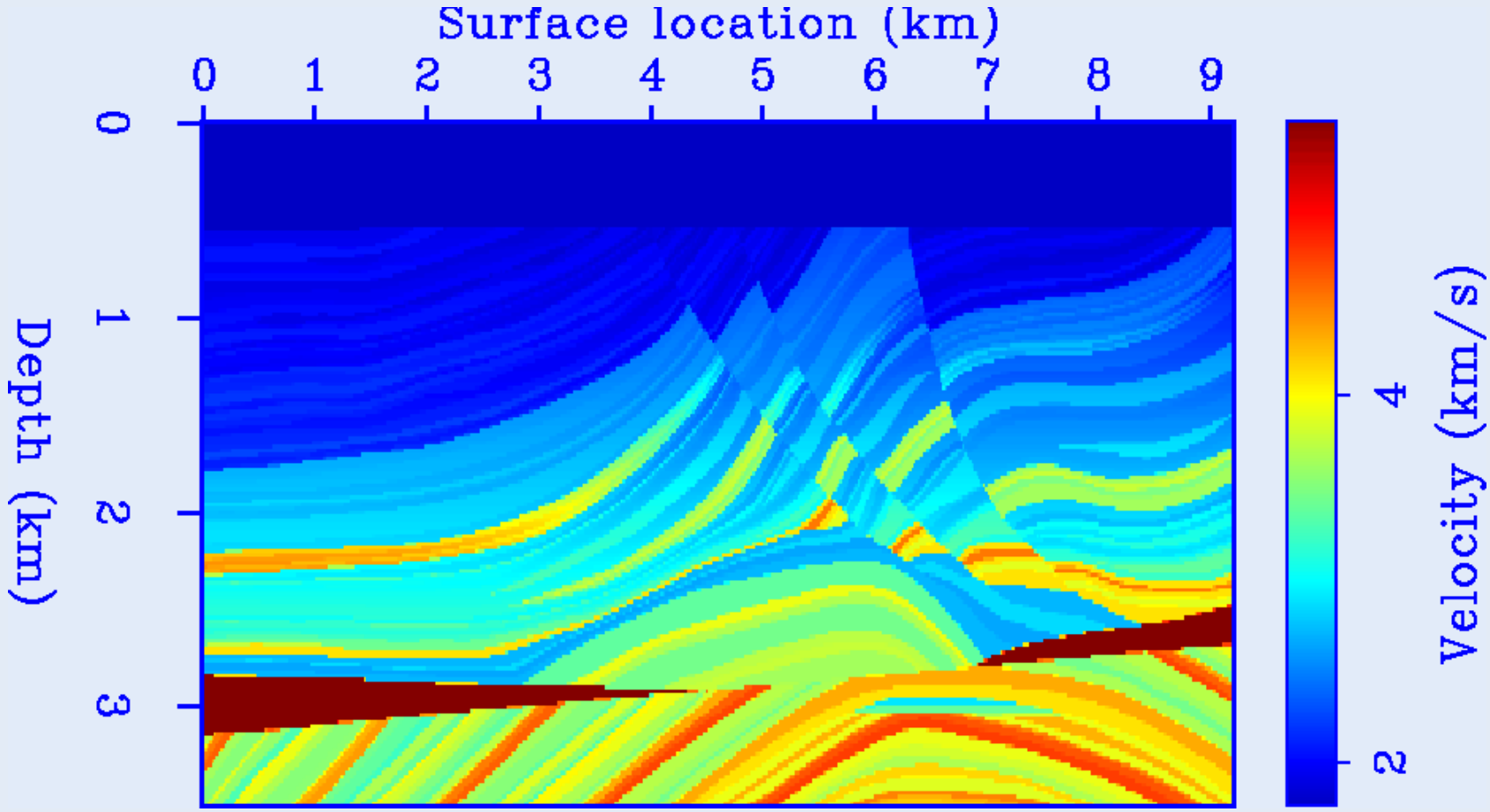
Tomographic Full Waveform Inversion (TFWI)

Biondo Biondi & Ali Almomin

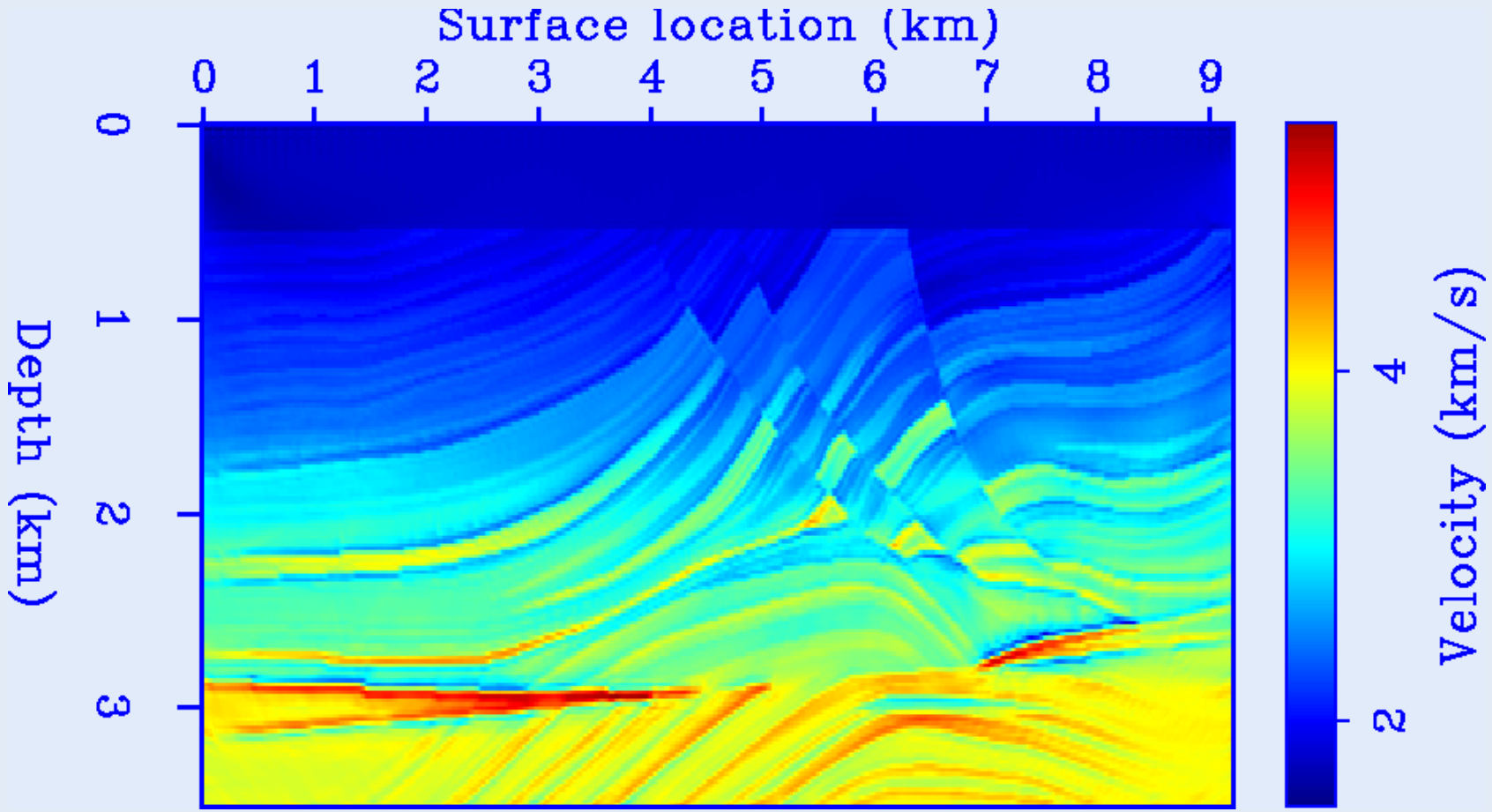
SEP 147 *pp. 1-12*

STANFORD EXPLORATION PROJECT

“Deep water” Marmousi model



TFWI result


Surface location (km)
0
1
2
3
4
5
6
7
8
9
Depth (km)
0
1
2
3
Velocity (km/s)
2
4

Simultaneous inversion for all model wavelengths from all data frequencies –Broadband inversion

- Reflections present in data low frequencies help inversion of model long wavelengths
- Transmissions effects present in data high frequencies help inversion of model long wavelengths

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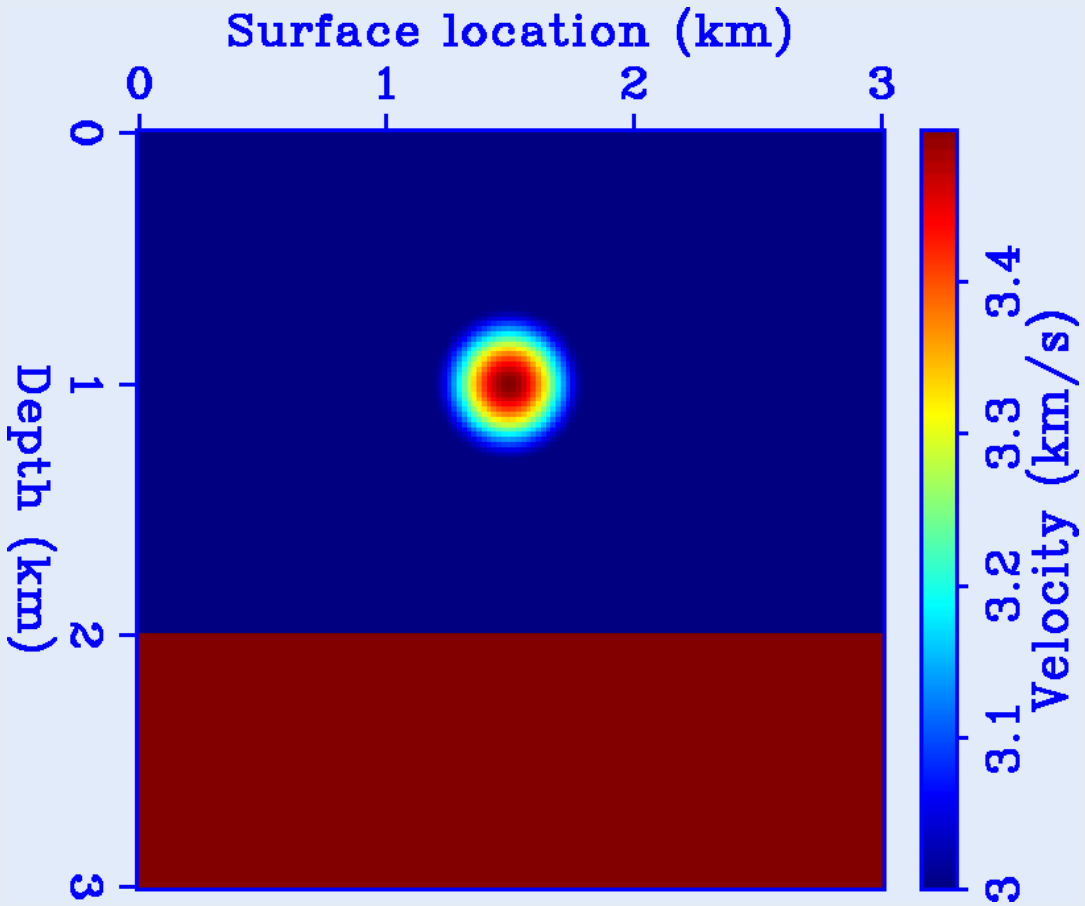
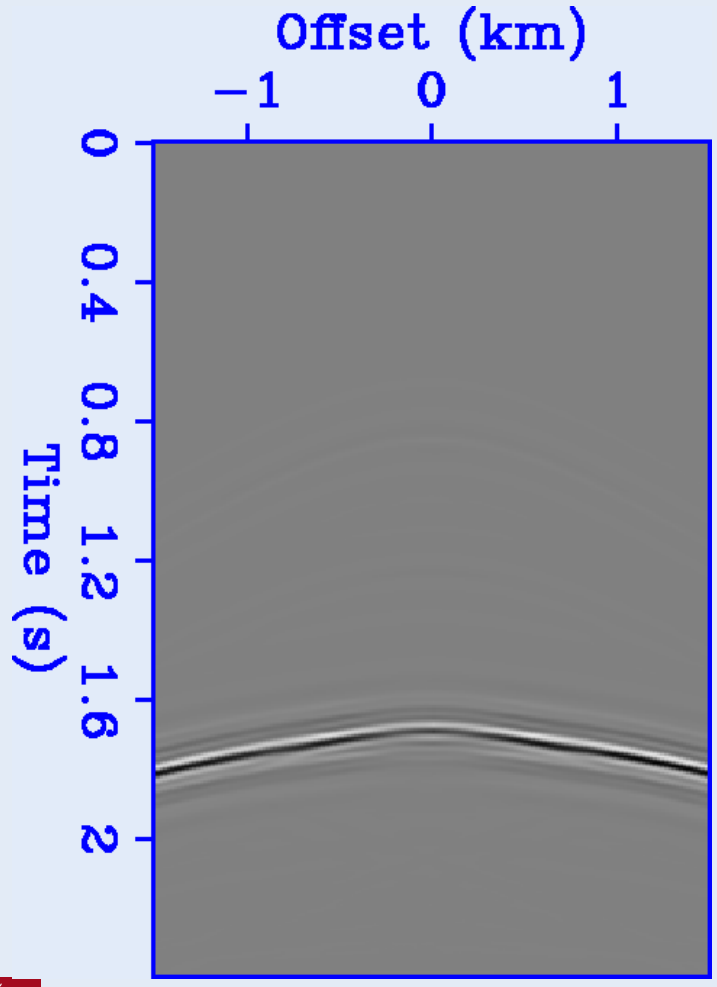
Gaussian anomaly model

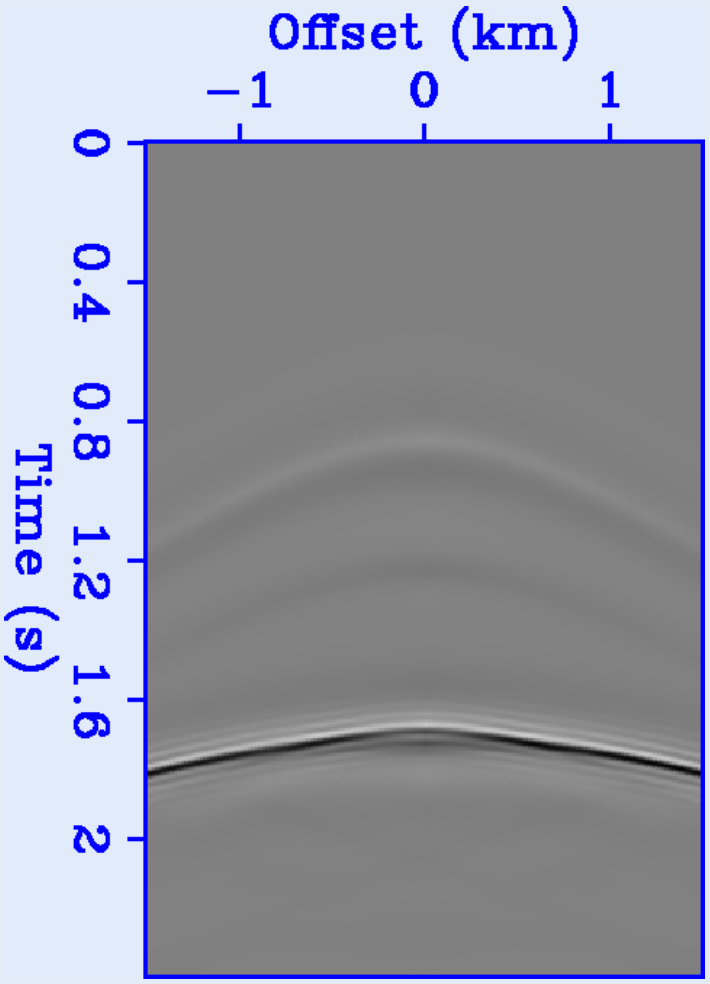


Shots recorded in the middle

"Old" data (8-40 Hz)

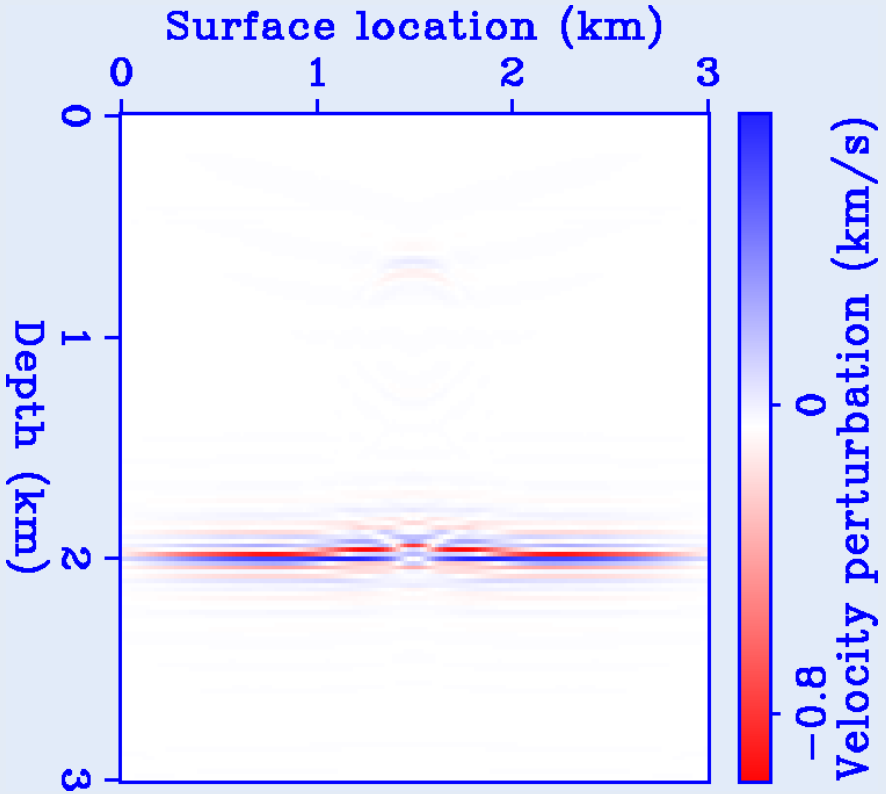


"New" data (4-40 Hz)



Model updates

"Old" data (8-40 Hz)



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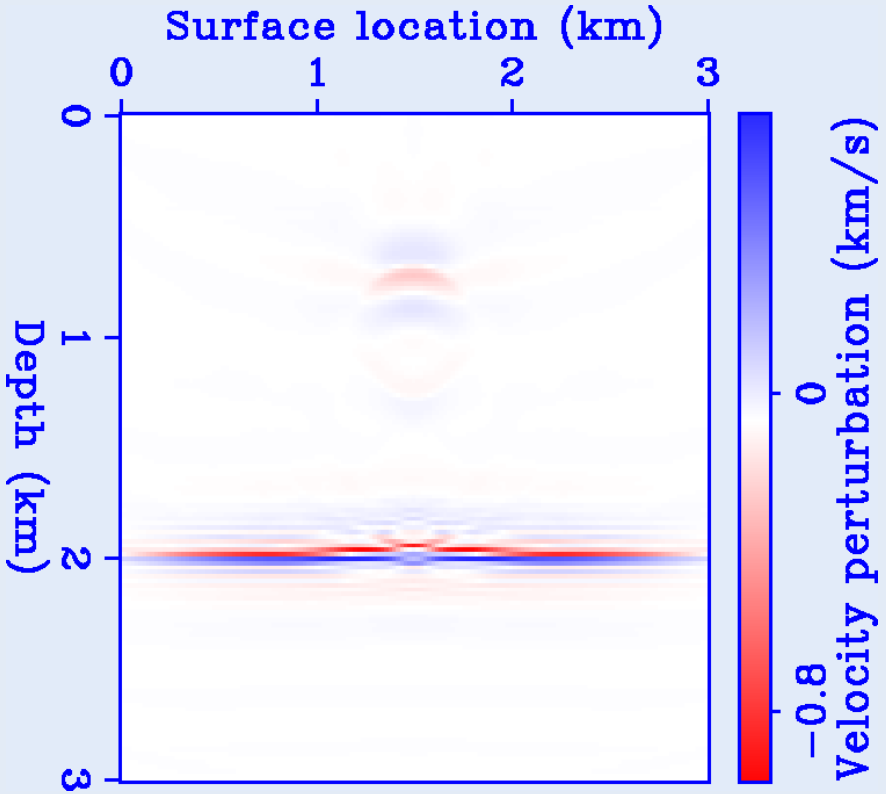

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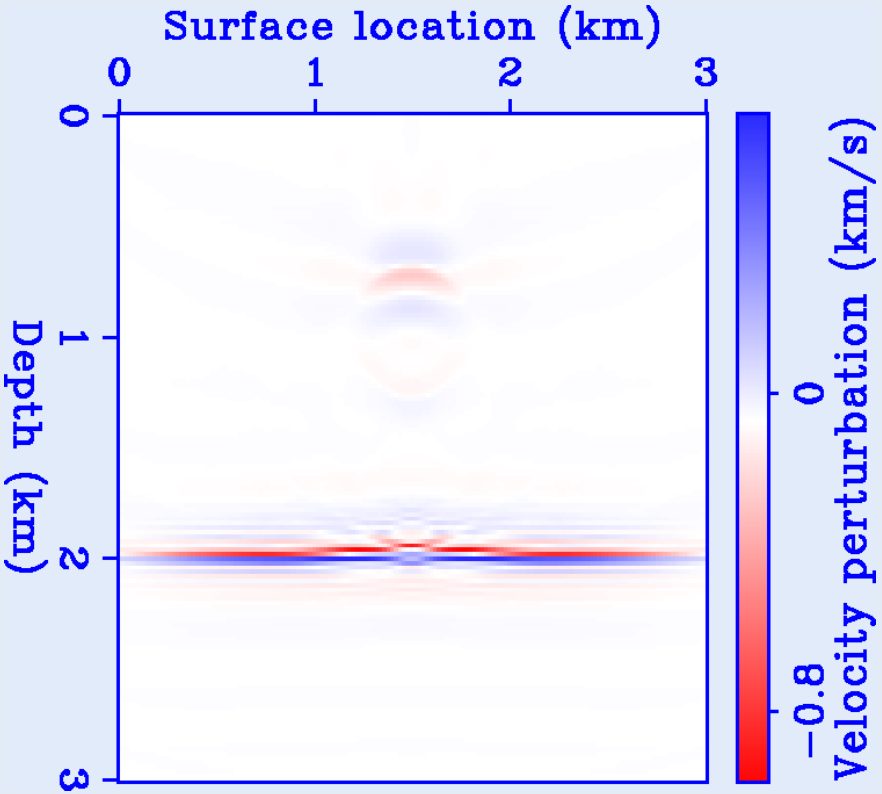
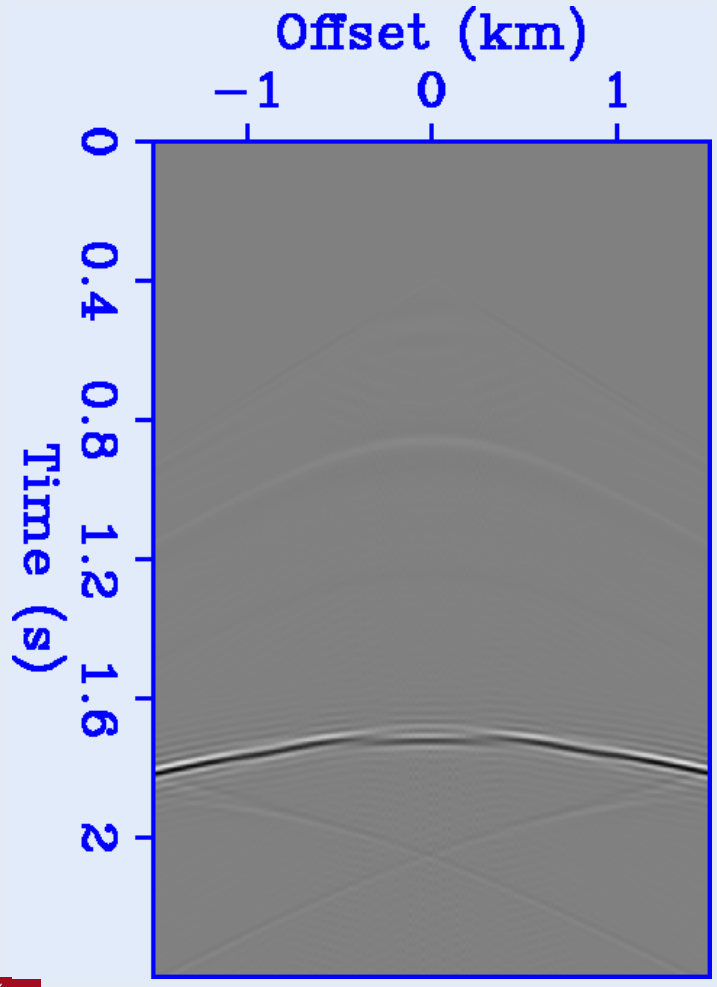
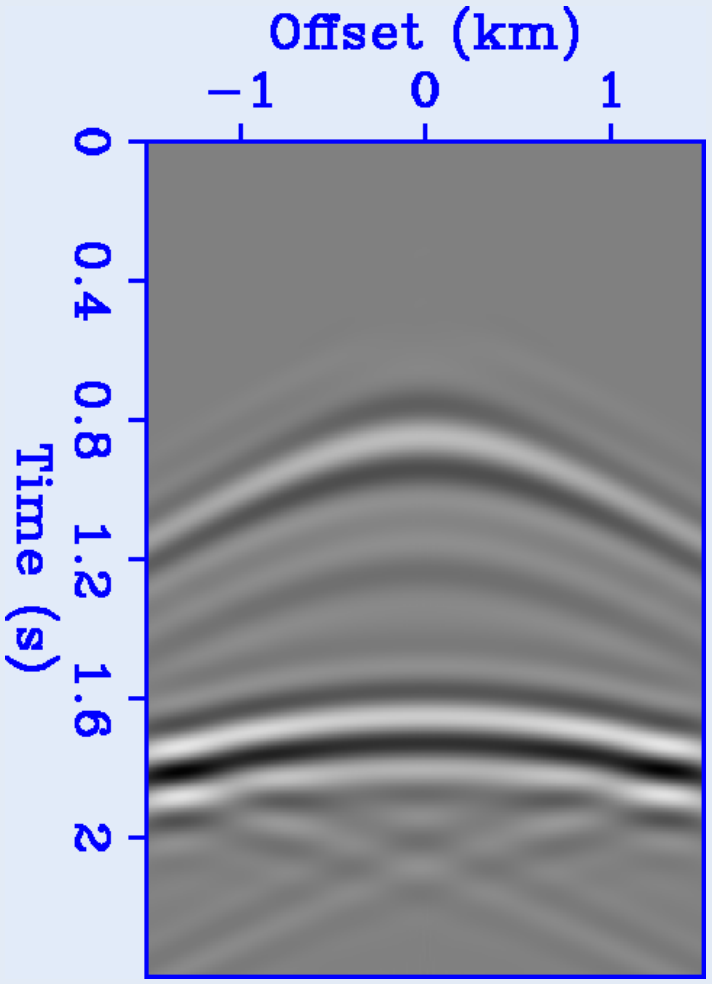


Data modeled after 1st iteration

Full bandwidth (4-50 Hz)

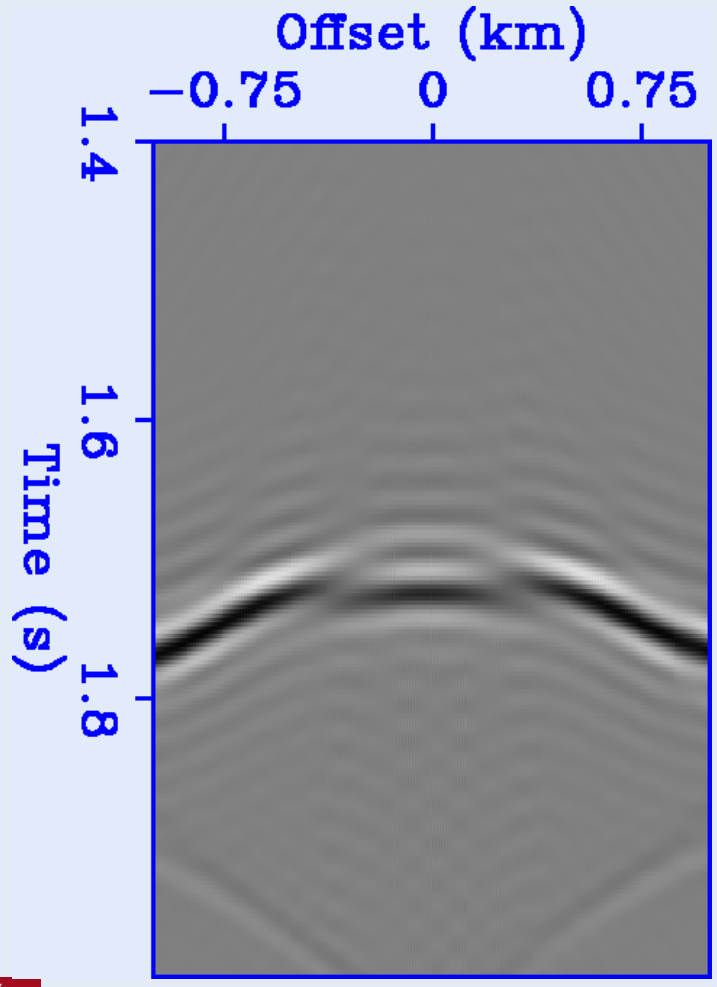


Low frequencies (4-8 Hz)

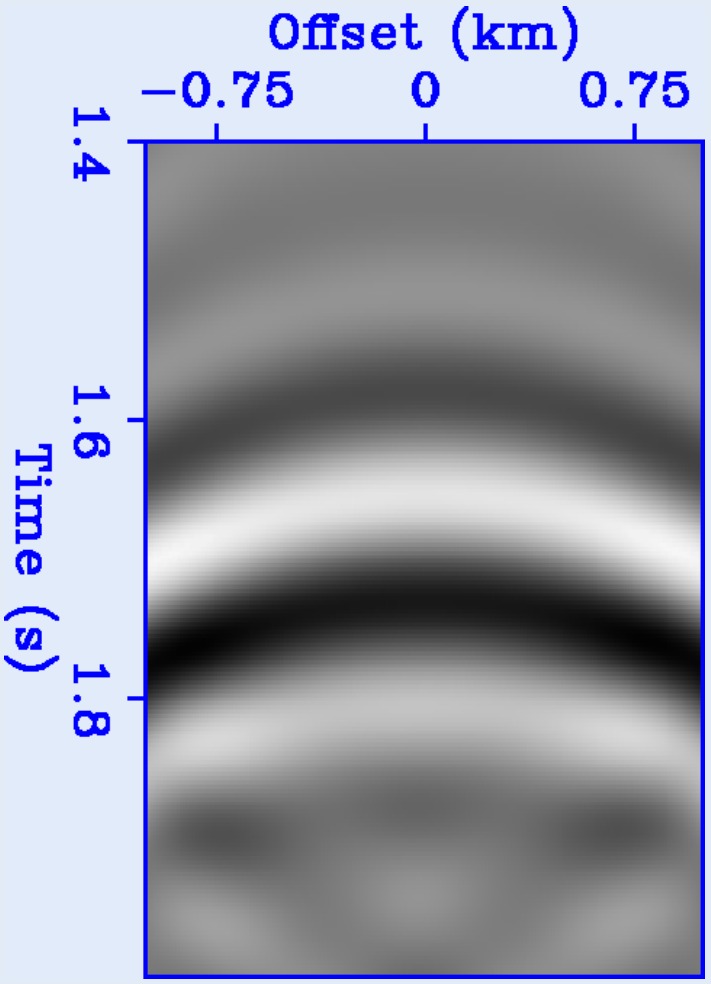


Data modeled after 1st iter. (zoom)

Full bandwidth (4-50 Hz)

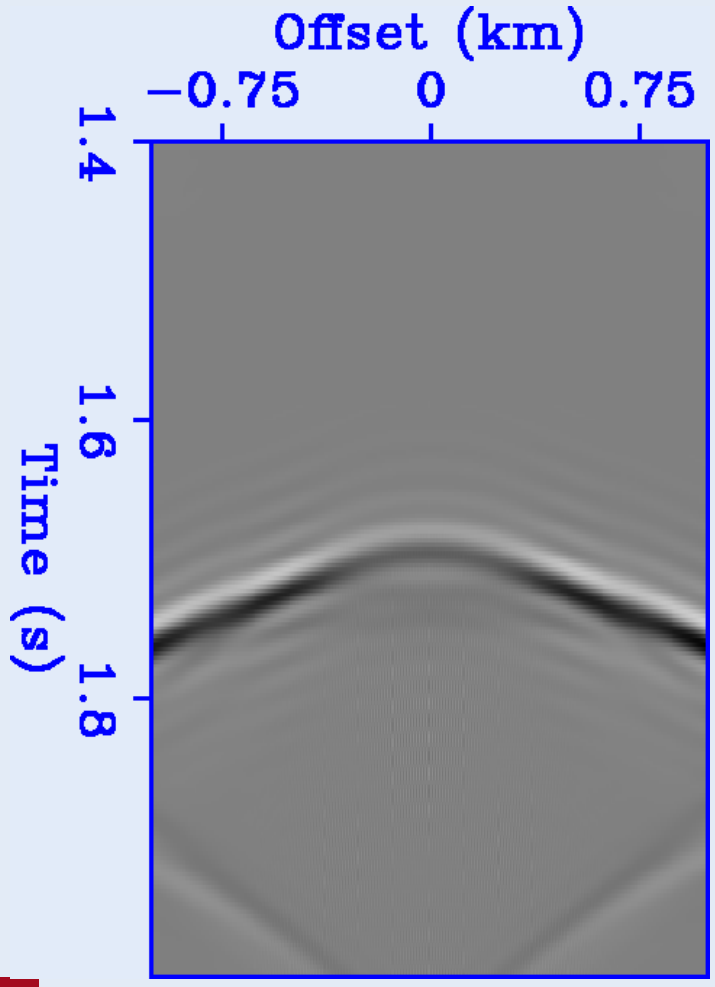


Low frequencies (4-8 Hz)

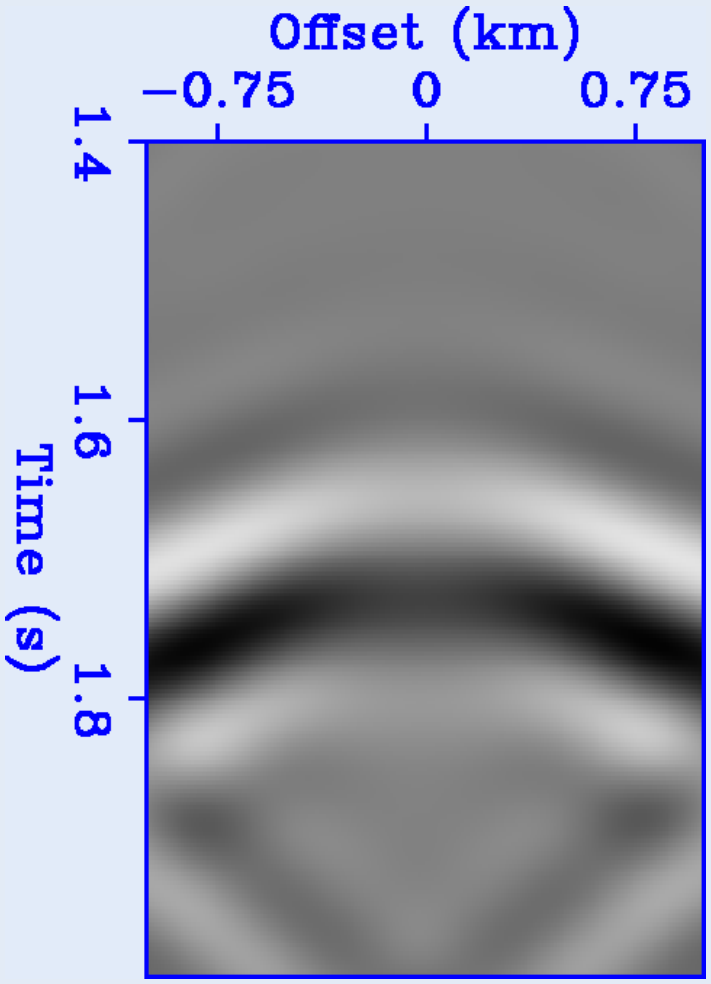


Recorded data (zoom)

Full bandwidth (4-50 Hz)

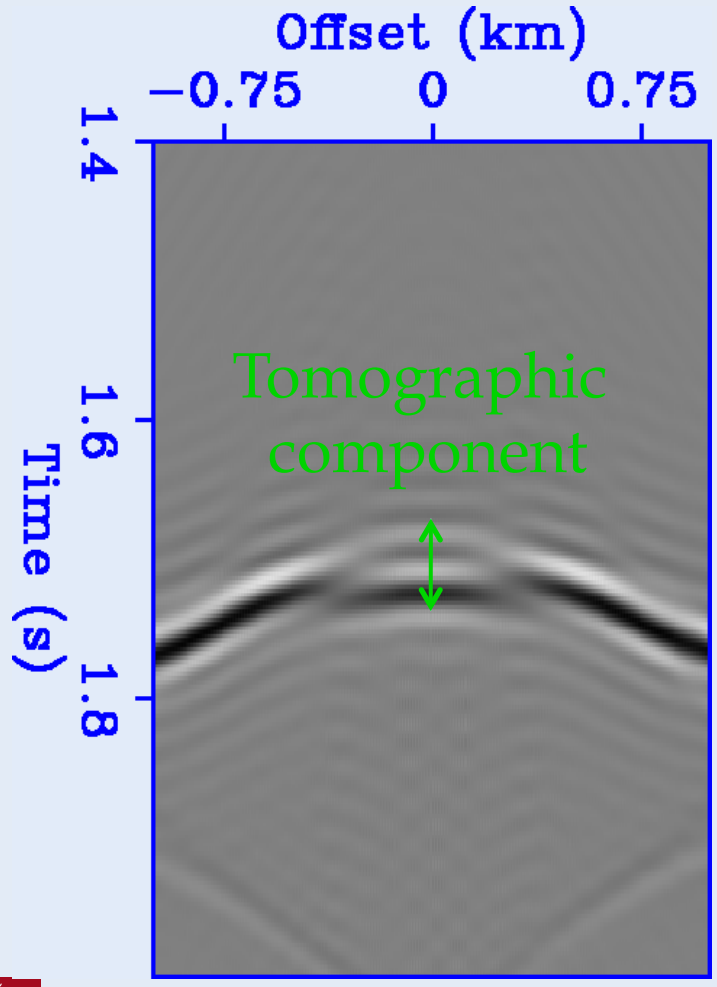


Low frequencies (4-8 Hz)

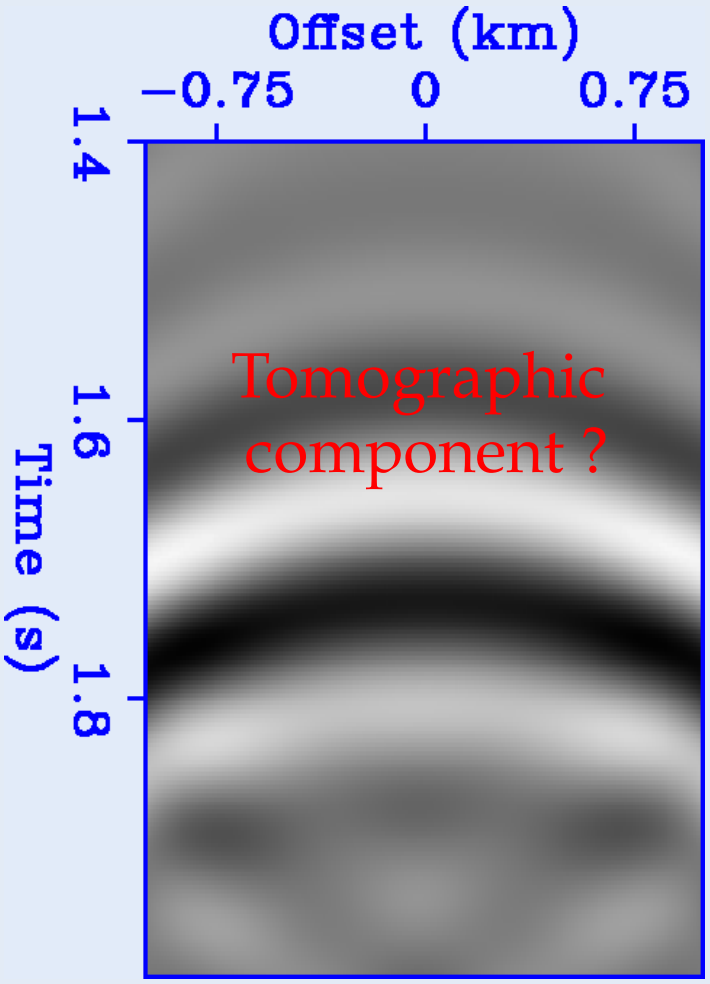


Data modeled after 1st iter. (zoom)

Full bandwidth (4-50 Hz)

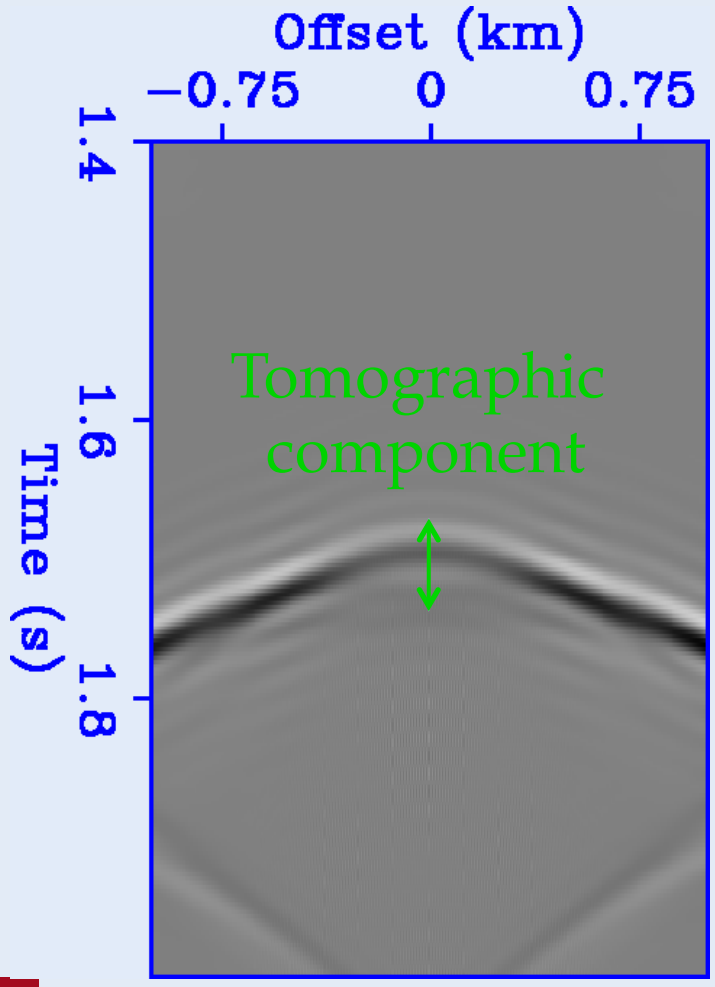


Low frequencies (4-8 Hz)

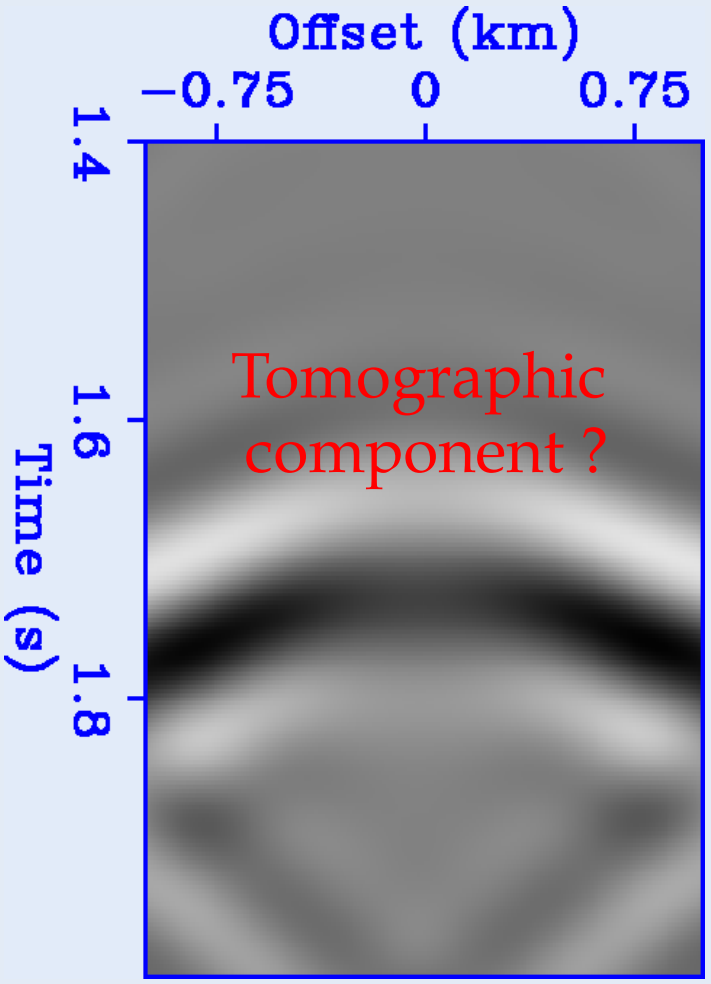


Recorded data (zoom)

Full bandwidth (4-50 Hz)



Low frequencies (4-8 Hz)



Elements of broadband inversion

- Solves for one model (v)

Data-domain objective function

Include tomographic component

Avoid cycle skipping

Elements of broadband inversion

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Include tomographic component

Avoid cycle skipping

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Elements of broadband inversion

- Solves for one model (v)
- Has data-domain objective function
- Includes tomographic component
- Avoids cycle skipping

Broadband inversion: try #1 (FWI)

- ✓ Solves for one model (v)
- ✓ Has data-domain objective function
- ✓ Includes tomographic component
- ✗ Avoids cycle skipping

$$J_{\mathbf{d}}(\mathbf{v}) = \left\| \mathfrak{L}(\mathbf{v}) - \mathbf{d} \right\|_2^2$$

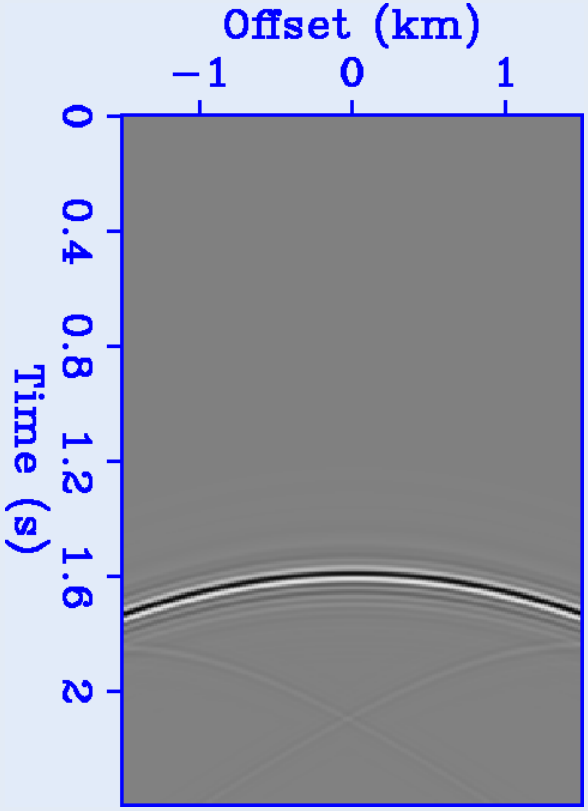
$\mathfrak{L}$: modeling operator,

$\mathbf{v}$: velocity model,

$\mathbf{d}$: recorded data.

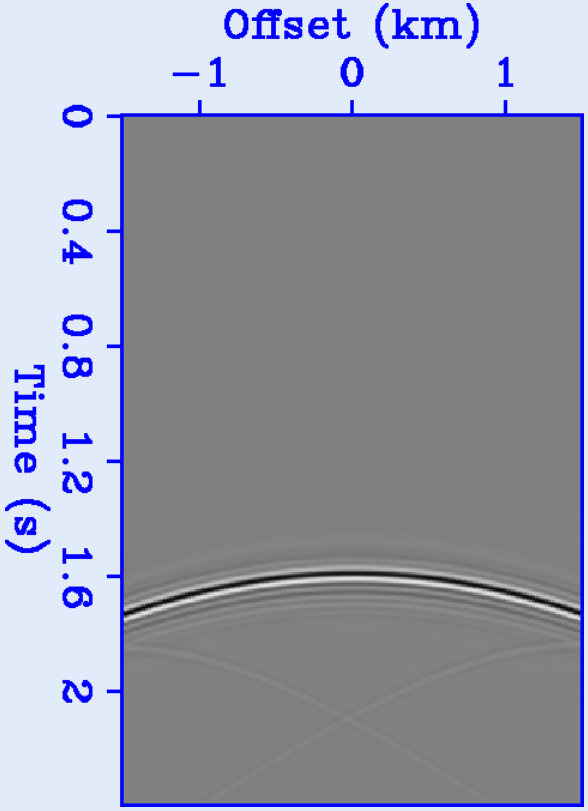
One reflector model

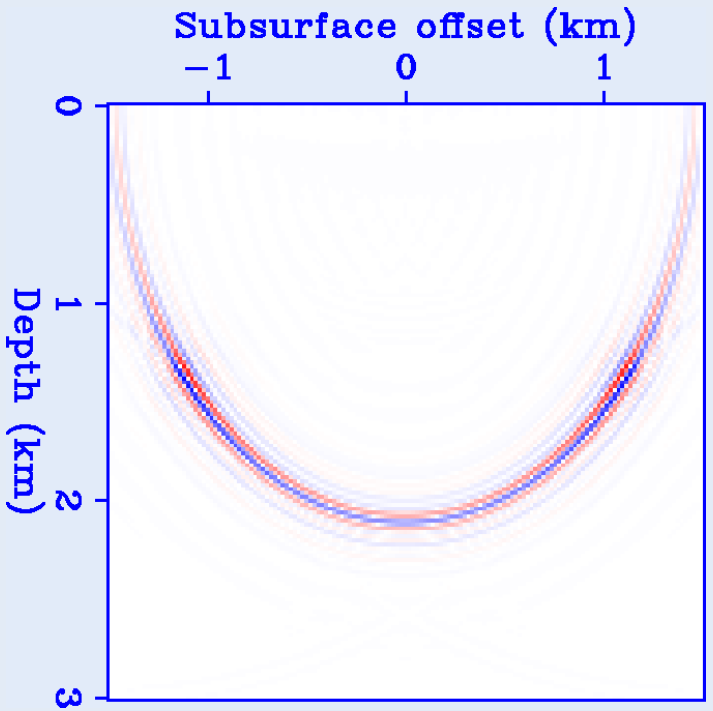
Recorded data



One reflector – High velocity

Recorded data

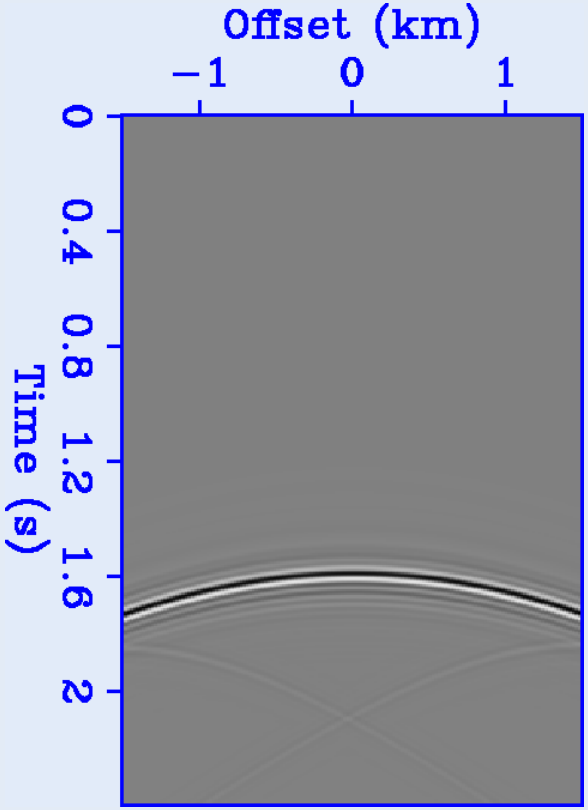




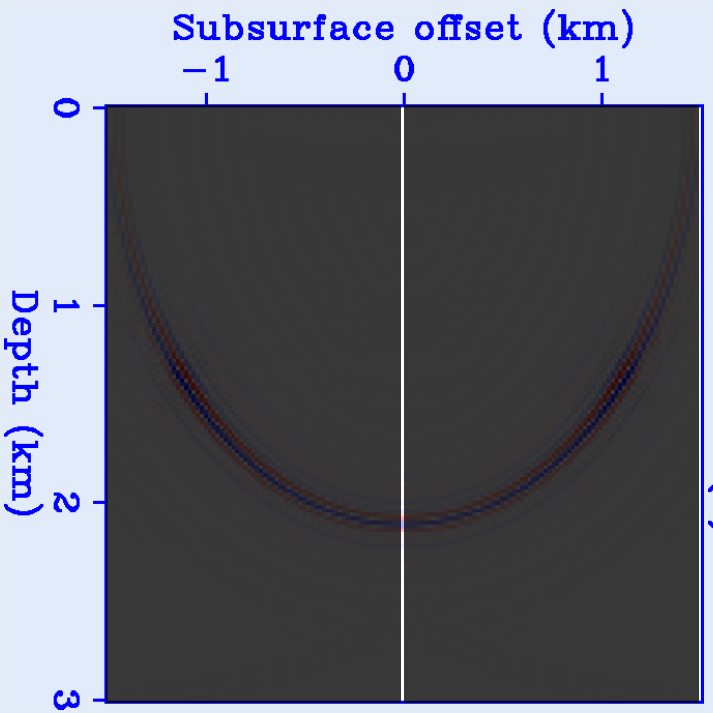
Common Image Gather

Data modeled after 1st iteration

Recorded data

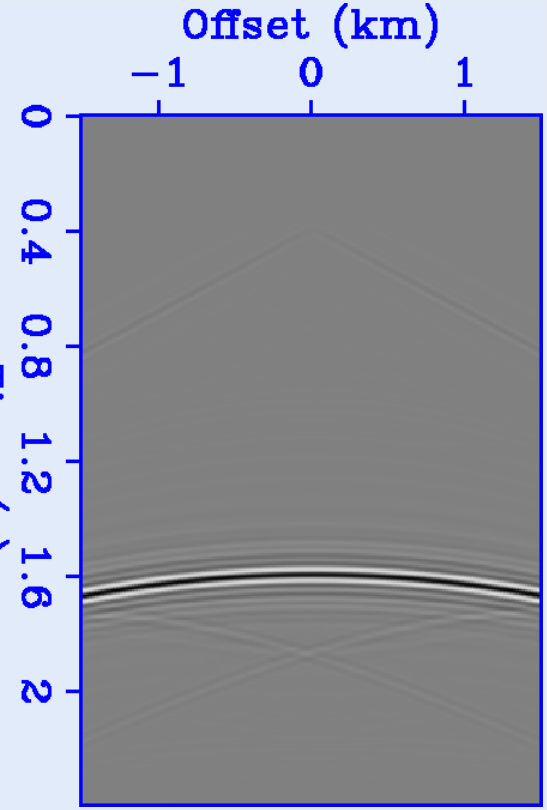


FWI - Model update



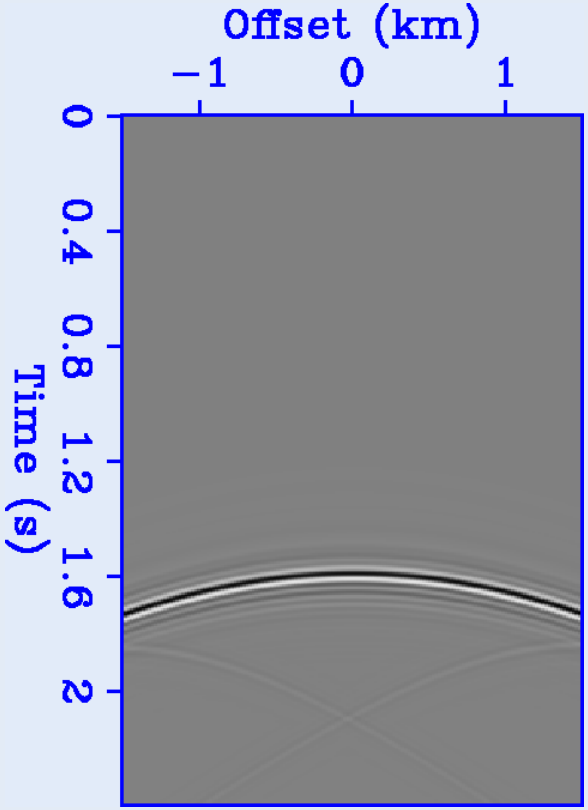
Common Image Gather

Modeled data



Modeled vs. recorded data

Recorded data



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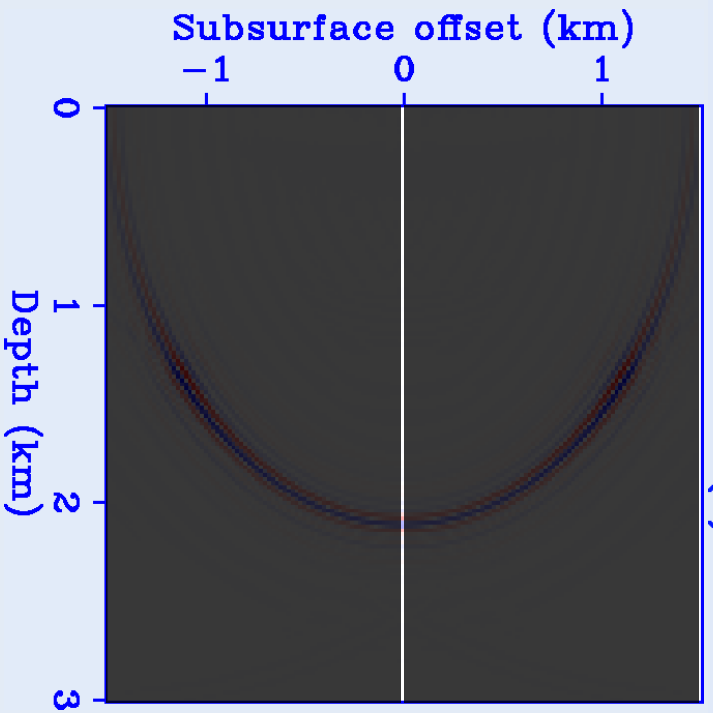
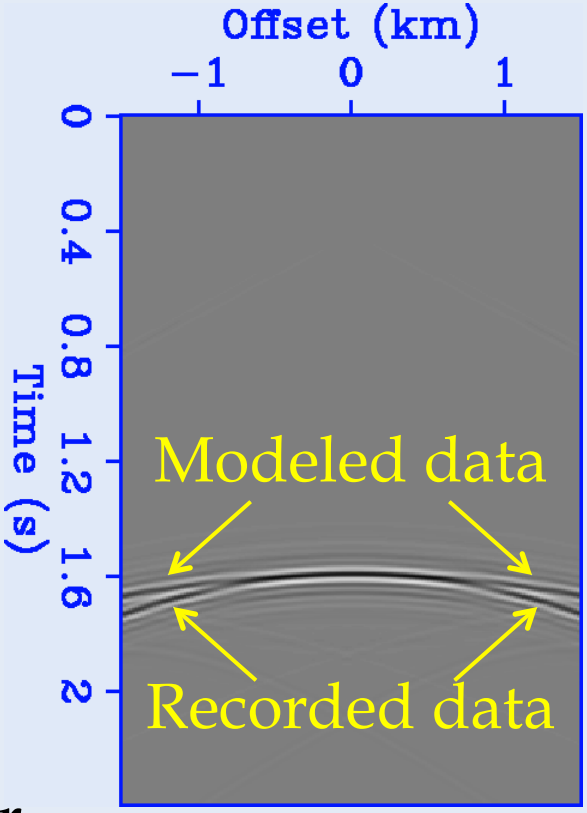
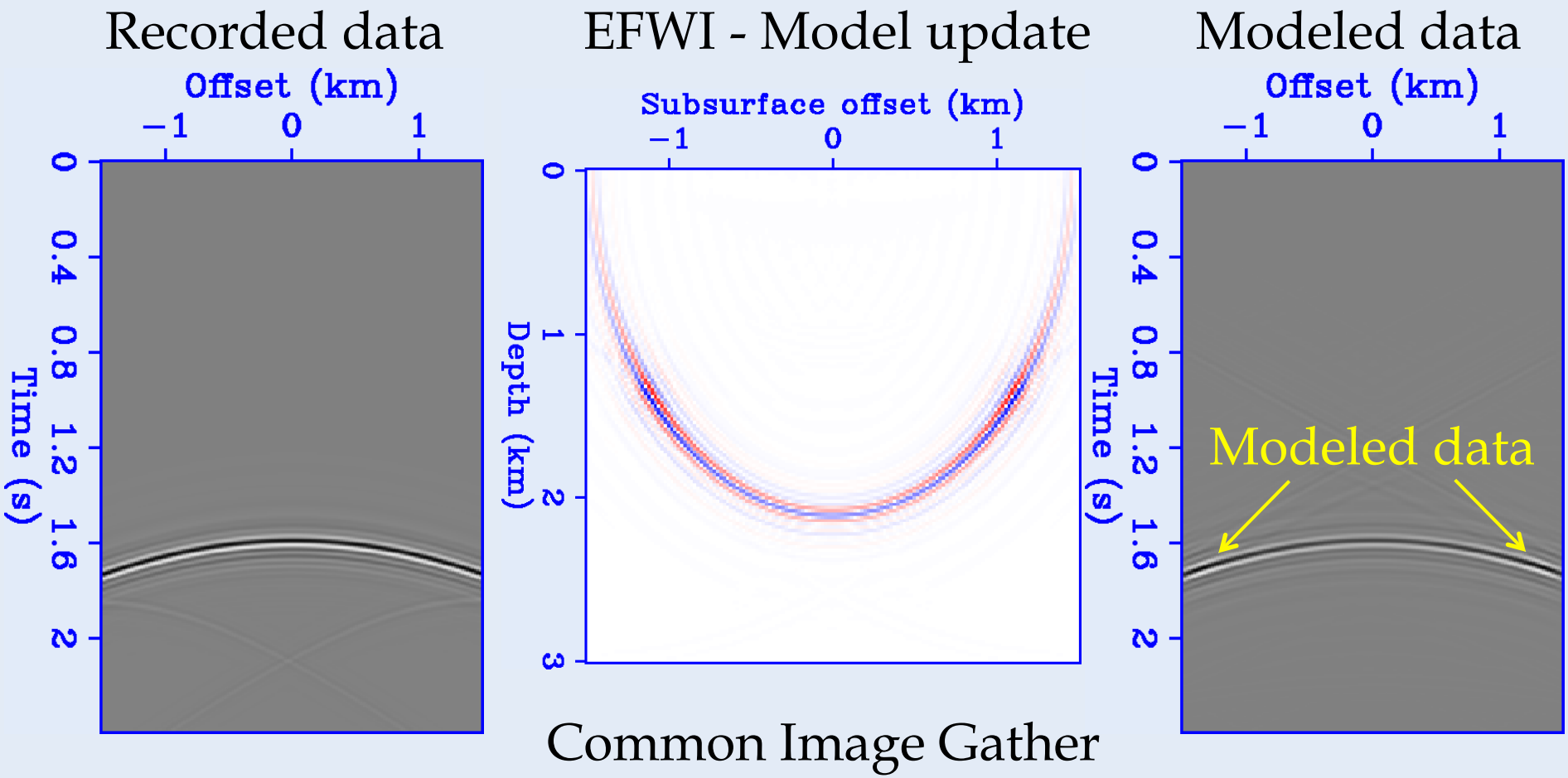


Common Image Gather

Mod. & Rec. data



Modeled vs. recorded data



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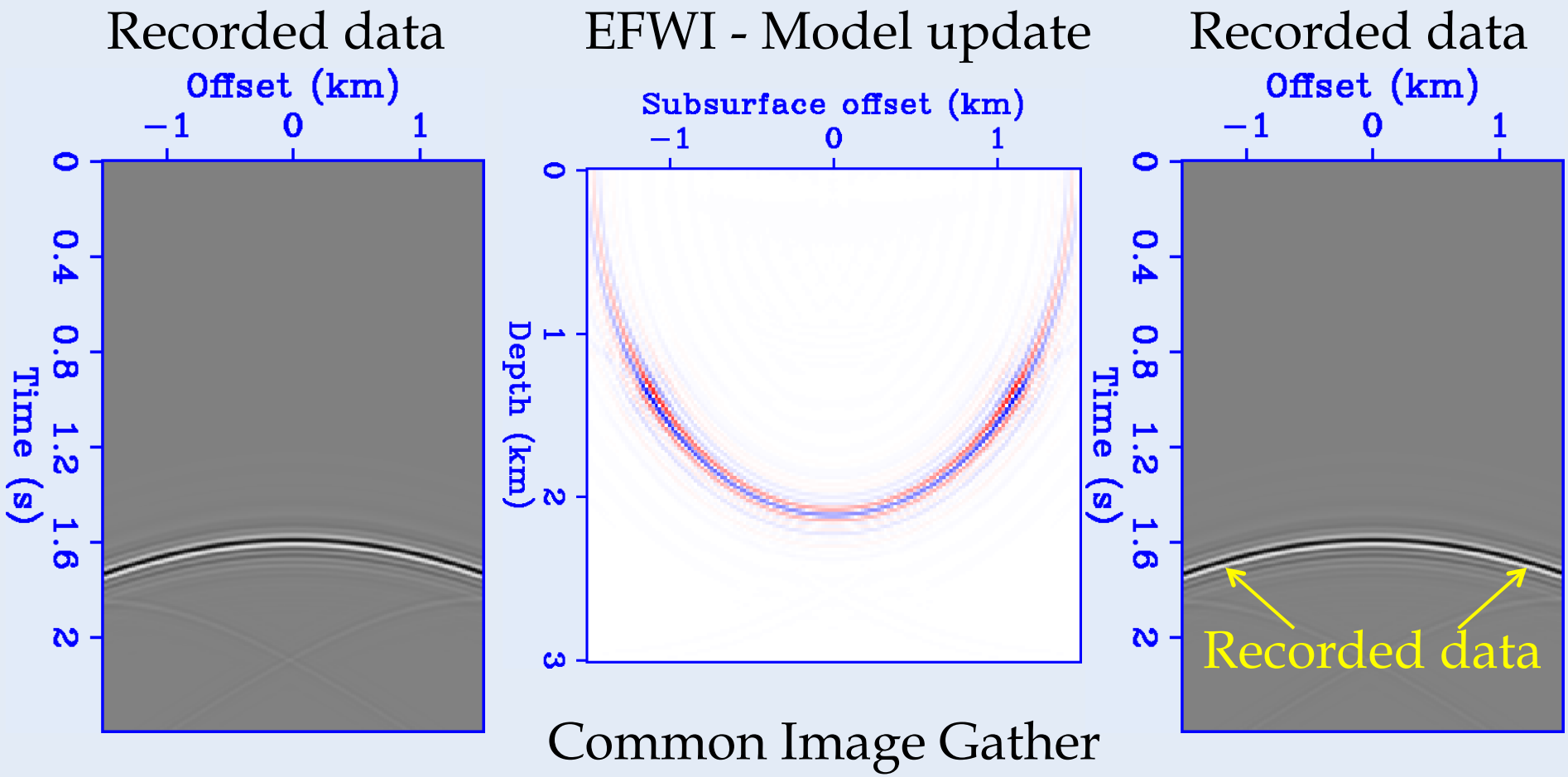

Broadband inversion: try #2 (EFWI)

- ✓ Solves for one model (v)
- ✓ Has data-domain objective function
- ✗ Includes tomographic component
- ✓ Avoids cycle skipping

$$J_{\mathbf{d}}(\tilde{\mathbf{v}}) = \left\| \tilde{\mathfrak{L}}(\tilde{\mathbf{v}}(\mathbf{h})) - \mathbf{d} \right\|_2^2$$

$\tilde{\mathfrak{L}}$: new modeling operator,

$\tilde{\mathbf{v}}(\mathbf{h})$: extended velocity,

$\mathbf{d}$: recorded data.

Symes, 2008
Geophysical Prospecting

Velocity model function of subsurface offsets???

- It requires solution of an "extended wave equation" where Laplacian of wavefield is convolved with velocity squared instead of simply multiplied.
- It is expensive!
- Assuring stability is a challenge because velocity may become negative at offsets $\neq 0$

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- ✗ Includes tomographic component
- ✓ Avoids cycle skipping

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$\tilde{\mathfrak{L}}$: new modeling operator,

$\tilde{\mathbf{v}}(\mathbf{h})$: extended velocity,

$\mathbf{d}$: recorded data.

Broadband inversion: TFWI

- ✓ Solves for one model (v)
- ✓ Has data-domain objective function
- ✓ Includes tomographic component
- ✓ Avoids cycle skipping

$$J_{\text{TFWI}}(\tilde{\mathbf{v}}) = J_{\mathbf{d}}(\tilde{\mathbf{v}}) \mp \left\| \mathfrak{F}(\tilde{\mathbf{v}}) \right\|_2^2$$

$\mathfrak{F}(\tilde{\mathbf{v}})$: measures focusing of $\tilde{\mathbf{v}}$

– Stacking after RMO,

+ DSO.

Broadband inversion: TFWI

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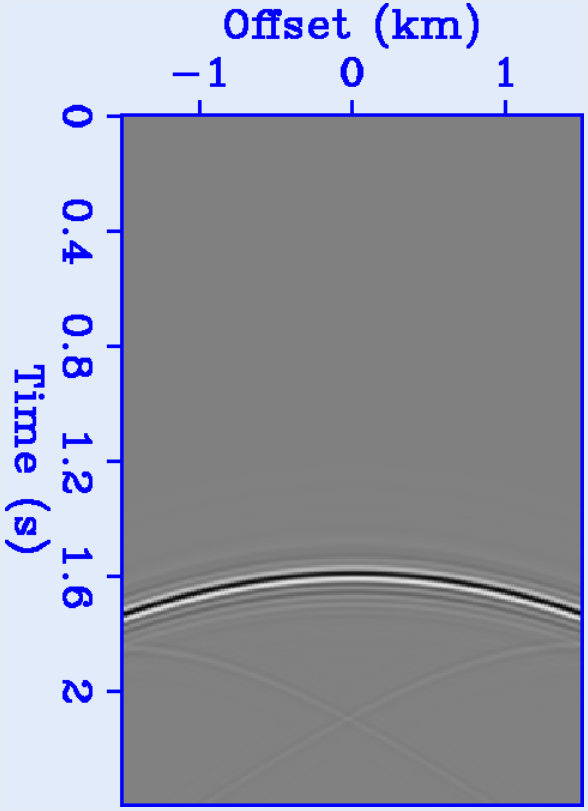
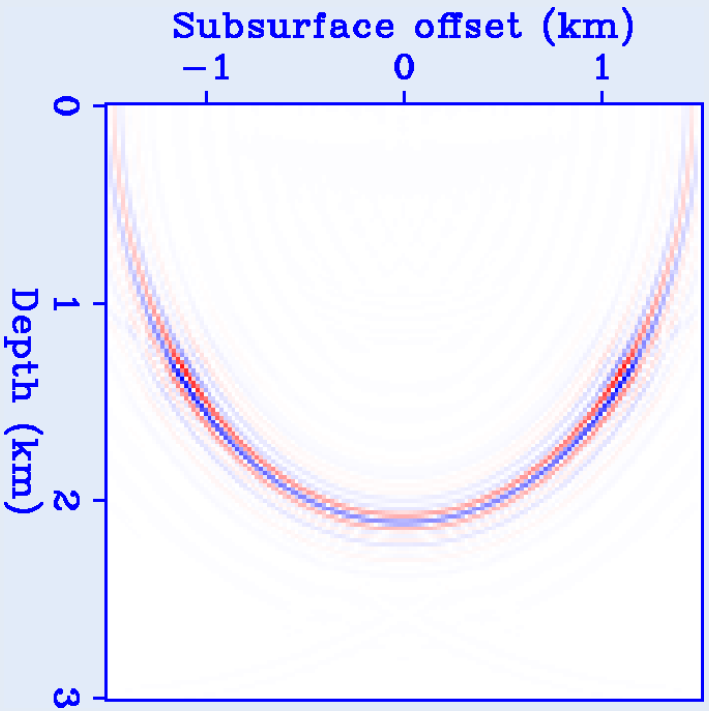
Symes, 2008
Geophysical Prospecting

One reflector – High velocity

Recorded data



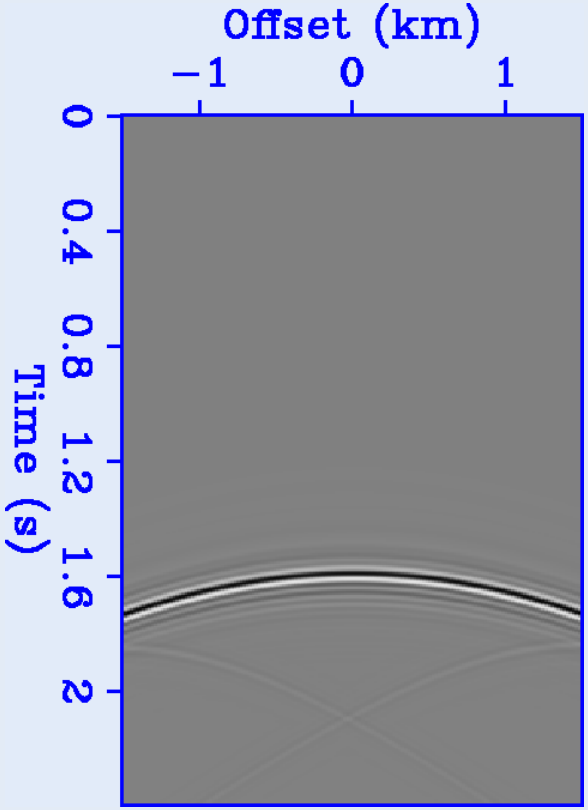
Model update at 1st iter.



Common Image Gather

One reflector – High velocity

Recorded data



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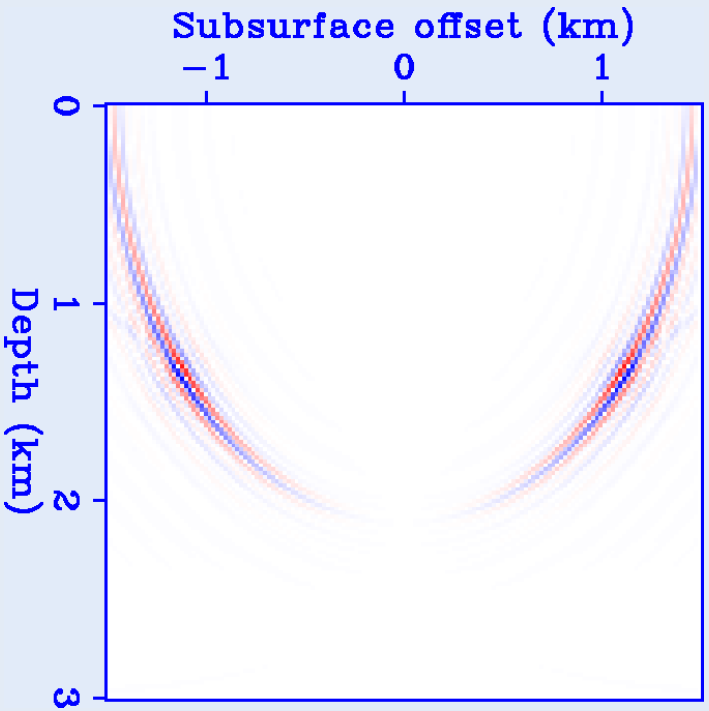
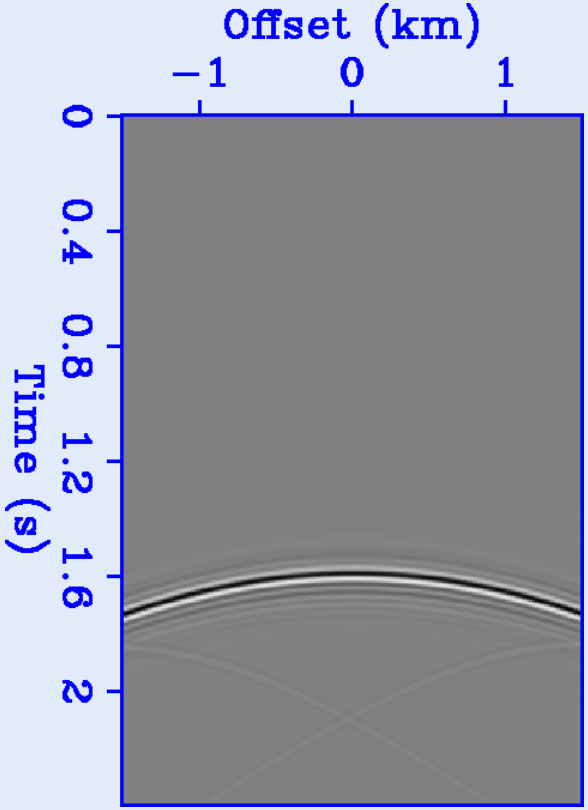


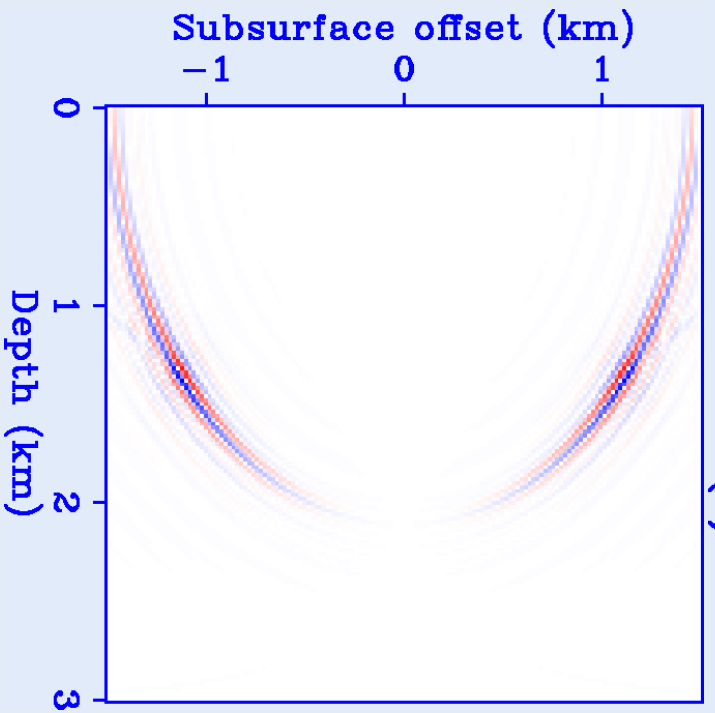
Common Image Gather after application of DSO

Modeled vs. recorded data

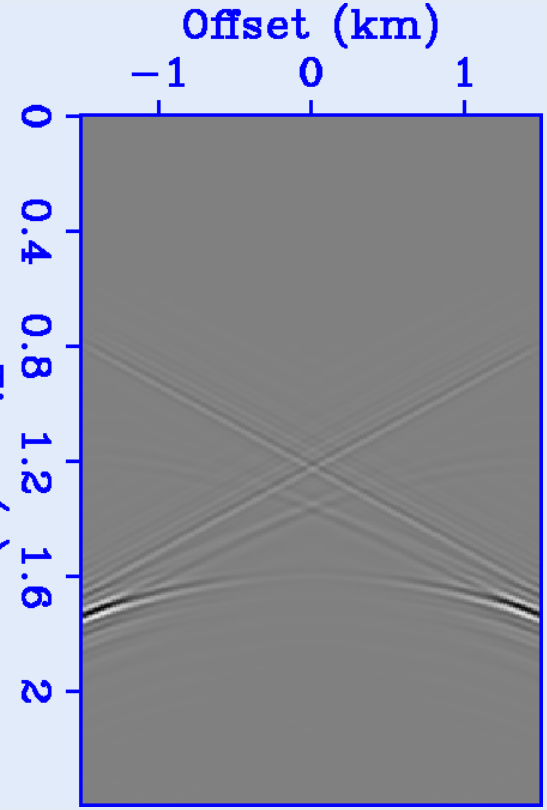
Recorded data



Model update at 1st iter.

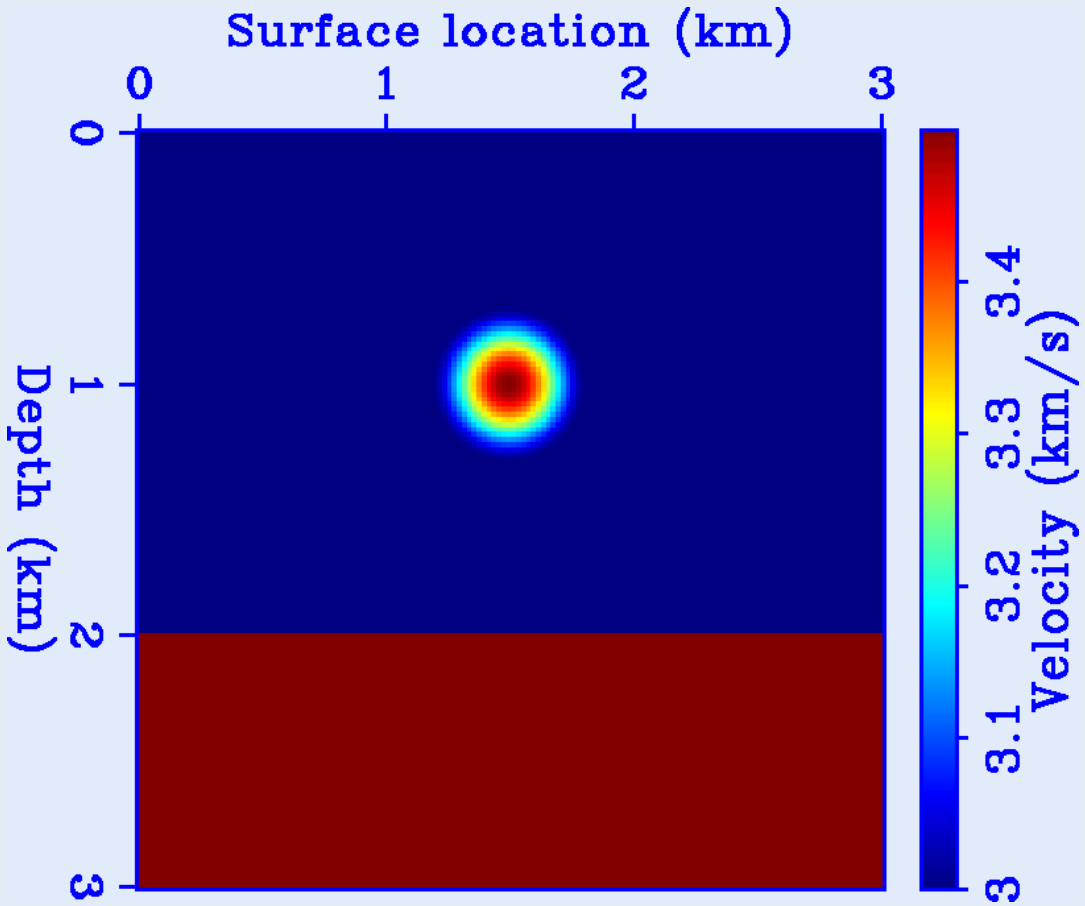


Modeled data

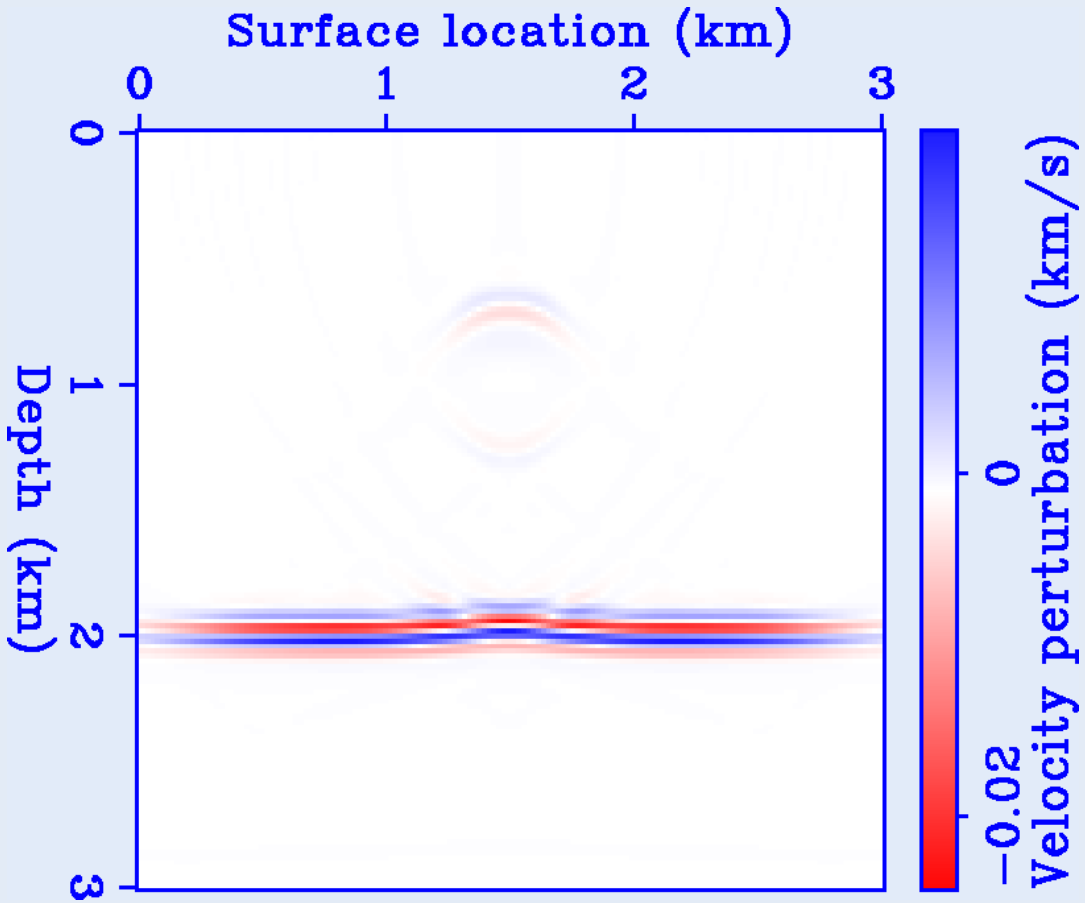


Common Image Gather after application of DSO

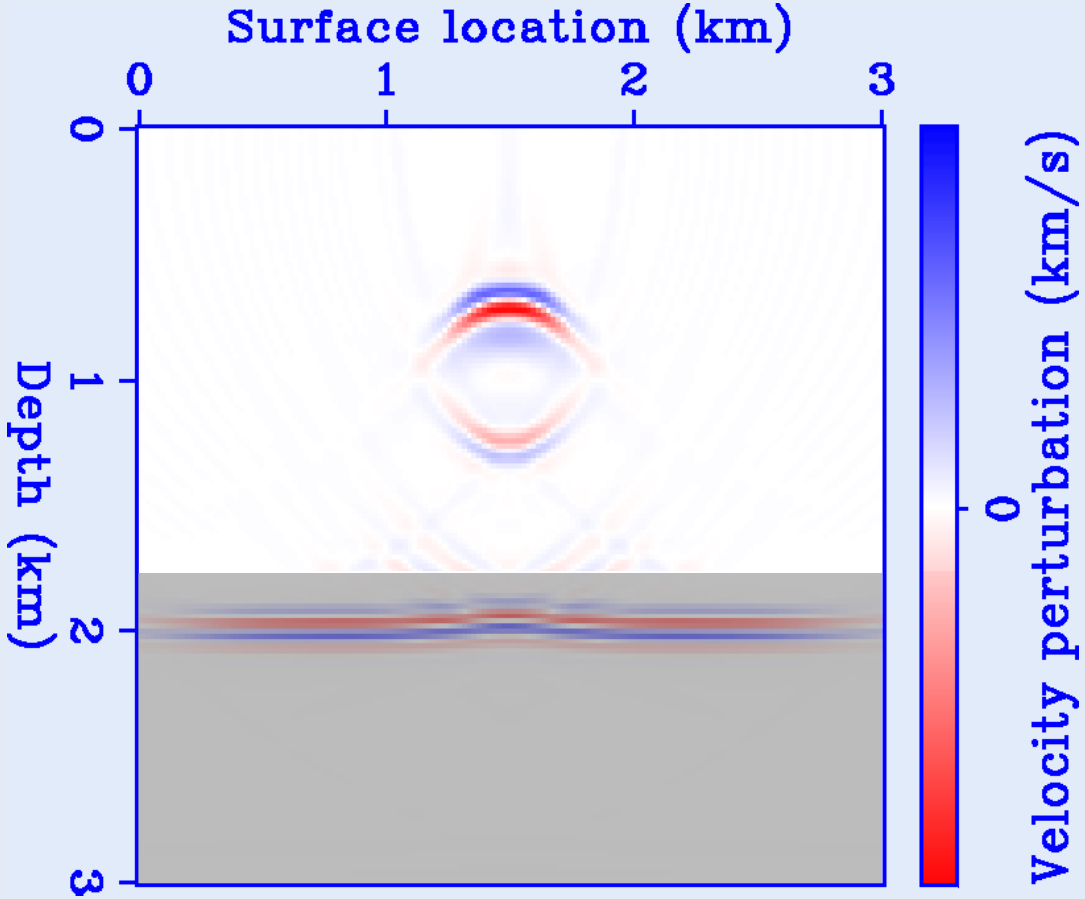
Gaussian anomaly model



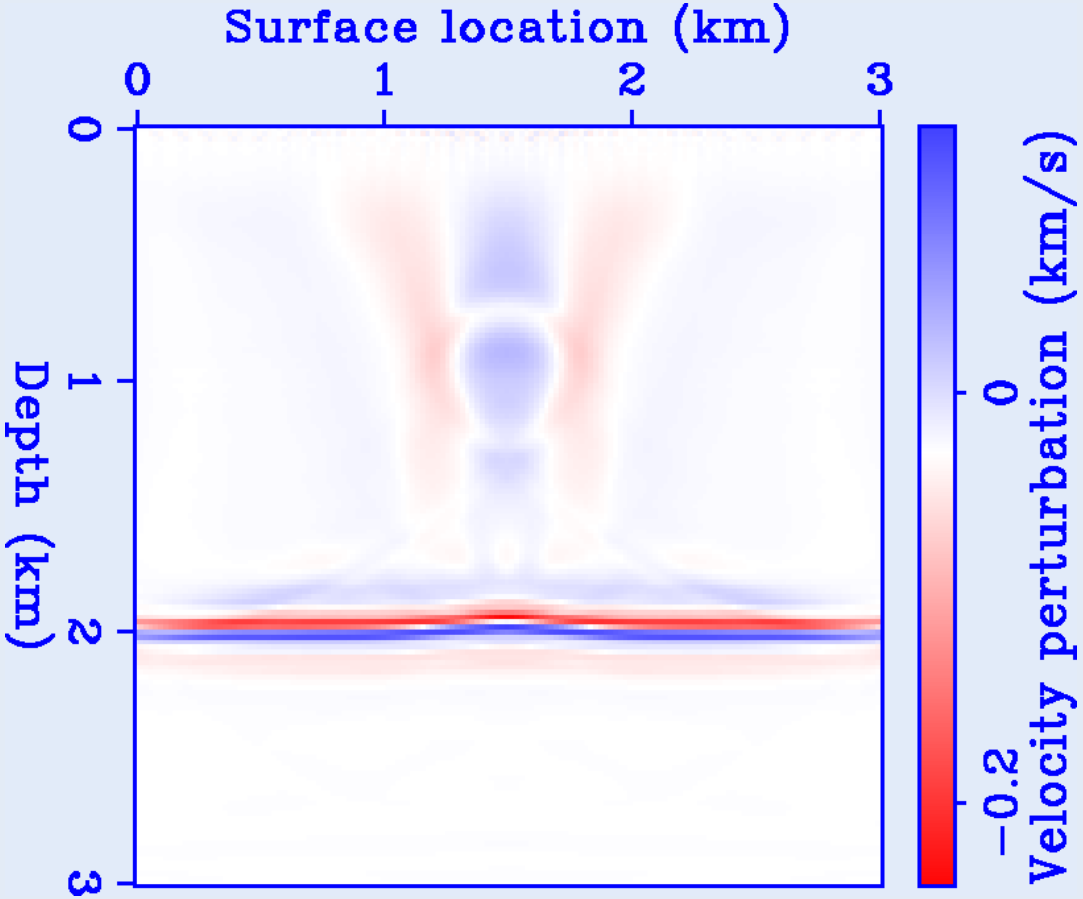
Model update at 1st iteration



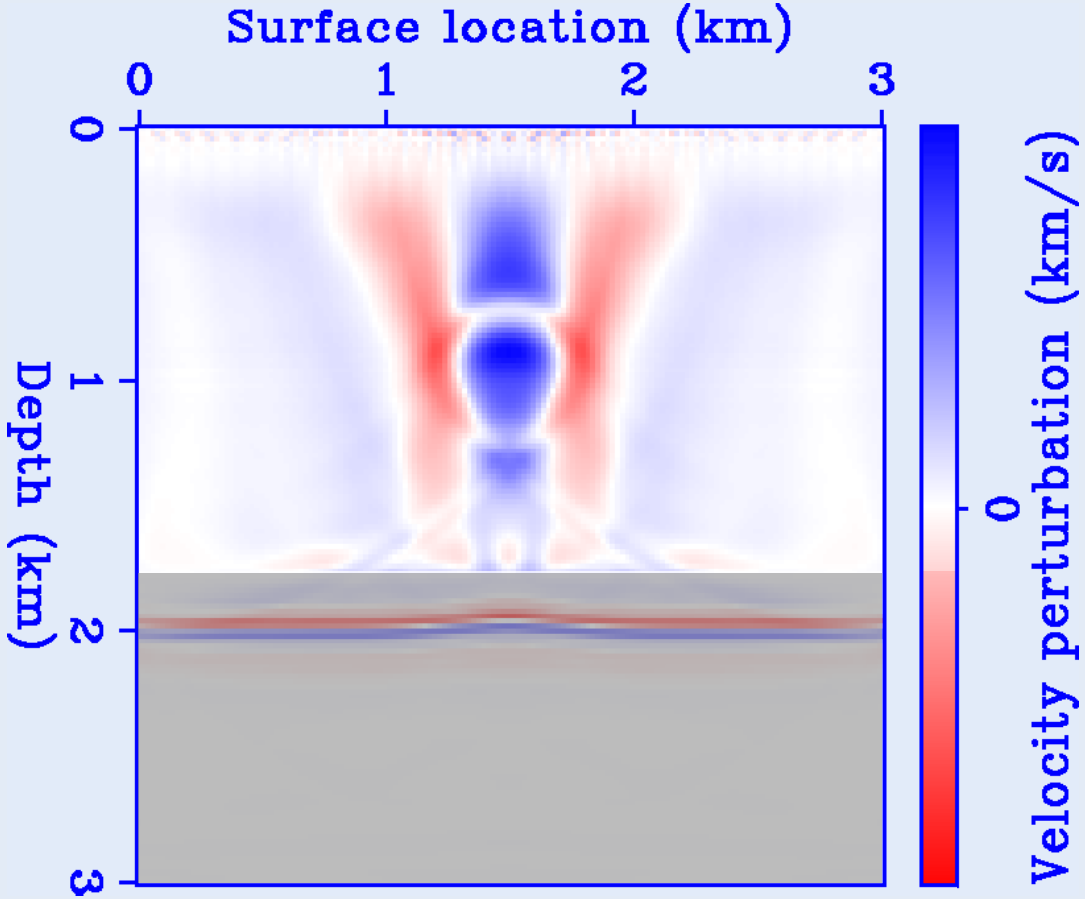
Update - clip based on anomaly



TFWI result after 400 iterations



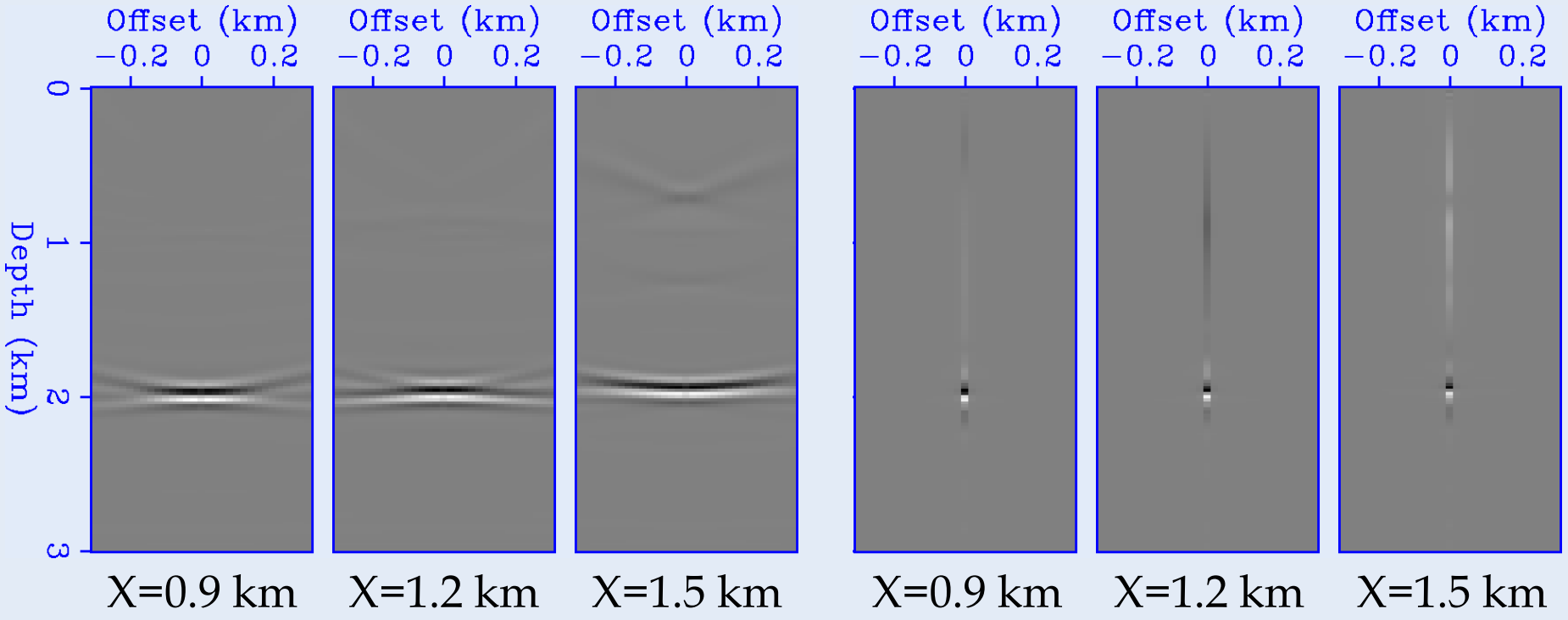
TFWI result- clip based on anomaly



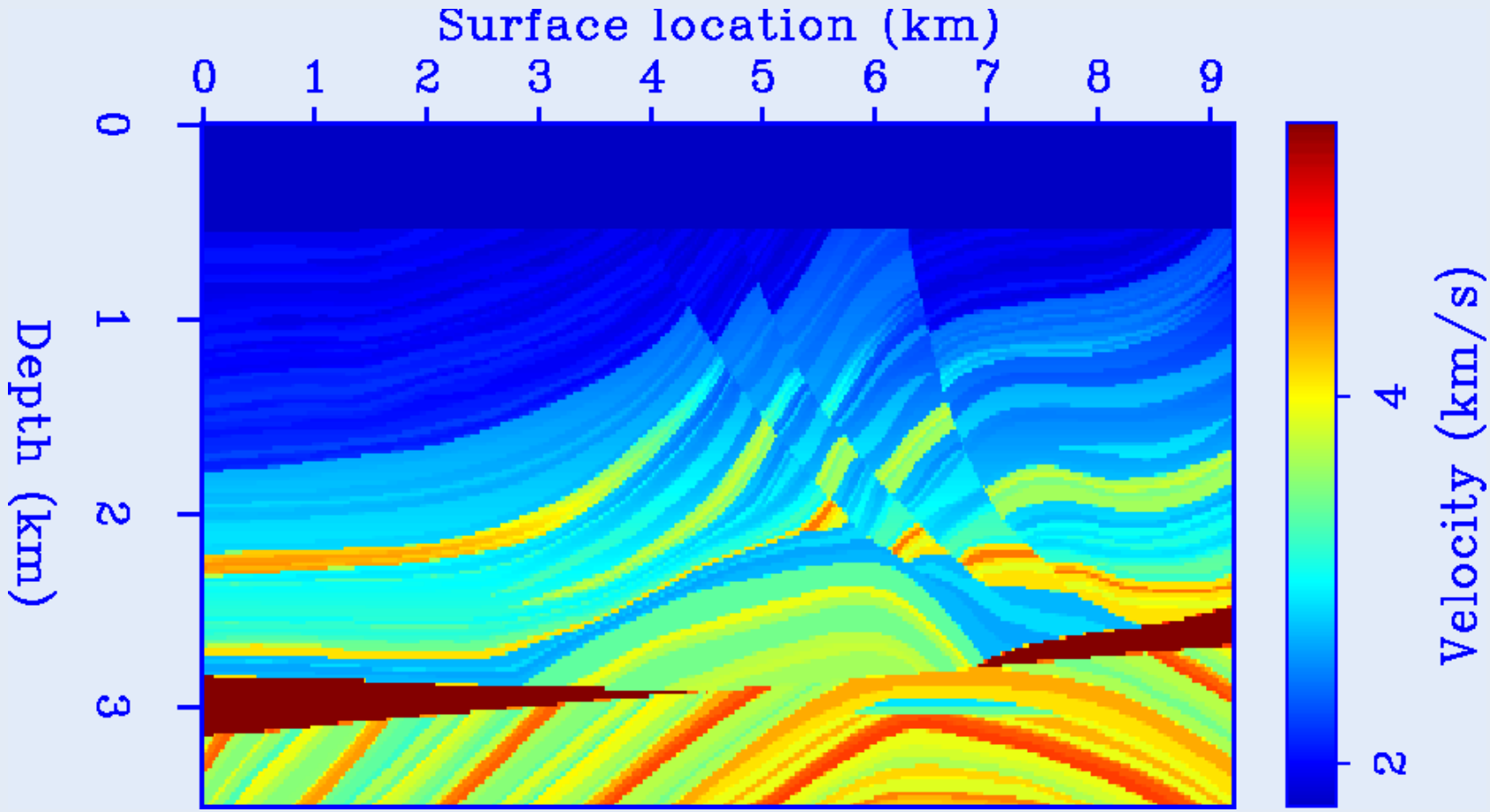
Common Image Gathers

First iteration

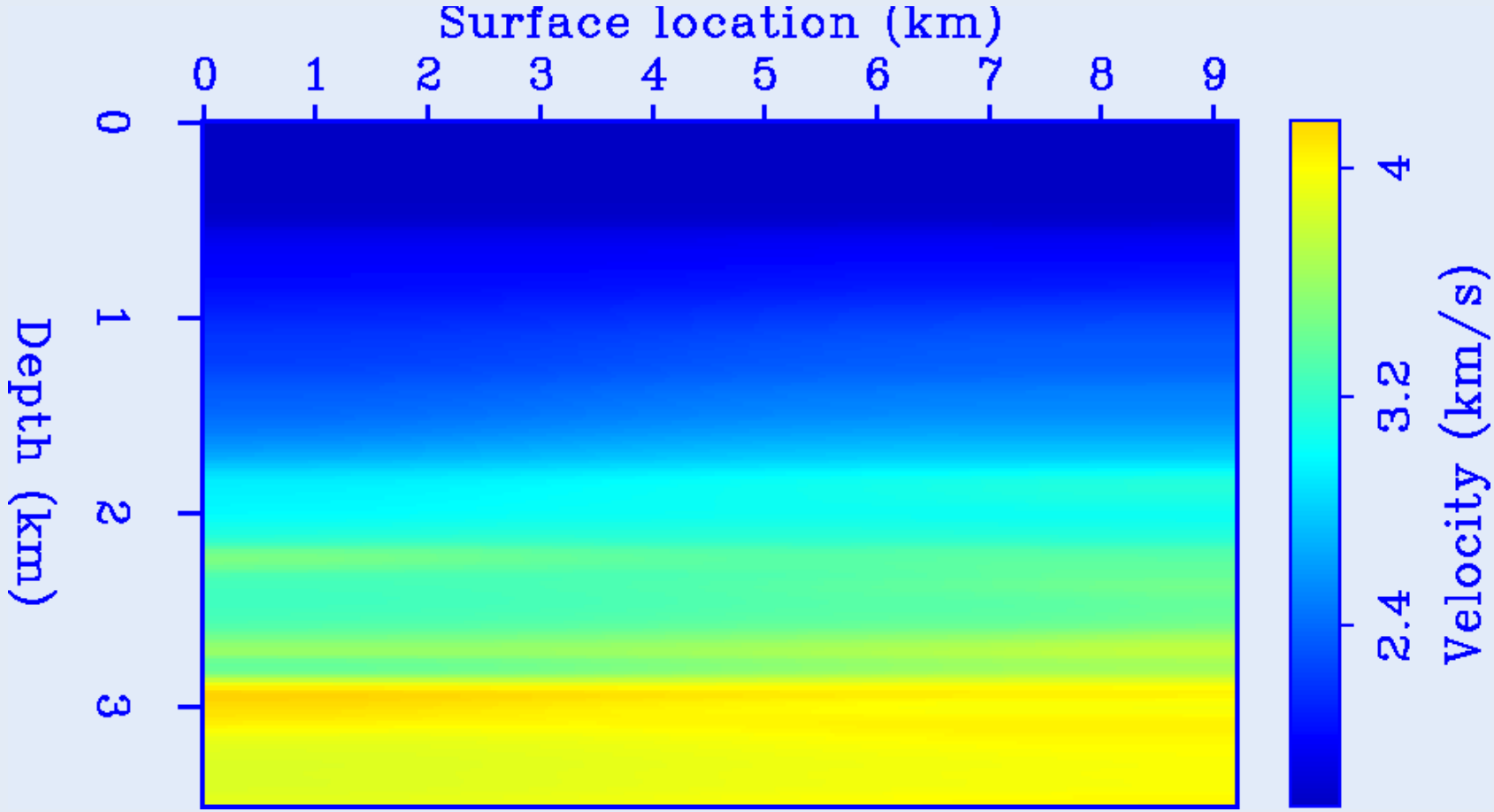
400 iterations



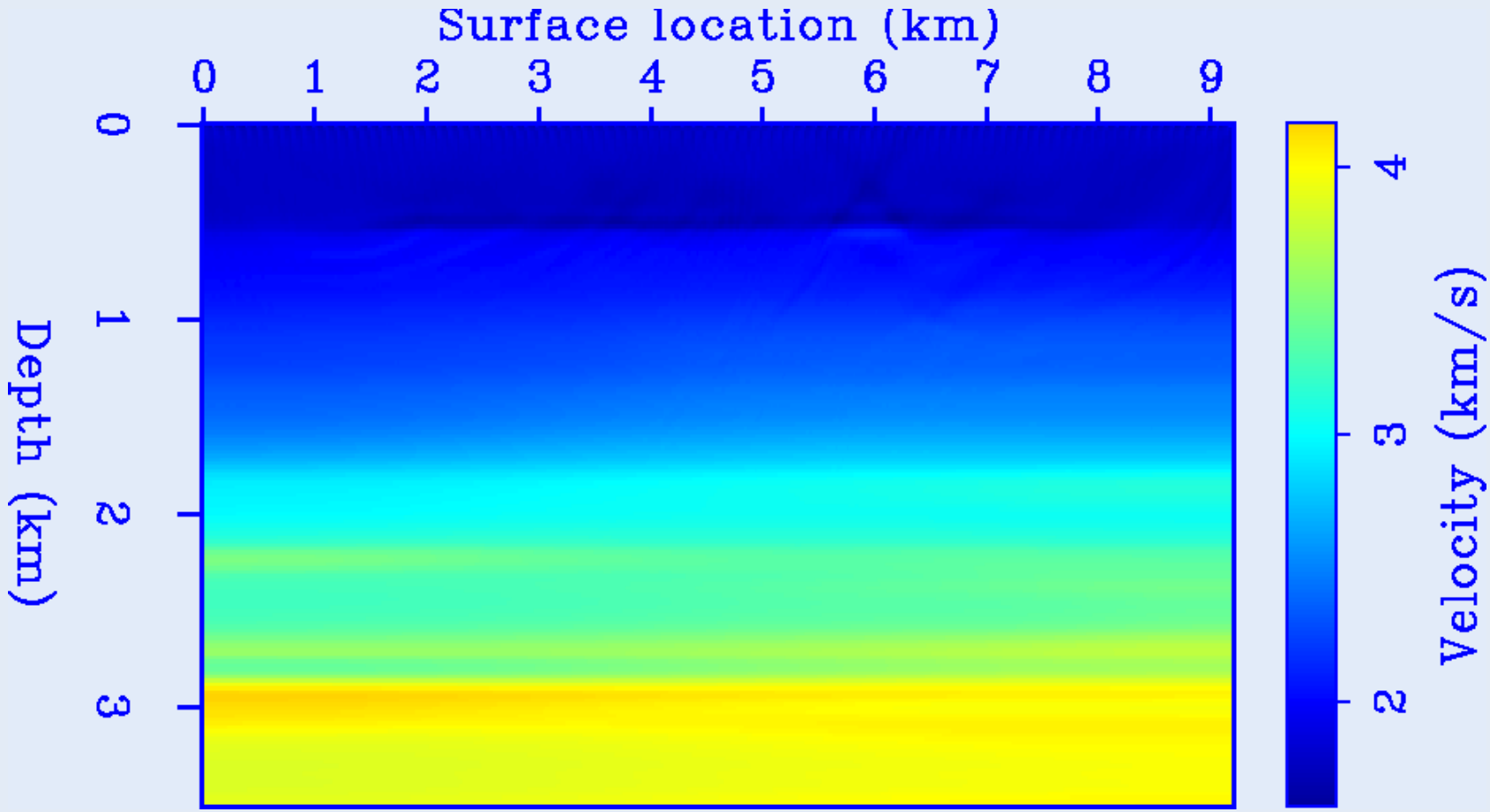
Modified Marmousi model



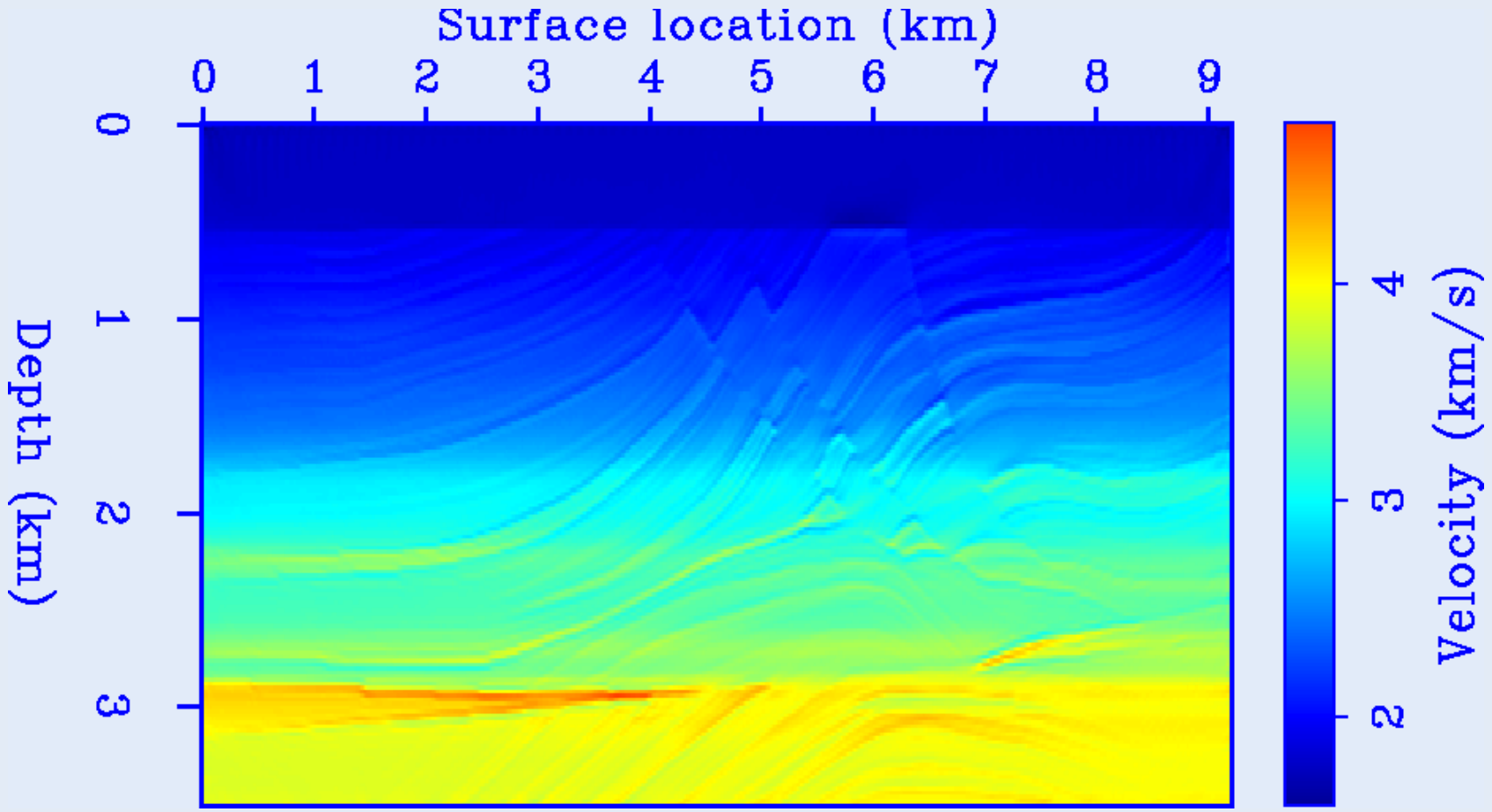
Starting model for inversion



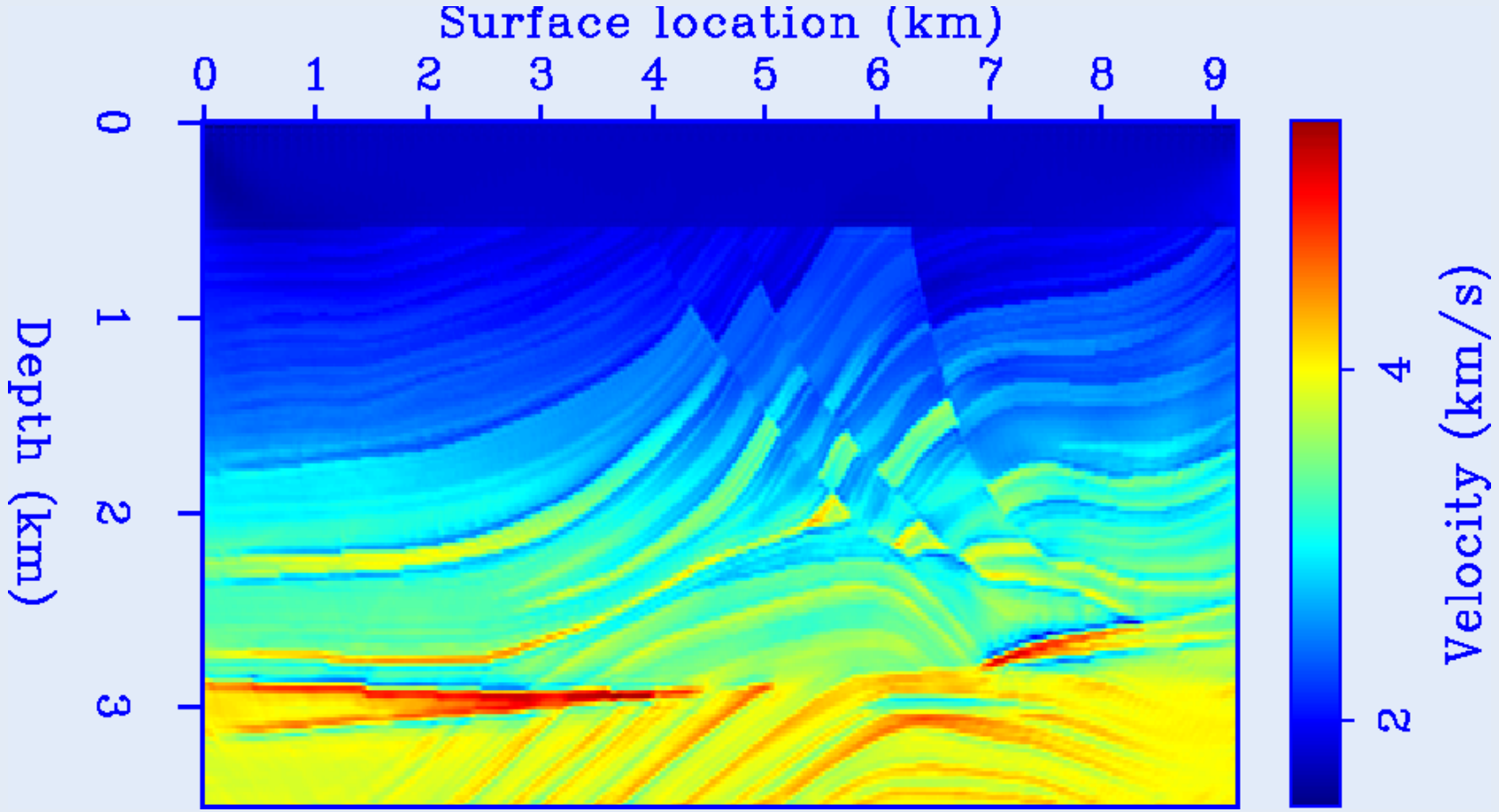
Result of FWI after ∞ iterations



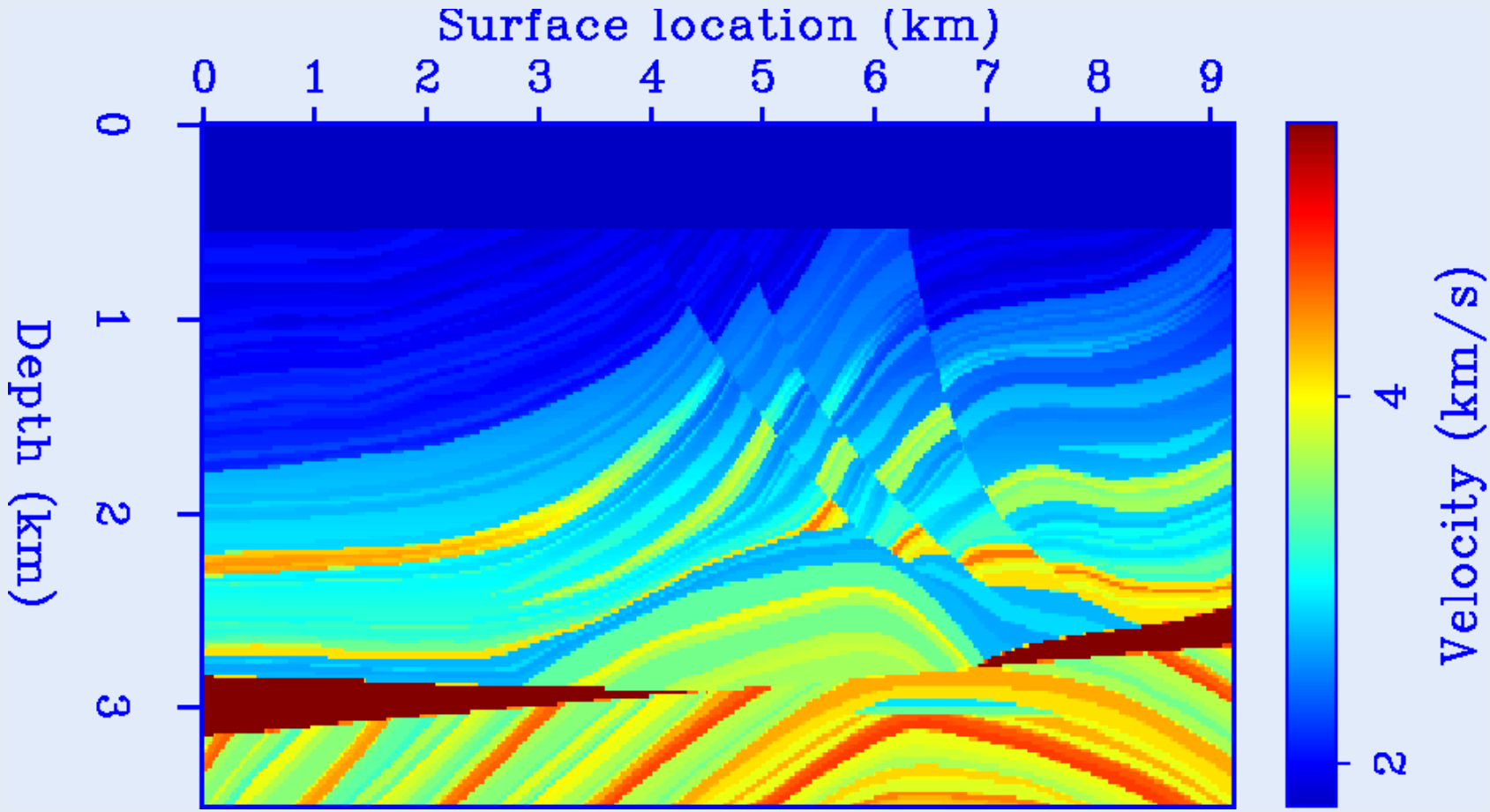
Result of EFWI after 610 iterations



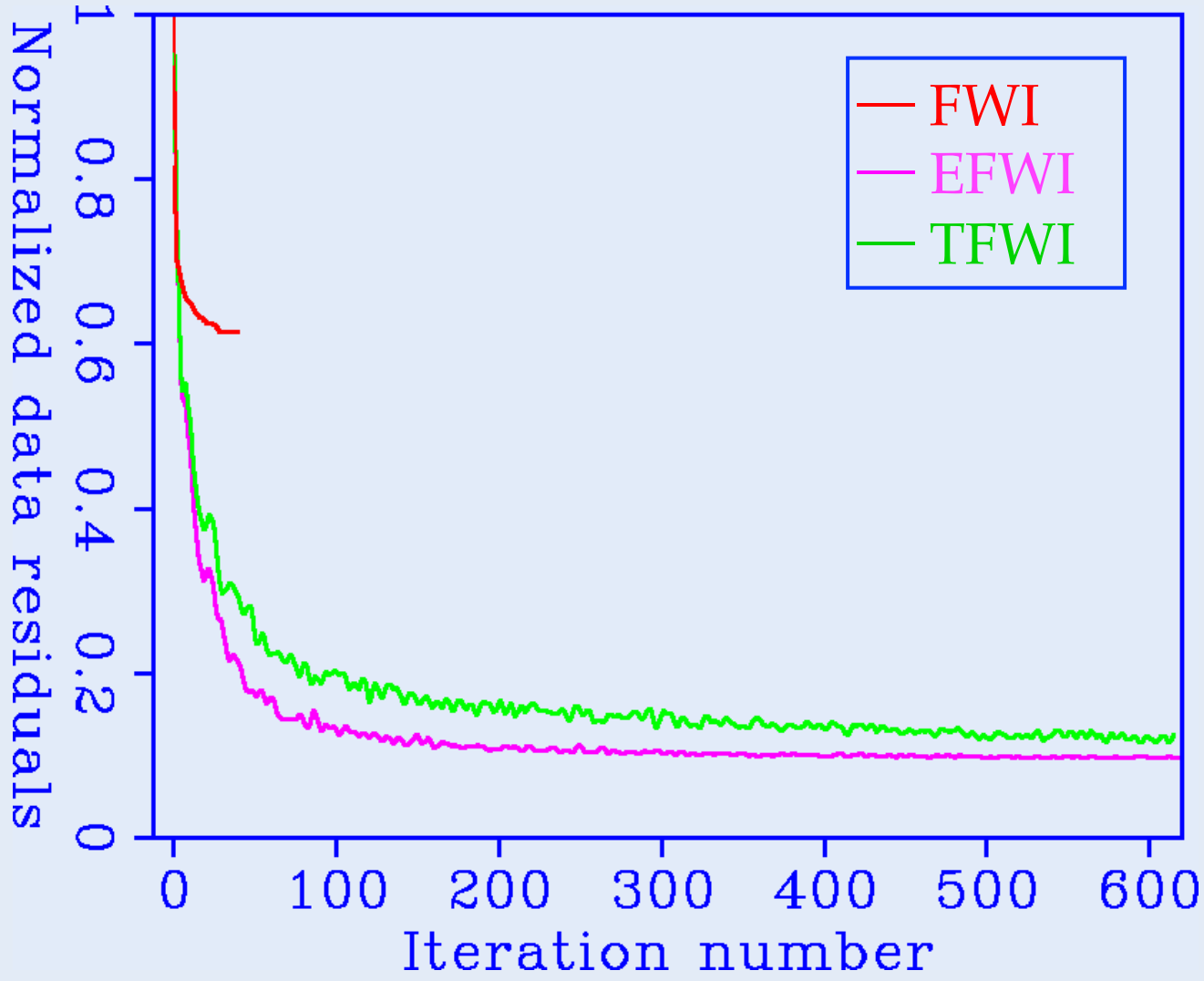
Result of TFWI after 610 iterations



Modified Marmousi model



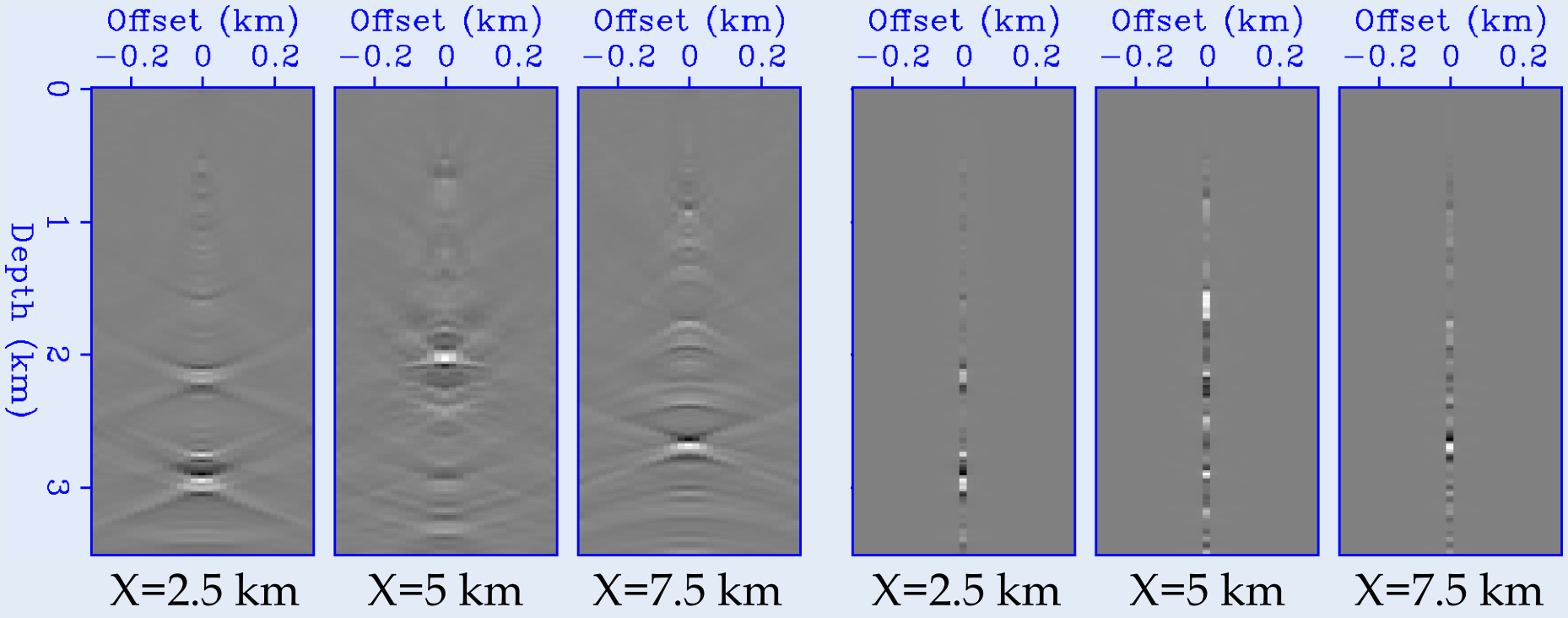
Data residuals (J_d) vs. iterations



CIGs: EFWI vs. TFWI

EFWI – 610 iterations

TFWI - 610 iterations



Conclusions
Good news

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TFWI enables simultaneous inversion and

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- TFWI enables simultaneous inversion and avoids cycle skipping of tomographic component.

Conclusions
Not so good news

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  - Modeling operator with extended velocity is computational demanding,
  - Convergence seems to be slow.

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- TFWI assumes constant density and no AVO.
- Ali's presentation addresses both concerns!