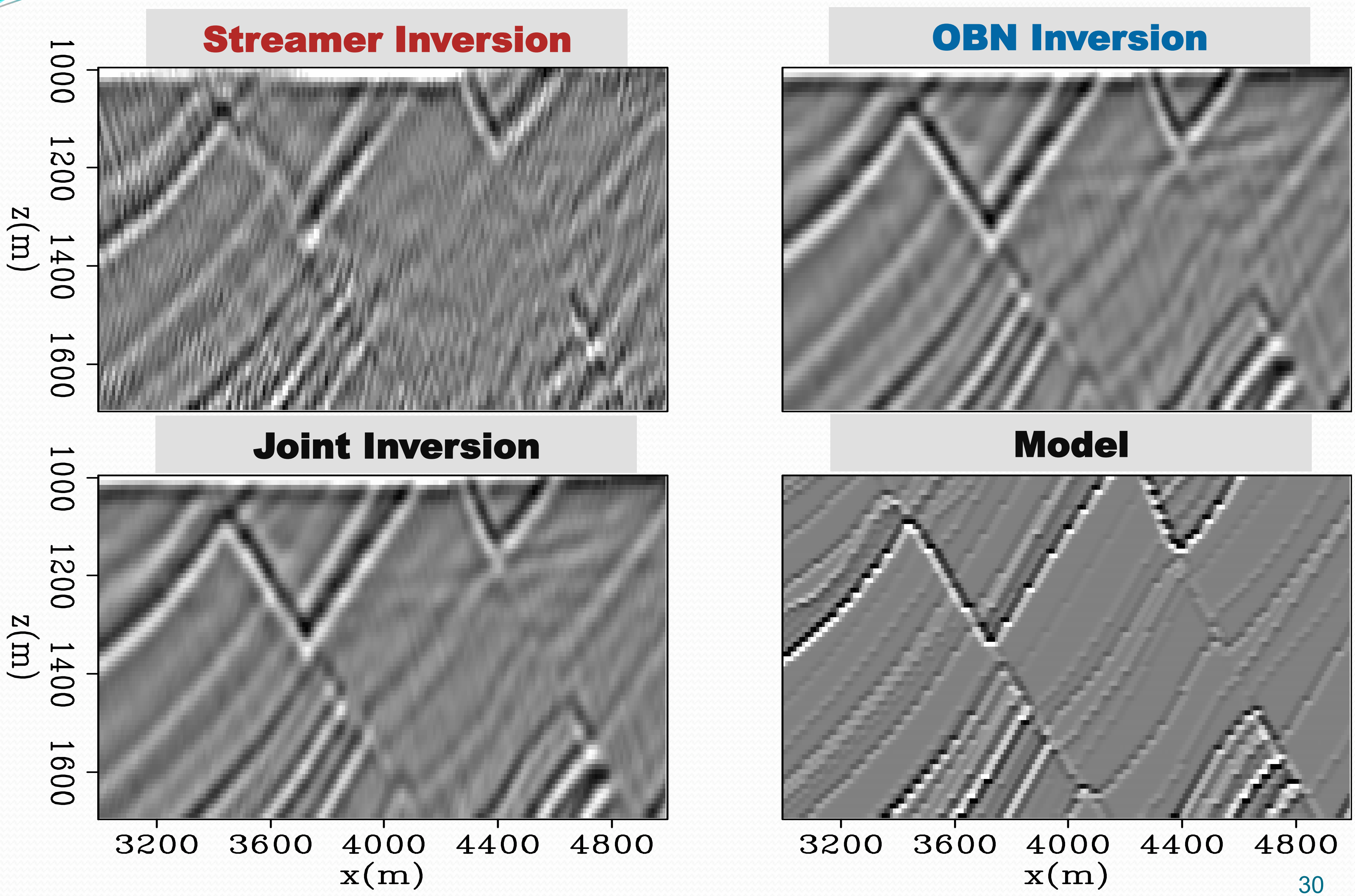

800
1600
2400
z(m)
Streamer RTM
800
1600
2400
z(m)
OBN RTM
0
800
1600
z(m)
Model
0
1000
2000
3000
4000
5000
6000
7000
x(m)

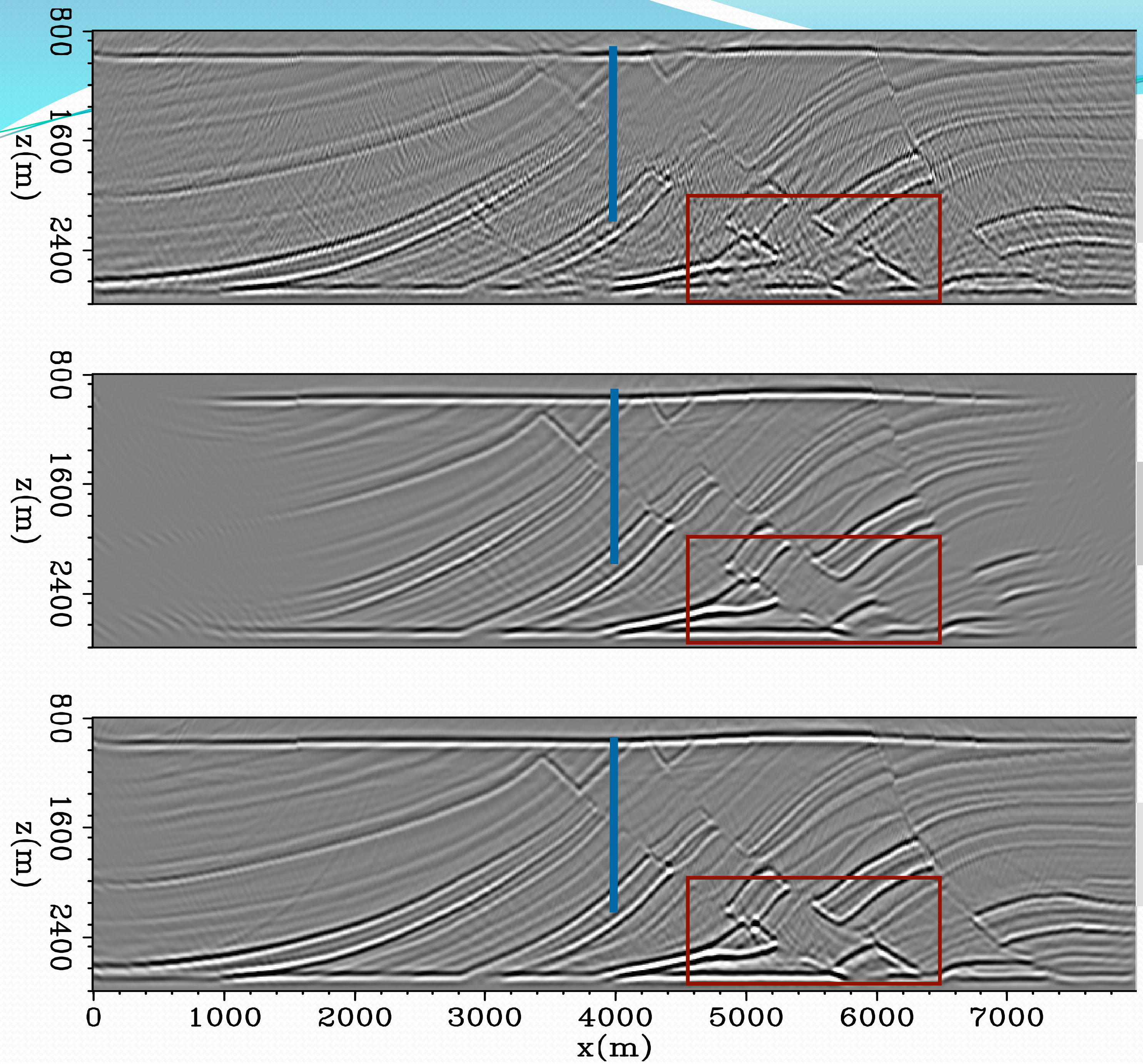


Streamer Inversion
OBN Inversion
Joint Inversion
z(m)
800
1600
2400
0
1000
2000
3000
4000
5000
6000
7000
x(m)


800
1600
2400
z(m)
Streamer Inversion
OBN Inversion
Joint Inversion
0
1000
2000
3000
4000
5000
6000
7000
x(m)

Comparison of Streamer and OBN imaging



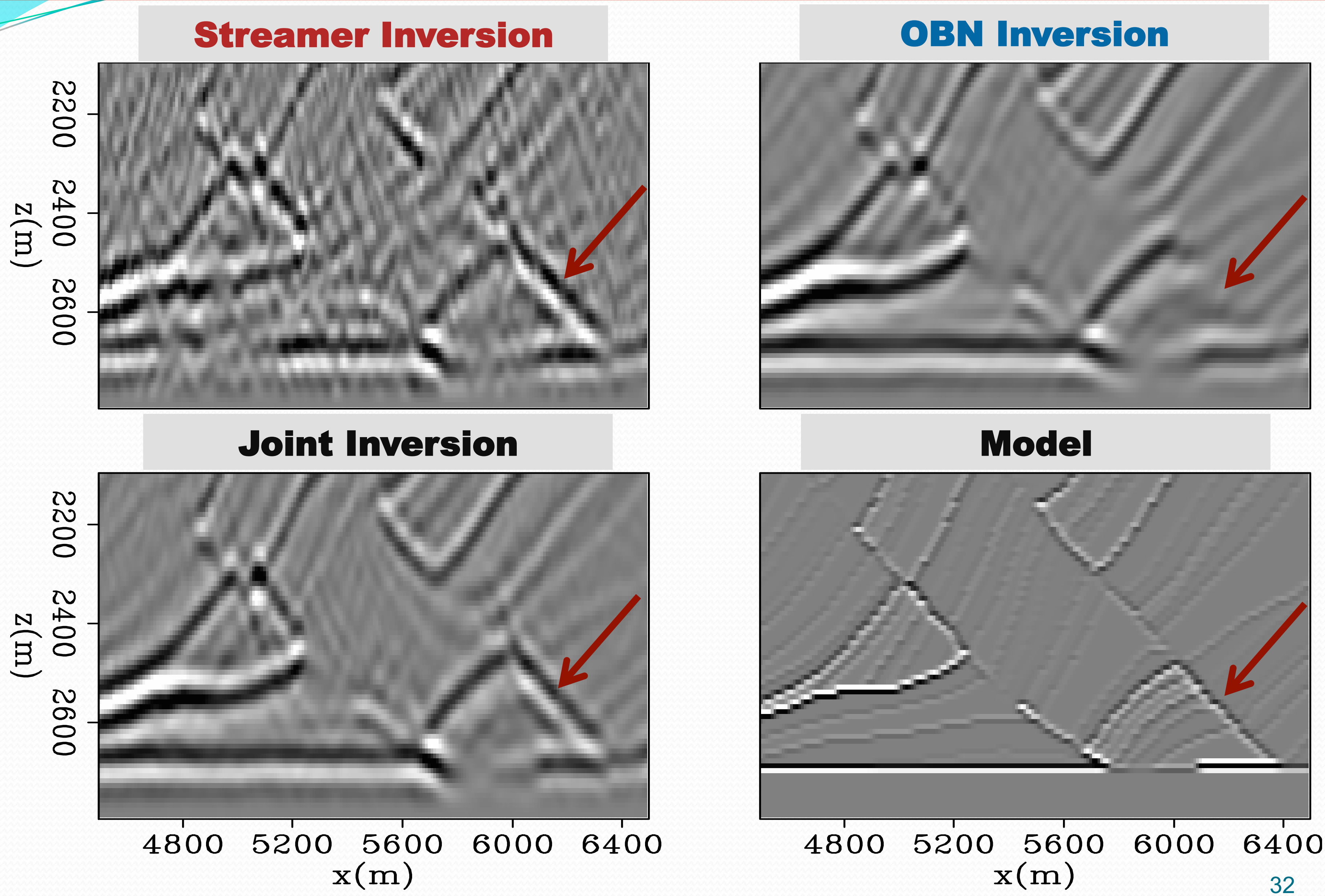


Streamer Inversion

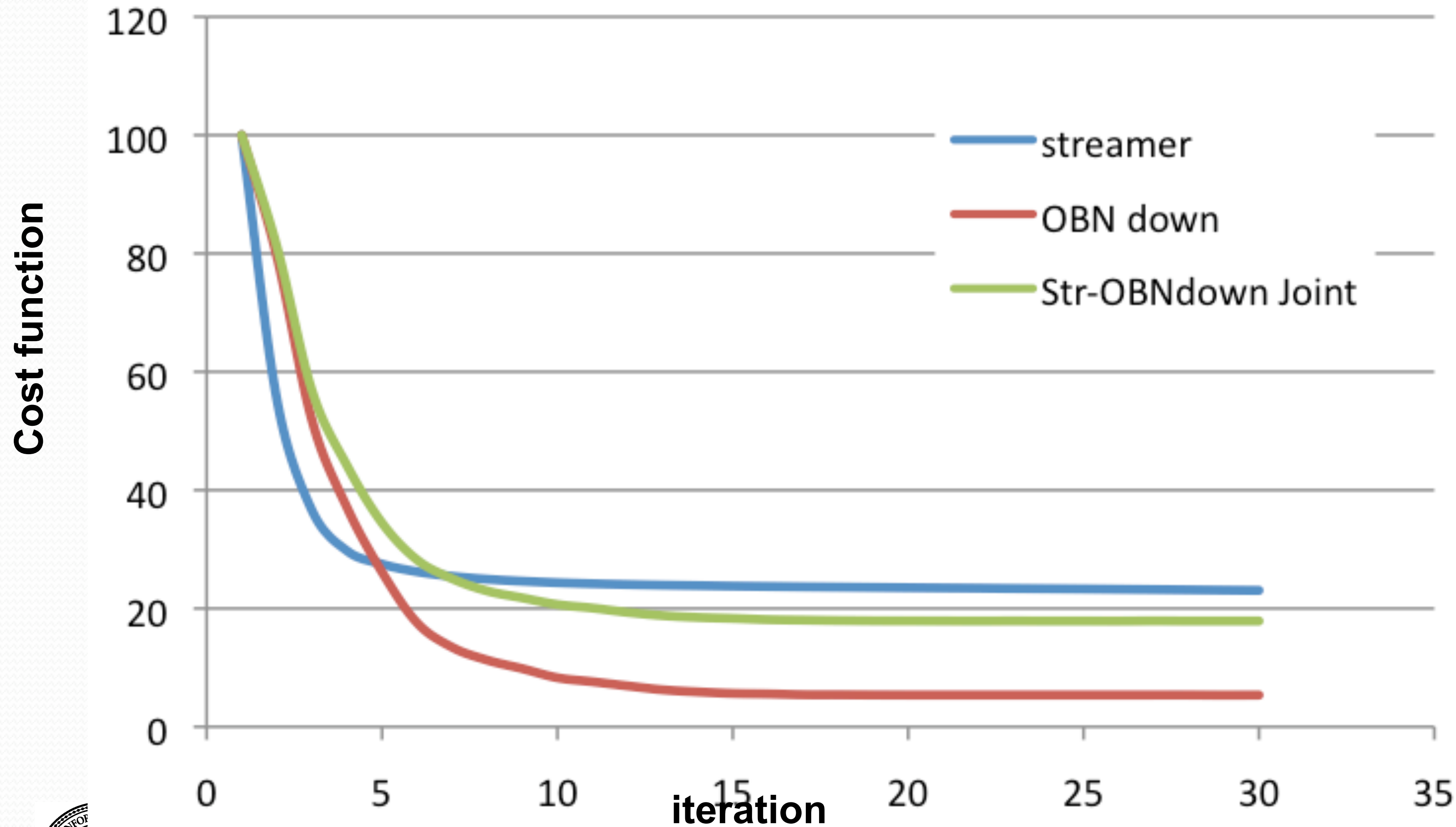
OBN Inversion

Joint Inversion

Comparison of Streamer and OBN imaging



Convergence



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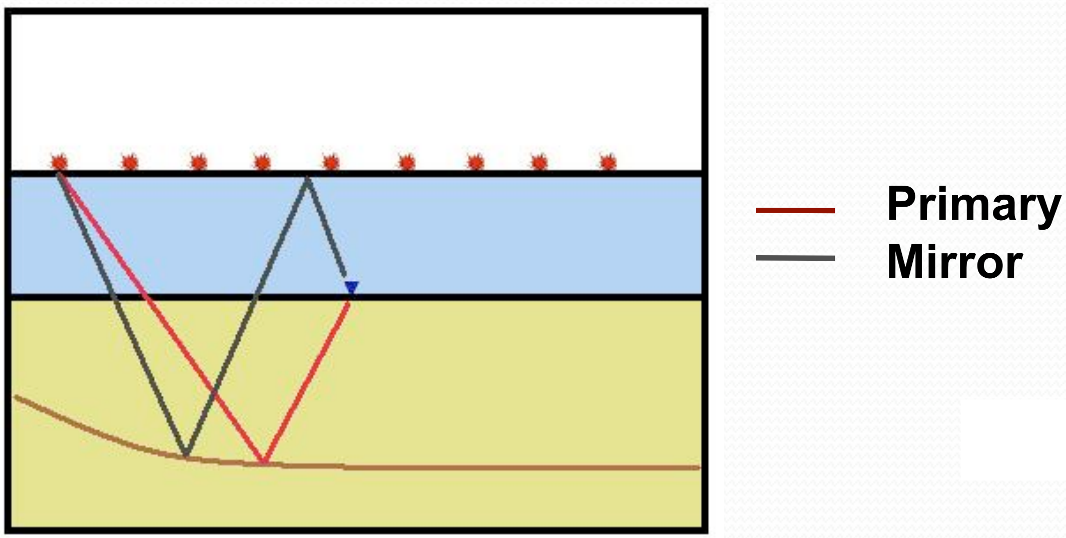
Conclusions

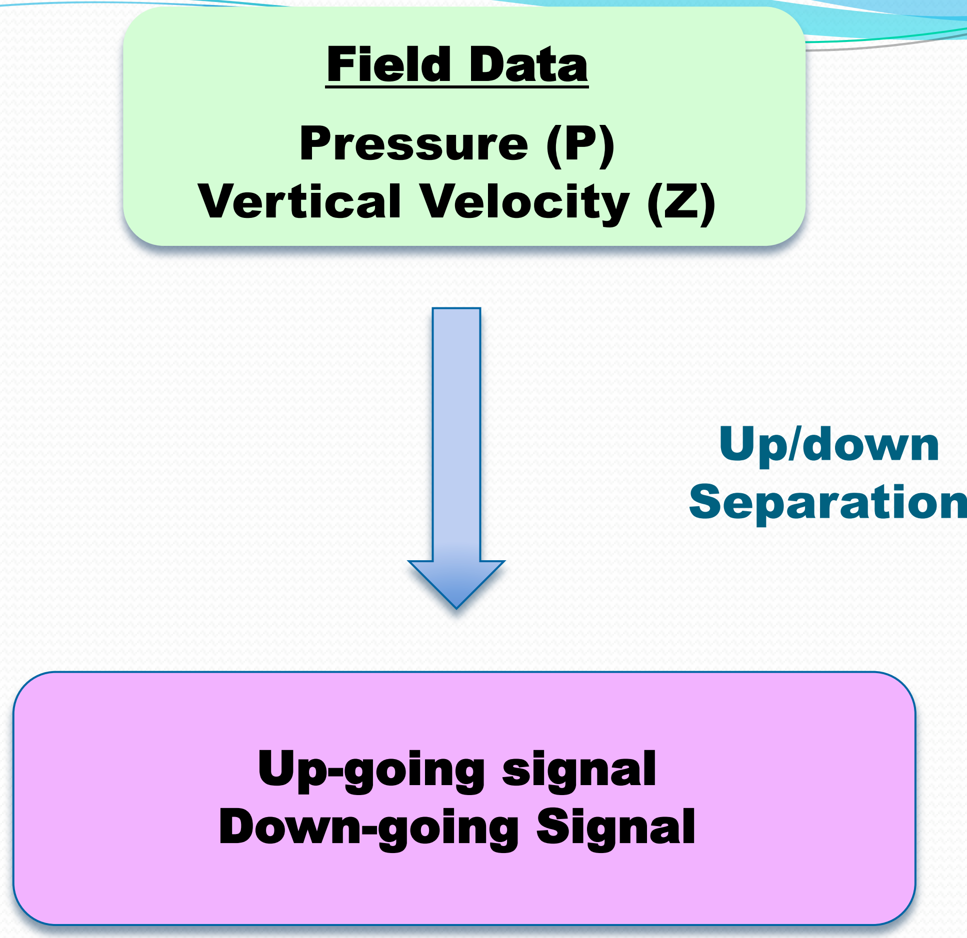
- **Joint inversion can coherently combine the information from NAZ and OBN data**
- **Results from a 2D synthetic Marmousi show that**
  - **Joint image is better than the streamer image with undershooting**
  - **Joint image is better than the OBN image along dipping reflectors**
- **Can extend to include all three modes OBN-up, OBN-down, and streamer**

Backup slides

Common Receivers

- Processing is sorted by common receiver gathers
- Therefore, reciprocity is used.




Field Data
Pressure (P)
Vertical Velocity (Z)
Up/down
Separation
Up-going signal
Down-going Signal

Formulation - Migration Operator

The migration operator is a linear operator applied to the recorded data

$$\mathbf{m} = \mathbf{L}^T \mathbf{d}$$

$$m_{mig}(x) = \sum_{\mathbf{x}_r, \mathbf{x}_s, \omega} \omega^2 f_s^*(\omega) G^*(x_r, x) G^*(x, x_s) d(x_r, x_s, \omega)$$

$d(x_r, x_s, \omega)$	deconvolved data from source x_s to receiver x_r at frequency ω
$G(x, x_s)$	Green function of the two-way acoustic constant density wave equation
$f_s(\omega)$	incident waveform that match the deconvolved data

Formulation - Migration Operator

The migration operator is a linear operator applied to the recorded data

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$$m_{mig}(x) = \sum_{\mathbf{x}_r, \mathbf{x}_s, \omega} \omega^2 f_s^*(\omega) G^*(x_r, x) G^*(x, x_s) d(x_r, x_s, \omega)$$

$$m_{mig}(x) = \sum_{\mathbf{x}_r, \mathbf{x}_s, \omega} U_s^*(x_r, x_s, \omega) G^*(x, x_s) d(x_r, x_s, \omega)$$

Formulation – Modeling operator

The migration operator is a linear operator applied to the recorded data

$$\mathbf{d}^{mod} = \mathbf{L}\mathbf{m}$$

$$d_{mod}(x_r, x_s, \omega) = \sum_{\mathbf{x}} U_s(x_r, x, \omega) G(x, x_s) m(x)$$